Prediction of Groundwater Level at Slope Areas using Electrical Resistivity Method

M F T Baharuddin¹ ², Z A M Hazreek², M A A Azman¹ ² and A Madun²

¹Research Center for Soft Soils, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat Johor, MALAYSIA
²Faculty of Civil and Environmental Engineering, Tun Hussein Onn University, 86400 Batu Pahat, Johor, MALAYSIA

E-mail: mdfaizal@uthm.edu.my

Abstract. Groundwater level plays an important role as an agent that triggers landslides occurrence. Commonly, the conventional method used to monitor the groundwater level is done by using standpipe piezometer. There were several disadvantages of the conventional method related to cost, time and data coverage. The aim of this study is to determine groundwater level at slope areas using electrical resistivity method and to verify groundwater level of the study area with standpipe piezometer data. The data acquisition was performed using ABEM Terrameter SAS4000. For data analysis and processing, RES2DINV and SURFER were used. The groundwater level was calibrated with reference of standpipe piezometer based on electrical resistivity value (ERV).

1. Introduction

Groundwater level plays an important role as an agent that triggers landslides occurrence. Natural processes such as weathering and erosion will contribute in the increasing amount of unconsolidated slope material and subsequently, chances to slope failures occurrence especially in hilly areas are greater. The failure will be accelerated by infiltration process of rain water especially in tropical region where the rain is more frequent compared to other regions. Thus, it may also increase the chances of having groundwater level underneath the slopes area. Therefore, the determination of groundwater level in slope area is significant as preventive measures. There are several methods used in the determination of groundwater level. For an example, conventional methods such as borehole drilling method, trial pits, auger method and alternative method are related to geophysical methods such as gravity, magnetic, electric and electromagnetic, radioactive and seismic method [1]. Standpipe piezometer which is commonly used to monitor the groundwater level also involves application of drilling method. There are several advantages and disadvantages of this conventional method. Conventional method is a direct method which the result is strongly confirmed. Nevertheless, the disadvantages of this conventional method were related to cost, time and data coverage. Recently, geophysical study provides supported data in order to reduce cost, time and data coverage. Geophysical methods can be used to determine depth to bedrock, nature of overburden materials and near surface structures such as sinkholes, cavities, voids, faults and boulders [2]. Geophysical techniques are adopted by geotechnical engineers for investigating shallow sub surfaces structures [3]. Geophysical studies are measurements of physical quantities (resistance, speed of propagation of...
sound, density, magnetism, and conductivity) aimed at identifying comprehensively the rock mass structure and lithology characteristics to be used in geotechnical studies, water investigations and others [4]. Based on those properties, geophysical methods such as electrical resistivity, seismic method (refraction and reflection), magnetic, gravity, ground penetrating radar and others were performed for geotechnical forensic, environment, structural and etc. The advantage of geophysical method is it is able to minimize conventional method problem related to cost, time and data coverage. Hence, this study focuses on geophysics method with particular reference, while electrical resistivity method will be applicable in groundwater level prediction in slope area.

2. Electrical Resistivity Method
The electrical resistivity method involves measuring the apparent resistivity of soil and rock as a function of depth position to determine subsurface resistivity distribution. The true resistivity of the subsurface can be estimated from these measurements. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock [5]. The method was based on measurements and interpretations resulting from earth materials with different electric properties as shown in Figure 1. In simple terms, the resistivity measurements are performed by applying a current $I$, which is introduced into the soil between two electrodes A and B. A potential difference can be measured by electrodes M and N [6]. Electrical tomography, also referred as electrical imaging is a survey technique which aims to build up an image of the electrical properties of the subsurface by passing an electrical current along many different paths and measuring the associated voltage (Figure 2). From these measurements, the true resistivity of the subsurface can be estimated. Igneous and metamorphic rocks typically have high resistivity values while clay has a significantly lower resistivity than sand [7 and 8] (refer Table 1). To obtain a good two-dimensional (2-D) picture of the subsurface, the coverage of the measurements must be in 2-D.

Figure 1. The principle of resistivity measurement [6].
3. Study Area and Methodology

The study area for electrical resistivity imaging is located at KM 19.3 Northbound, Senai Inbound, Johor. This study area is located at slope beside the New Senai Inbound toll plaza. The location of the study is at the gentle sloping area that approximately has 240m in width and 8 berms in height. Figure 3 shows the arrangement of the resistivity line 1 near the BH1/PSS4-1T at the top of the slope and BH2/PSS4-1B at the bottom of the slope. Electrical resistivity measurements used ABEM Terrameter SAS4000 and electrode selector ES 10-64. Field resistivity data was obtained along four (4) imaging lines at study area. Then, the results of resistivity images were analysed by using RES2DINV software.

Table 1. Resistivity of some common rocks and minerals [8].

| Material               | Resistivity (Ohm.m) |
|------------------------|---------------------|
| Igneous / Metamorphic  |                     |
| Granite                | \(5 \times 10^3 \) – \(10^8\) |
| Weathered granite     | \(1 \) – \(10^2\)   |
| Basalt                 | \(10^3 \) – \(10^6\) |
| Quartz                 | \(10^7 \) – \(2 \times 10^6\) |
| Marble                 | \(10 \) – \(2.5 \times 10^8\) |
| Schist                 | \(20 \) – \(10^4\) |
| Sediments              |                     |
| Sandstone              | \(8 \) – \(4 \times 10^3\) |
| Conglomerate           | \(2 \times 10^3 \) – \(10^4\) |
| Shale                  | \(20 \) – \(2 \times 10^3\) |
| Limestone              | \(50 \) – \(4 \times 10^2\) |
| Unconsolidated sediment|                     |
| Clay                   | \(1 \) – \(100\) |
| Alluvium               | \(10 \) – \(800\) |
| Marl                   | \(1\) – \(70\) |
| Clay(wet)              | \(20\)               |
| Groundwater            | \(10 \) – \(100\) |
| Fresh water            | \(10 \) – \(100\) |
4. Results and Discussions

4.1 Two-dimensional electrical resistivity tomography (2DERT)

Resistivity results are presented and discussed based on Figures 4-7. It was found that horizontal distance and depth of penetration was 190 m and 35 m respectively. Penetration depth is due to the electrode spacing (2.5 m) that was setup during data acquisition. The very low resistivity values that were shown in the lines image represented by a blue colour are less than 100 ohm.m. The very high resistivity values that were clearly shown in the image are up to 8000 ohm.m which were represented as red colour. Resistivity line 1-3 surveys were operated inclined from bottom to the top of slope at KM 19.3, Northbound, Senai Inbound, PLUS Highway. Based on Figures 4-5, the first layer of low resistivity value (10-120 ohm.m) can be seen on top soil at 152.5 m to 162.5 m horizontal distance. The second layer of low resistivity value is at 3.10 m depth and varied on horizontal distance. On the other hand, the first layer of low resistivity value in Figure 6 can be seen at 1.96 m depth while second layer of low resistivity value is at 4.35 m depth and varied on horizontal distance.
Figure 4. 2-D electrical resistivity tomography for resistivity line 1 at the site.

Figure 5. 2-D electrical resistivity tomography for resistivity line 2 at the site.

Figure 6. 2-D electrical resistivity tomography for resistivity line 3 at the site.

Resistivity line 4 survey was conducted horizontally on average elevation of the slope at KM 19.3, Northbound, Senai Inbound, PLUS Highway. Resistivity result was presented and discussed in Figure 7. First layer of low resistivity value can be seen at 4.35 m depth while second layer of low resistivity value is at 8.89 m depth and varied on horizontal distance.
4.2 Three-dimensional electrical resistivity tomography (3DERT)

This section discusses on the advantages of the application of 3DERT in subsurface profile mapping. The 3DERT is able to present better and global perspective compared to the 2DERT. For an example, 2DERT can obtain the subsurface profile image only in localize perspective. However, 3DERT is able to compliment the subsurface profile in a global perspective. 3DERT is also able to obtain image cross-sectional area in wider coverage. This 3D image is produced by interpolation technique of four (4) spread lines based on ERV kriging interpolation technique. In order to produce good 3DERT, suitable spread line spacing needs to be carefully decided. Larger line spacing interval will produce low accuracy of 3DERT due to the interpolation constraint. For example, for specific purposes (groundwater level), 3DERT is able to produce better result interpretation compared to the 2DERT. All 3DERT products in this study are shown in Figure 8. This study is successful in detecting groundwater level based on 3DERT as shown in Figure 8. It was found that, large groundwater zone was occurred at depth of 5.72 m – 12.73 m and posibbly over. This zone is interpreted as groundwater zone due to its low ERV (10-120 ohm.m).

Figure 7. 2-D electrical resistivity tomography for resistivity line 4 at the site.
5. Conclusions
The 2DERT and 3DERT were carried out to predict the presence of groundwater level at slopes area. In order to study the resistivity images together with other destructive methods such as boreholes and piezometer, the application on how to run the equipment was also discussed. Therefore, it can be concluded that the 2DERT and 3DERT are suitable as applications in geotechnical engineering works, mining, hydrology, environmental, especially in slope engineering as it may help to minimize chances of slopes failures and landslides tragedy. It was proven that the application of this survey is appropriate to measure the distribution of resistivity on the ground surface. With the results from the resistivity images, the layers of the ground subsurface can be determined. It is also can help to monitor the presence of the groundwater level at every soil layer. Collectively, the result data from piezometer can also be used to detect the groundwater level at the slope areas arise and results from resistivity survey were analysed to ensure their similarity. This kind of resistivity survey is a good indirect predictor of water content and it is an instrument that can measure the depth of slope profile. The cross section of the slope can also be made and visualize the distribution of the resistivity of the ground subsurface.

Figure 8. 3-D electrical resistivity tomography.
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