The Application of 2-D Resistivity and Self Potential (SP) Methods in Determining the Water Flow

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Abstract. Existence of water flow at urban area will decrease the shear strength and increase hydraulic conductivity of soil which finally caused subsurface problems at this area. To avoid landslide, slope instability and disturbance of the ecosystem, good and detailed planning must be done when developing hilly area. The understanding about geological condition has to be considering before construction activities be done. Six 2-D resistivity survey lines with minimum 5 m electrode spacing were executed using Pole-dipole array. The field investigation such as borehole was carried out at multiple locations in the area where the 2-D resistivity method have been conducted. The directions and intensities of the water were evaluated with self-potential (SP) method. Subsequently, the results from borehole were used to verify the results of electrical resistivity method. Interpretation of 2-D resistivity data showed a low resistivity value (< 40 ohm-m), which appears to be a zone that is fully saturated with sandy silt and this could be an influence factor the increasing water level because sandy silt is highly permeable in nature. The borehole, support the results of 2-D resistivity method relating a saturated zone in the survey area. There is a good correlation between the 2-D resistivity investigations and the results of borehole records.

1. Introduction
Soils in urban areas are highly disturbed, which has less organic matter and non-soil material with different hydrological properties from those of natural soils [1]. Construction and development activities in modern cities change soil, geological, and hydrological conditions and often caused dramatic changes in groundwater level [2] and [3]. Rising groundwater destroys buildings and causes landslide [3] and [4] therefore, timely soil and hydrological information is essential to prevent destruction. Stratification of saturated zone, weak zone and estimation of groundwater levels are important. Obtaining the subsurface information with conventional methods, such as drilling and
excavation, is destructive and therefore difficult and prohibitive in most urban areas. Rapid and non-destructive methods for soil investigation and subsurface conditions are highly desirable in modern cities [5] and [6].

The most engineering challenges come from an open waste disposal sites is water seepage erosion. In designing building and detecting environmental problems, borehole data and soil test are still needed by the engineers. Therefore, selection of geoelectrical method will be appropriate by considering of the cost effective and non destructive method. 2-D resistivity and Self potential were conducted by [7] to detect the groundwater contamination and to locate possible pathways of leachate plume that comes from an open waste disposal. Besides, these methods were also carried out by [8] to map the presence of the unknown underground water sources (saturated zones) and its movement. With the total of seven resistivity lines parallel to each other and self potential (SP) with 5 m × 5 m gridding survey were successfully done. The resistivity result shows that the subsurface consist of saturated zones which are believed as the accumulation zone. As for SP result it shows the water flow from higher value (north-east) towards the lower value which is mostly at the south area

2. 2-D resistivity
The basic principle of resistivity surveys is to determine the subsurface resistivity distribution by injecting the current on the ground surface. The ground resistivity measurement is depends on several factors such as mineral content, porosity, fluid content and degree of water saturation in rock which may influence the resistivity values. Variations in electrical resistivity may indicate changes in composition, layer or contaminant levels [9].

3. Self-Potential (SP)
SP method is extremely sensitive to man-made electrical interferences. SP data is generated from measurements of naturally occurring electric potentials across two electrodes placed on the earth’s surface and the potentials measured during the survey. It may be positive or negative to locate anomalies of interest [10] and [11]. Sources of SP effects are varied (sulphide mineral, vegetation, concentration in water, fluid motion and other meteorological). The pore space has an ability to displace fluid motion with excess mobile charge at grain surface. The collection charge creates an electric field that drives a secondary return current (Figure 1).

![Figure 1. The basic principles diagram for self potential measurement.](image-url)
4. Methodology
Six resistivity profiles were carried out at the surveyed area, with separation of 5 m electrode spacing using Pole-dipole array. Pole-dipole was choosing due to its good horizontal and vertical resolution [9]. However in some parts of the survey line data could not be acquired due to the space constraint. For the measurements, SAS4000 and four channel selector ES10-64C was employed (Figure 2(a)). Processing was performed using Res2DinV software. In addition, borehole information from the standard penetration test (SPT) N-values was used to constrain the interpretation of resistivity data. The data from 2-D resistivity and borehole was correlated to predict soil parameters at the survey area. Further, Self Potential was also conducted at L1 and L2 to validate the flow of water (Figure 2(b)). The data will process using Surfer8 software.

![Figure 2. The equipment used for a) 2-D resistivity b) Self Potential method.](image)

The SP method utilizes two electrode (base and moving porous pot), voltmeter, small hoe and connecting wire. The base porous pot was buried away from the grid in a shaded area devoid of grass cover and moving porous pot to measure potential differences on a gridded survey lines were spaced every 5 m with a total of 34 points. SP field survey was employed by measured electrical potential differences between two pairs of electrodes on the ground at a number of survey stations which spaced along a grid, one station is selected as a base station which is fix point and all potentials that are moving are referenced to that point. The base station was located at a point removed from expected anomalous activity then measurements are made by connecting to ABEM SAS 300C Terrameter with two electrodes, base and a moving electrode.

5. Study area
Geoelectrical survey lines were conducted at Selangor, Malaysia. Six 2-D resistivity survey lines were employed at L1 to L6 and Self-Potential (SP) survey was carried out near L1 and L2 as shown in Figure 3. There are seven boreholes located at the study area, however only two borehole (DBH 3 and DBH 4) located on L5 and L6 respectively.
6. Geology of the study area

Near to the Puchong area, in the northern part, the formation consists of alluvium. Generally, the study area is covered by granite and is dominated with quartzite at the Cretaceous age. There are some low granite hills and in the eastern part, the area covered by limestone. The contact between granite and limestone is the alluvium as shown in Figure 4.

Figure 3. Study area with 2-D resistivity profile lines (L1 to L6), borehole location (DBH 1 to DBH 7) and Self-Potential (SP) location [12].

Figure 4. Geology of the study area at Selangor.
7. Results and Discussions

2-D resistivity produce soil resistivity data which can be used to predict soil types with correlation of borehole record and SP result was use to see the water flow of the subsurface. Figure 5 shows the inversion model of 2-D resistivity of all survey lines and Figure 7 shows the SP results which show the water was flowing from L1 to L2.

Figure 5. Inversion model resistivity for L1 to L6.
L1 and L2 shows resistivity value of 300-500 Ωm from the inversion model resistivity which is indicated as permeable layer at depth of less than 15 m from the surface. The permeable layer is made up of sand and coarse gravel. It is also has an ability for water to pass through easily. This characteristic is indicated as good potential for groundwater aquifer. The saturated zone (0-40 Ωm) at the depth of 10 m to 20 m was found scattered at L3, L4 and L6 as shown in Figure 5. Sandy silt was found at the depth of 10 m to 20 m from DBH4 which is the nearest borehole located at L6. Sandy silt is highly permeable in nature therefore the low resistivity value at 10-20 m depth could be mainly due to sandy silt and this could be an influence factor the increasing water level. This is prove by borehole DBH4 which confirm that sandy silt is located at depth of 10-15 m and water level is full at the end of the borehole. L5 shows high resistivity value of > 1000 Ωm (Figure 5) which could be interpreted as weathered sandstone at depth > 10 m, this is further confirmed by the borehole record that fractured and highly weathered sandstone was found at depth of 10 m. According to DBH3 water level was located at L5 with depth < 15 m and the similar results also found in inversion model resistivity. These low resistivity value at the surface, fracture and highly weathered sandstone at L5 has possibility to cause tension crack at this area. A lot of fractures found in the study area indicated of poor rock quality [13]. Fault zone was found at L6 due to the highly contrast of 2-D resistivity values [14], [15] and [16].

![Figure 6. Inversion model resistivity for L6 with DBH4.](image)

Sandy silt was found at depth of 10 m to 20 m from the borehole (DBH4) that is located at 63 m at L6. 2-D resistivity result show low resistivity value which is interpret as saturated zone (0-40 Ωm) at the depth of 10 m to 20 m from the surface. Therefore, the saturated zone in 2-D resistivity was indicated as sandy silt. The inversion model of 2-D resistivity with resistivity value of 800 Ωm was interpreted as highly weathered sandstone with SPT N-value of 20 at depth 6 m from the surface. The SPT N value of 50 and resistivity value of 3000 Ωm is bedrock located at 27 m. Therefore, the higher the resistivity value, the higher the SPT N-value. However water and clay content may affect the soil resistivity value.

Figure 7 shows three major iso-potential areas with negative potentials were formed along L2. These areas were indicated as the areas of water infiltration into the soil and development of groundwater flow. The most negative potential (-40 mV) along the L2 path indicated the most intensive subsurface water flow in this area [8][17]. The surface peaty sand developed at the -40 mV iso-potential areas with resistivity value < 150 Ωm. The seepage area was enriched with sandy silt material having resistivity value from 0-40 Ωm. Therefore, the percentage of sandy silt in the soil increased towards L2.
Figure 8 shows the arrangement of 2-D inversion model of all the survey lines overlay on map. Subsequently, figure 9 shows that the 2-D resistivity and SP results is closely arranged where it matches the existence water flow on the study area.

Figure 7. Self-Potential (SP) result near L1 and L2 showing the distribution of water flow with x-axis (North) and y-axis (East) in degree (°) unit.

Figure 8. The arrangement of 2-D Inversion model resistivity at the study area.
8. Conclusion

The 2-D resistivity and SP results show a good correlation. The data obtained from the 2-D resistivity method indicates the soil resistivity can be affected by water and clay content. A saturated layer has also been identified by the survey which could be a concern in relation to the possible cause of landslides and collapse of the retaining wall. The SP shows direction of the water seepage which integrated with 2-D resistivity results which shows the highly saturate zones location. Both results correlated well and show the presence of saturated zone, with depth range between 0-15 m depths. Generally, high anomaly area represents discharge zones with strong lateral flow meanwhile, the low anomaly areas correspond to infiltration's area. The result of 2-D resistivity and SP methods could be used to detect subsurface problem induced by water flow supported by borehole records.
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