

Groundwater Level Detection by Using a Two-Dimensional Electrical Resistivity Imaging

A. Derahman, H. Awang and N. M. Osman

Abstract Groundwater level is one of the main factors that should be considered in slope stability analysis. Generally, surface water resulted from rain infiltrates to the ground will increase the groundwater table, thus can trigger slope failures. Many methods can be employed to explore and investigate the presence of water in the sloping areas. One of the conventional methods that are commonly used is observation well where piezometer is installed in the well. The purpose is to measure the level and hydraulic head of groundwater in aquifers. However, this kind of technique needs to be dealt with tedious works as drilling is to be carried out for standpipe installation. Even though this technique is technically easy to understand, it only can provide one single point water level data of the area unless there are a numbers of well to be drilled. This means that the observation well can only provide the information at a discrete point. In order to obtain continuous ground water level and other underground profile a technique that can provide the continuous sub-surface information should be carried out. This paper presents findings of a study of groundwater detection using a non-destructive method namely electrical resistivity imaging. The objective of the study is to determine how reliable the method can be used in detecting ground water level and to what extent it can provide the sub-surface information. A 2-D electrical resistivity imaging was carried out on two slope areas where a landslide was taken place at one of the areas. The groundwater level was also monitored using the observation well at very limited borehole points. The results of the 2-D electrical resistivity imaging and piezometer then were compared.

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1 Introduction

In tropical country like Malaysia, natural hazards such as slope failures are very common. One of the factors that contribute to this hazard is groundwater which plays an important role as an agent that triggers to the slope failures. The groundwater occurs in two distinct zones which are separated by the water table or also known as phreatic surface. The phreatic zone is subjected to the gravitational forces. It saturates the pore spaces in the soil below the water table. It also has an internal pore pressure that is greater than the atmospheric pressure and the water tends to flow laterally. The vadose water zones are located above the water table where the water percolates and moving downwards to link together with the phreatic water below the water table. Increasing of groundwater level beneath the slopes is assisted by infiltration of rain water as rains are very frequent in the tropical region. The effect of wetness on shear strength of soil is characterised based on a stress state variable known as suction. The suction effect is derived from the surface tension force on the water meniscus, which clings between soil particles [6] and generally its magnitude increases as moisture decreases. However, shear strength does not indefinitely increase with suction since it started to decrease beyond residual suction [3, 5, 9, 12]. The apparent shear strength reduction due to the surface water infiltration is actually governing the rain induced slope failure [10]. Therefore determination of groundwater level in any areas of concern is significant as a prevention measures.

There are many methods that can be carried out to investigate the presence of groundwater level. One of the common methods used is piezometer. This conventional method is widely used where a hole need to be drilled for observation well and also for the installation of the piezometer. This method requires more care during the installation work to ensure a proper installation is done. Besides, if the vibrating wire of piezometer is to be used, the electric units have a risk to damage due to lightning. Furthermore the power source needs to be maintained by replacing a new battery periodically. Even though this method is technically easy to understand, the information provided is limited to a single data point. Meaning that for an area it needs more than one point to represent enough information of the groundwater level as it may varies from one point to another. Due to these reasons, a method that can provide continuous information of groundwater levels, a non-tedious and a non-destructive works is highly recommended. Friedel et al. [4] investigated a case study of a slope endangered by rainfall-induced landslides using 3D resistivity tomography together with geotechnical assessment. They found that the combination of electrical resistivity survey and geotechnical survey able to help in optimizing the design of forthcoming monitoring experiment. Rosli et al. [11] used the resistivity technique for slope failure monitoring and they found

that the factor which cause landslide is the subsurface boulders and the saturated zone which result subsidence of the surface.

Even though many researches have been carried out in using resistivity method, but there is still no finding of reliability in detecting groundwater level using this non-destructive method at slope areas. In reflection to the above problem and the gaps in the previous researches, a study on detecting groundwater level using electrical resistivity imaging method was carried out at two locations of slope areas in the states of Johor and Perak. A landslide was taken place at one of the areas few years ago. The objectives of this study are to determine the groundwater level of the slopes using resistivity images and to compare the groundwater level between the values of piezometer and the image provided by resistivity method. Thus it is hope that this study will show how reliable electrical resistivity imaging can be used as a groundwater level detector and to what extent it can contribute information related to slope instability.

2 Materials and Methods

2.1 Site Locations

Two sites of Southern and Northern Peninsula Malaysia were selected for this study. The southern site is located in Senai, Johor and the northern is located at Slim River, Perak as shown in Fig. 1.

The site in Senai had experienced slope failure in 2007. This slope has a height of about 24 m and a width of 240 m. It was surrounded by palm trees plantation before the tragedy of the slope failure. Meanwhile the site in Slim River is a very steep slope which is higher than slope at Senai. It is also surrounded by palm trees plantation.

2.2 Borehole and Piezometer Test

Four boreholes were drilled where two boreholes were sunk at each site. From the boreholes record the soil profiles of the slopes were prepared to shows the each layer of the soils material. The soil profiles are to be used in analysis in order to predict the presence of groundwater level at the slopes area. Several data are needed such as coordinates of the boreholes point and reduced ground level for this process such as borehole name, total depth of boreholes, coordinates, water level, SPT 'N' values etc.

The application of the piezometer was used in measuring the groundwater levels and pressures in the boreholes. The piezometers were installed inside of the boreholes which is similar as the observation well. The electrical dip meter used to measure the head inside of the piezometer. Installation of piezometer is referred to



Fig. 1 Location of study sites at Senai, Johor and Slim River, Perak

Carter [2], where the equipment of piezometer consists of a porous pot connected to a vertical pipe which is installed in a borehole or driven into the ground. The installation of piezometer in boreholes usually uses Polyvinyl Chloride or also known as PVC pipes. This kind of materials is the ultimate in simplicity, reliability and cheapness where it is the most common types of piezometer in use. The piezometer tip is surrounded by a sand filter and it is usual to seal off test section with plugs of bentonite clay, which forms a water tight seal. Besides, the bentonite powder also used and mixed with water in a bucket so that it can be moulded into balls in the hands. Then the balls are thrown down into the borehole. Otherwise, the bentonite pellets may be poured down the hole. When the electrodes at the bottom of the dip meter touched the water surface, an electrical circuit is closed and a buzzer sounds inside the reel will activated, during that time, then record the reading of the water surface.

In Senai site, there are two piezometers that were installed at BH1 and BH2 namely as PSS4-1T and PSS4-1B respectively as in Fig. 2a. Also in Slim River site, there are two piezometers were installed at BH1 and BH2 namely as PSC2-1T and PSC2-1B, respectively in Fig. 2b.

2.3 Electrical Resistivity Imaging

The main equipment used in the electrical resistivity measurement is ABEM Terrameter SAS 4,000 with multi electrodes system. It consists of 41 stainless steel

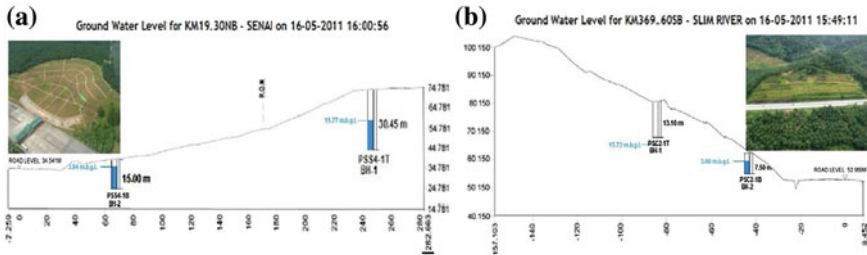


Fig. 2 a Locations of piezometer installation in Senai. b Locations of piezometer installation in Slim River

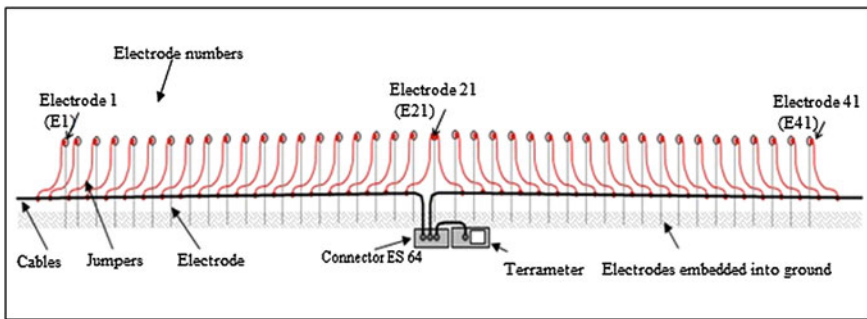


Fig. 3 Schematic layout of the resistivity line

electrodes that were pinned to the ground along a survey line. Two cables were laid and connected to each electrodes starting from electrode number one (E1) and end up with electrode number 41 (E41). Each of the cables has 21 take outs where E1 and E21 were connected to first and last take out of cable number one respectively. The first takeout of cable number two was also connected to E21 and the last takeout to E41. Both cable number one and cable number two were connected by electrode selector (ES64) at the centre of the survey line where the main unit of Terrameter SAS 4,000 was then connected to ES64. The schematic layout of the resistivity line is shown in Fig. 3. Spacing between the electrodes at Senai site is 5 m and at Slim River site is 2.5 m. These lines were located near to the boreholes locations which were at the top and bottom of the slopes. The location of resistivity lines at both sites is shown in Fig. 4.

Data collected by Terrameter were transferred to computer for data conversion and interpretation. A software named as RES2D Inversion was used to process and to convert the resistivity data into resistivity image. All methods of electrical resistivity imaging including field procedures and data conversation were referred to Instruction Manual for Terrameter SAS 4000 Version 8 [1] and Loke and Baker [8].

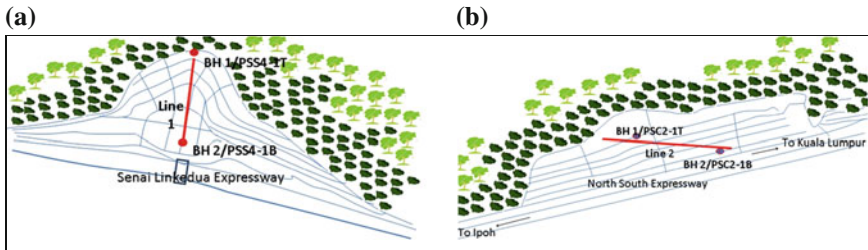


Fig. 4 a Locations of resistivity lines in Senai. b Locations of resistivity lines in and Slim River site

3 Result and Discussion

3.1 Boreholes Result

The borehole results for Senai site is shown in Tables 1 and 2 and for Slim River site the results is shown in Tables 3 and 4. BH-1 and BH-2 for Senai site shows there are three layers of soils which indicate the CLAY, GRAVEL and SILT. This type of soils is categorized in the associated group of fine grained, gravel and fill, respectively. BH-1 and BH-2 for Slim River site shows there are shows four layers of soil which indicate the SILT, SAND, GRAVEL and SANDSTONE where the soils is categorized in the associates groups as fill, sand, gravel and rock, respectively.

3.2 Piezometer Results

The results of groundwater level were collected from the piezometers that were installed at the both sites. The result of groundwater level at Senai site is shown in Table 5. The groundwater level reading was taken from PSS4-1T at the top and PSS4-1B at the bottom of the slope which is 15.77 and 3.94 m respectively below the ground level. As well as for groundwater level at Slim River site the reading of groundwater level is shown in Table 6. The groundwater level reading at this location was taken from PSC2-1T at the top and PSC2-1B at the bottom of the slopes which is 15.72 and 3.00 m respectively below the ground level.

3.3 Results of Electrical Resistivity Imaging

The results of electrical resistivity imaging were obtained in resistivity images and values. The results of resistivity images are displayed as scaled resistivity-depth pseudosections. In this study the blue colour region represents a lower resistivity

Table 1 BH-1 at Senai site

Depth (m)	Thickness (m)	Soil description	'N' value
0.00–1.50	1.50	Top soil: dark brownish yellow silty CLAY	–
1.50–3.00	1.50	Medium dense dark reddish brown silty sandy GRAVEL (laterite)	18
3.00–4.50	1.50	Stiff dark reddish orange clayey SILT	6
4.50–7.50	3.00	Stiff to medium stiff dark reddish orange clayey SILT	9
7.50–9.00	1.50	Stiff light yellow brown clayey SILT	13
9.00–10.50	1.50	Very stiff light yellowish brown sandy SILT	23
10.50–12.00	1.50	Stiff dark reddish yellow slightly sandy SILT	14
12.00–13.50	1.50	Very stiff dark reddish yellow clayey SILT	19
13.50–15.00	1.50	Very stiff dark reddish yellow mottled brown clayey SILT	17
15.00–18.00	3.00	Very stiff dark yellowish red mottled brown clayey SILT	17, 18
18.00–19.50	1.50	Stiff light yellowish brown clayey SILT	11
19.50–21.00	1.50	Very stiff dark yellowish brown clayey SILT	20
21.00–22.50	1.50	Stiff dark yellowish brown clayey SILT	14
22.50–24.00	1.50	Stiff dark reddish yellow clayey SILT	10
24.00–25.50	1.50	Stiff dark reddish yellow clayey SILT	12
25.50–27.00	1.50	Very stiff dark reddish brown slightly sandy SILT	20
27.00–28.50	1.50	Very stiff dark yellowish brown spotted white clayey SILT	22
28.50–30.00	1.50	Very stiff light red spotted white clayey SILT	17
30.00–30.45	1.50	Very stiff dark red spotted white clayey SILT	25

Table 2 BH-2 Senai site

Depth (m)	Thickness (m)	Soil description	'N' value
0.00–1.50	1.50	Top soil: dark reddish brown silty CLAY	–
1.50–3.00	1.50	Medium stiff light yellowish brown clayey SILT	5
3.00–6.00	3.00	Medium stiff light yellowish brown silty CLAY	7
6.00–7.50	1.50	Hard dark greenish grey gravelly SILT	50
7.50–9.00	1.50	Very dense dark greyish grey very silty sandy GRAVEL	50
9.00–10.50	1.50	Medium dense dark greenish grey very silty very sandy GRAVEL	20
10.50–13.50	3.00	Stiff dark greyish green slightly sandy CLAY	9, 18
13.50–15.00	1.50	Stiff dark yellowish orange silty CLAY	10
15.00–15.45	0.45	Stiff light brownish red silty CLAY	12

area, yellow or green colour region represents a medium resistivity area while the red or purple colour regions represent a relatively higher resistivity area. The images of the resistivity measurement for both site studies were correlated with the piezometer and borehole results. The resistivity values was correlated to the borehole and was interpreted as in Table 7. The resistivity value for Line 1 is 1.00–1,000 ohm m for Senai site as in Fig. 5. Meanwhile, the resistivity value for Line 2 is 10.00–12,000 ohm m for Slim River site as shown in Fig. 6.

Table 3 BH-1 Slim River site

Depth (m)	Thickness (m)	Soil description	'N' value
0.00–1.50	1.50	Top soil: brownish sandy SILT	–
1.50–3.00	1.50	Stiff light grey red slightly sandy SILT	15
3.00–4.50	1.50	Hard yellowish brown slightly gravelly SILT	50
4.50–6.00	1.50	Hard yellowish brown slight sandy SILT	50
6.00–7.50	1.50	Hard light grey clayey SILT	50
7.50–9.00	1.50	Hard yellowish gravelly SILT	50
9.00–10.50	1.50	Hard yellowish sandy SILT	50
10.50–11.60	1.10	Hard light grey sandy SILT	50
11.60–13.10	1.50	Weak rock light grey mottled red fractured moderately weathered medium strong rock SANDSTONE	–

Table 4 BH-2 Slim River site

Depth (m)	Thickness (m)	Soil description	'N' value
0.00–1.50	1.50	Wash bore	–
1.50–3.00	1.50	Hard brownish gravelly SILT	50
3.00–4.50	1.50	Hard brownish clayey SILT	50
4.50–6.00	1.50	Very dense brownish very silty very sandy GRAVEL	50
4.50–6.00	1.50	Very dense brownish very silty very sandy GRAVEL	50
6.00–7.50	1.50	Encounter rock light brown grey moderately weathered medium strong rock SANDSTONE	50

Table 5 Groundwater level (GWL) statistic from 15-05-2011 to 16-05-2011 at Senai site

Boreholes	Highest GWL (m.b.g.l)	Lowest GWL (m.b.g.l)
BH-1	15.77	15.77
BH-2	3.94	0.00

Table 6 Groundwater level (GWL) statistic from 15-05-2011 to 16-05-2011 at Slim River site

Boreholes	Highest GWL (m.b.g.l)	Lowest GWL (m.b.g.l)
BH-1	15.72	15.72
BH-2	3.00	0.00

The groundwater level for Senai which is 15.77 m below ground level for BH-1 is located at the top of the slope. However, the BH-2 indicated the groundwater level is 3.94 m below ground level. The piezometer reading shows that the groundwater level is matched and fell within the area of resistivity values that indicated the low resistivity and consist of higher water content. The results also shown that BH-2 was fallen at clayey material which is the typical resistivity

Table 7 Results of resistivity values at Senai site and Slim River site with soil profiles by referred the typical resistivity values

Types of soils and waters	Typical resistivity values of soil/rock materials (Ohm m)	Line 1 (Senai) Resistivity value (Ohm m)	Line 2 (Slim River) Resistivity value (Ohm m)
Clay	1–100	30–100 and 1–50	–
Alluvium (silt and gravel)	10–800	50–300	200–800
Groundwater (fresh)	10–100	10–100	10–100
Sand	200–3,000	–	1,000–3,000 and 1,500

Notes Typical resistivity values of soil/rock material, Loke [7]

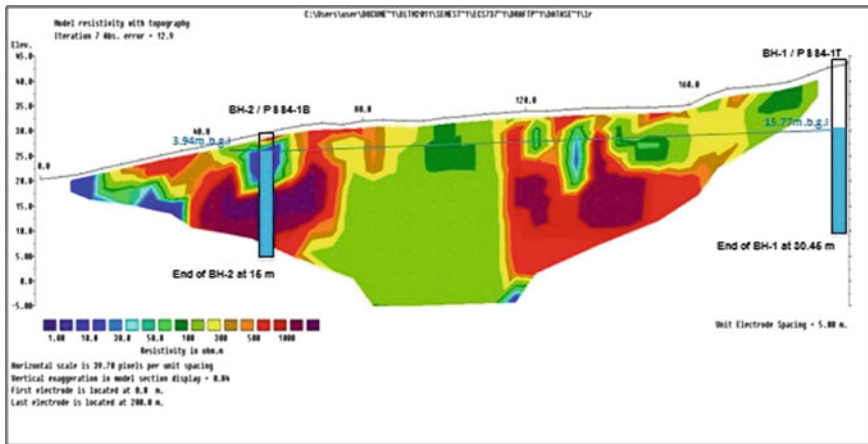


Fig. 5 Comparison between soil profiles and resistivity values at location 1 Senai

values is around 1–100 ohm m. It is shown that the groundwater level for Senai site was fell at the lower resistivity values which is around 1–800 ohm m, where the soil materials is consist of clayey and silt materials.

The groundwater level for Slim River site which is 15.72 m below ground level for BH-1 is located at the top of the slope. The BH-2 indicated the groundwater level is 3.0 m below ground level. The result also shown that BH-2 was fallen at silt material which is the resistivity values is 3,000 ohm m. It is shown that the figure indicated that the groundwater level for Slim River site fell at a medium resistivity values and near to the lower resistivity area where consist of water content.

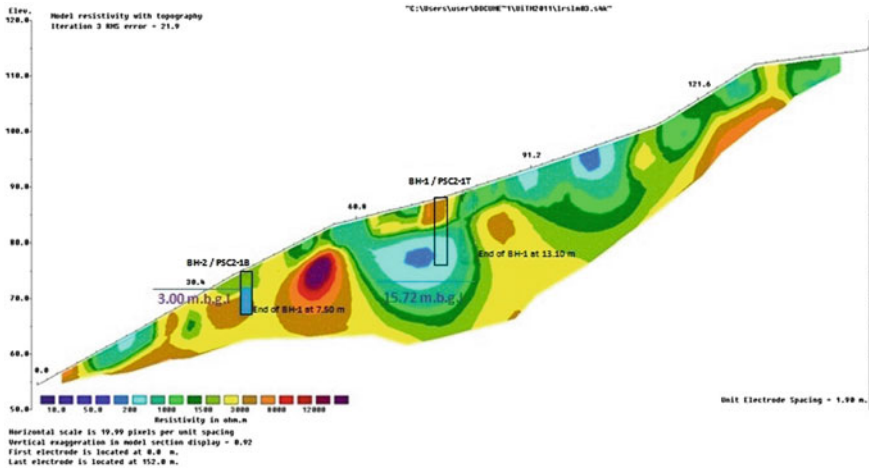


Fig. 6 Comparison between soil profiles and resistivity values at location 2 Slim River

4 Conclusions

The two-dimensional electrical resistivity imaging is 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’s were also discussed.

Therefore, it can be concluded that the two-dimensional electrical resistivity imaging is suitable as application in geotechnical engineering works, mining, hydrology, environmental, especially in slope engineering as it may help to provide some data 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’s subsurface can be determined. It also can help to monitor the presence of the groundwater level at every soil layers. This is meets the objective of these studies.

Collectively, the results data from piezometer can also use to detect the groundwater level at the slope areas arise and results from resistivity survey were analyzed to ensure their similarity. This kind of resistivity survey is a good indirect predictor of water content and 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.

Finally, the result shows that a groundwater level by piezometer and resistivity images located at the area where a slope failure occurred matched to each other. It is also proven that the increasing groundwater level contributed to the slope failures. This finding meets the objective of the study where it is reliable to detect groundwater using electrical resistivity as a non-destructive method.

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