Journal of the Earth and Space Physics, Vol. 45, No. 4, Winter 2020, P. 77-87

DOI: 10.22059/jesphys.2019.266387.1007041

Determination of Soil Moisture Content at Bukit Bunuh Meteorite Impacted Area using Resistivity Method and Laboratory Test

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(Received: 7 Oct 2018, Accepted: 14 May 2019)

Abstract
Determination of soil moisture content is of vital importance to many fields of study; civil engineering, hydrology, agriculture, geology, ecology and forestry. The occurrence of impact crater in Bukit Bunuh, a meteorite impacted area, made it an area of great interest to many researchers. In view of the process of impact cratering, the subsurface soil characteristics such as moisture content of the impacted area are prone to change and therefore prompted for this study. 2-D resistivity survey, borehole and laboratory test were used for the study. The outcome revealed that the subsurface soil inside the crater has high moisture content of 29 – 59 %, which corresponds to low resistivity values of < 300 Ωm at a depth of < 20 m. This is probably caused by the geological processes involved in the impact cratering, which made the soil to be loose, porous and permeable, thus enhancing the moisture content. The soil overlying the crater rim and outside the crater has higher resistivity values > 300 Ωm, which is indicative of low moisture content (< 29 %). The highly resistive soil is more pronounced on the crater due to the reclaimed soil during the impact cratering. Based on the data analysis, significant correlation between the soil moisture content and the electrical resistivity was established.

Keywords: Moisture content, Soil, Impact Crater, 2-D Resistivity, Laboratory Test.

1. Introduction
The importance of determining soil moisture content in civil engineering, hydrology, agriculture, geology, ecology, forestry and other environmental fields cannot be overemphasized (Gardner et al., 2000). Soil moisture content determination is one of the major engineering considerations and activity that is undertaken before erecting a structure, because the strength and stability of most structures depend on it (Adid, 2015). Impact crater results when a large meteoroid (asteroid or comet) traveling at high velocity collides with a planetary body that has a solid surface, such as earth and moon. The process of formation of an impact crater is quite complex and depends on the factors such as the type, size and velocity of the traveling meteorite, the angle of impact and the target materials (Collins et al., 2012; Ernstson & Claudin, 2013; Melosh & Ivanov, 1999; Selen, 2013). It is a rapid, highly dynamic, continuous sequence of events that occur within some minutes (Turtle et al., 2005). The occurrence of impact crater and stone tools in the study area, made the area to be of great interest to researchers (Archaeologists, Geologists and Geophysicists) who proposed for the construction of structures within the study area. In view of the processes that led to the impact crater, there is a tendency that the soil characteristics within the impacted area have been altered. The study was triggered based on the aforementioned reasons. Some major tools for delineation and affirmation of impact crater on earth – as opposed to volcanic craters – are the geophysical methods (Pilkington and Grieve, 1992).

Although, this research is not aimed at detecting the impact crater, as considerable number of researches have been conducted to delineate the possible occurrence of impact crater in the Bukit Bunuh area (Ismail et al., 2015; Ismail et al., 2014; Nawawi et al., 2004; Nur Amalina et al., 2012; Saad et al., 2012; Saad et al., 2014; Saad et al., 2011;

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Samsudin et al., 2012). Hence, this study is focused on the determination of the soil moisture content of the impacted area. Findings from this study coupled with other geotechnical parameters will serve as a guide to the engineers in designing their foundation within the area. The methods adopted in this study were based on the works of Arjwech & Everett, 2015; Hazreek et al., 2013; Nijland et al., 2010; Ozcep et al., 2010; Schwartz et al., 2008; Siddiqui et al., 2012. Their results ascertained the effectiveness of the methods in determining soil moisture content.

2. Location and geology of the study area

Bukit Bunuh is situated in Lenggong town of Perak, Malaysia. It lies between two mountain ranges; Titiwangsa Range and Bintang Hill with rugged topography. The entire Lenggong Valley is underlain and dominated by a granitic rocks of Jurassic end to Carbonaceous low era, which originated from Bintang Range at West of Lenggong (Saidin, 1993). Bukit Bunuh is made up of Quaternary sediment and small lithology units of Tertiary tephra ash and metasediments. Nawawi et al. (2009) reported that the surrounding topography of Bukit Bunuh was formed due to a meteorite impact, about 1.83 million years ago. Figure 1 depicts the Geological map of Lenggong Valley showing the location of Bukit Bunuh.

3. Methodology

The study is divided into two phases: 2-D resistivity survey and Laboratory measurement of soil samples obtained during the borehole drilling. The first phase involves the resistivity method based on a principle of injecting electric current into the ground through a pair of current electrodes (C_1 and C_2). The resulting potential difference (voltage) is measured at the surface between a pair of potential electrodes (P_1 and P_2). As the current is introduced into the ground, any variation from the pattern of potential difference expected for a homogeneous ground gives an information about the subsurface inhomogeneities (Kearey et al., 2002). The resistance values can be obtained using Ohm's Law (Equation 1). The apparent resistivity is obtained using Equation 2. Generally, in 2-D resistivity survey, current and potential electrodes are arranged linearly (Figure 2).

$$R = \frac{V}{I} \quad (1)$$

$$\rho_a = \frac{V}{I} \times G \quad (2)$$

where V is the measured potential difference, I is the input current and G is the geometric factor (which depends on the resistivity array arrangement type).

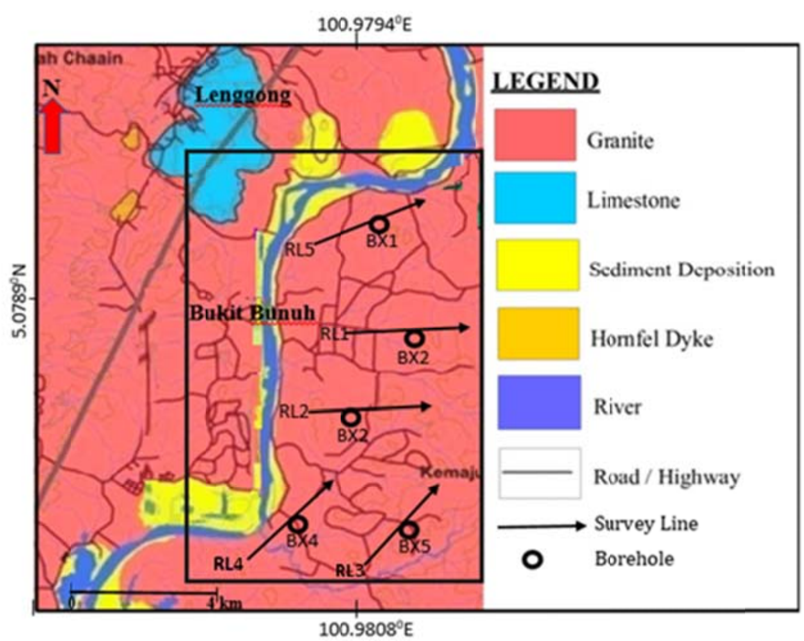


Figure 1. Geology map of Lenggong Valley with study area marked in the black box showing arrangement of resistivity survey lines and borehole locations (modified after Hidayah, 2015).

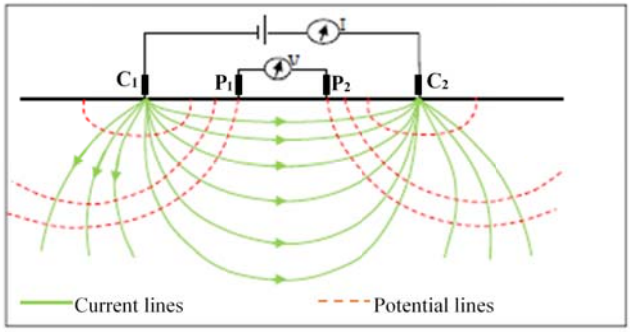


Figure 2. Four-point electrode configuration showing current and potential distribution (Modified from Nordiana et al., 2012).

ABEM Terrameter SAS4000 system (which includes electrode selector, cables, electrodes, jumpers and a 12-volt battery) was used in acquiring the 2-D resistivity data. Pole-dipole array was used because of its high signal strength and deeper penetration to acquire data along five 2-D electrical resistivity survey lines (RL1-RL5); survey lines RL1 and RL2 inside the crater, RL3 and RL4 on the crater rim and RL5 outside the crater. Each survey line has a total length of 400 m. The acquired data was processed using RES2DINV and Surfer software packages.

In the second phase of this study, five boreholes (BX1 – BX5) were drilled along the survey lines to collect samples for the laboratory test. Two of the boreholes (BX3 and BX2) were situated inside the crater, while two others (BX4 and BX5) on the crater rim and one (BX1) outside the crater. Laboratory measurements were performed on eleven (11) samples obtained from each borehole at varying depths. Moisture content was then determined for the soil samples while Rock Quality Designation (RQD) test was carried out for the rock core sample. Equation 3 was used to calculate the moisture content. The 2-D resistivity result was correlated with the laboratory parameters result to generate a standard table for bulk resistivity against moisture content and RQD for impacted soil and rock inside, on the crater rim and outside the crater.

$$MC = \frac{m_2 - m_3}{m_3 - m_1} \times 100 \qquad (3)$$

where m_1 is the mass of container, m_2 is the mass of container and wet soil and m_3 is the mass of the container and dry soil.

4. Results and Discussion

The results obtained from 2-D resistivity survey and laboratory test of the study are presented. Two resistivity groups were identified from results obtained for all the survey lines (RL1-RL5); low resistivity zone with values < 300 Ωm and high resistivity zone with values > 300 Ωm. The moisture contents were identified in the range of 7 - 59 % for all samples collected. They are also grouped into classes; low (7 - 28 %) and high (29 - 59 %).

4-1. Inside the crater

Data from 2-D resistivity survey lines RL1 and RL2 (Figure 3) conducted inside the crater show comparable results; a prominent low resistivity zone of < 300 Ωm interpreted as the overburden, which consists of clay, silt, sand with some gravel. The low resistivity might be due to the meteorite impact that create fractures, thereby making the soil to be loose, porous, and permeable that results to high moisture content. Conspicuous very low resistive zone (0 – 30 Ωm) was observed on Figure 3b. It indicates water saturated zone, which occur due to the infiltration and accumulation of water and sediments to fill the fractures created by the impact. There is presence of high resistivity zones at certain locations within the bedrock. These may be high resistive rock fragments (boulders) with resistivity values of about 2000 - 5000 Ωm, displaced during the crater forming process.

Borehole BX3 and BX2 were tied with the 2-D electrical resistivity survey lines RL1 and RL2 at distances of 200 m. The results within the range of the boreholes depth show that the overburden consists of cohesive and non-cohesive soils with resistivity values ranging from 100 - 400 Ωm. The cohesive soils being the dominant material, consists of silt, sandy silt and sandy clay. The laboratory test for the soil samples from both boreholes (BX3 & BX2) revealed high moisture content in the range of 29 - 59 % for cohesive soil and 9 - 21 % for the non-cohesive soil. These results are in conformity with previous studies, which indicated that the moisture content increases with decreasing soil resistivity (Hazreek et al., 2013; Ozcep et al., 2010; Tezel & Ozcep, 2003). The bedrock is made up of slightly weathered granite with RQD values of 47 - 75 % and highly weathered granite with an RQD value of 0 % (Table 1). The RQD value of 0% means the rock is completely weathered and there would be problem of bearing capacity when founding civil engineering structures.

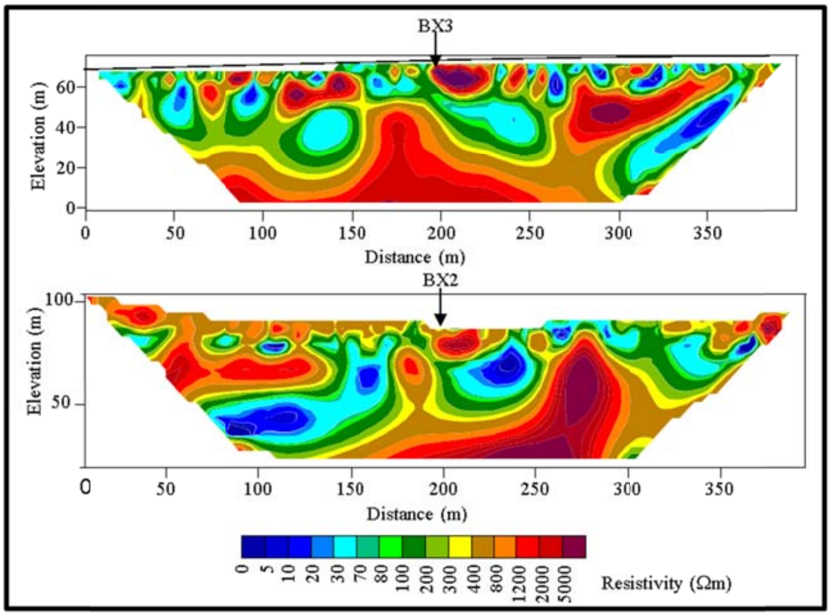


Figure 3. 2-D resistivity model of (a) RL1 and BX3 and (b) RL2 and BX2.

Table 1. Laboratory and field measurement of some geotechnical parameters of BX3 & BX2.

BH No.	Sample No.	Depth (m)	ρ (Ωm) Section	Resistivity, ρ (Ωm)	Moisture Content (%)	RQD (%)	Lithology
BX3	S1	1.5		102.4995	35		Sand, Coarse Sand & Gravel
	S2	3		194.9456	29		
	S3	4.5		287.3918	27		Silty Sand & Clay
	S4	6		2028.033	17		
	S5	7.5		2768.674	11		
	S6	9		4509.315	16		Stiff Silt with some Sand
	S7	10.5		5616.328	9		
	Y1	12.5		5723.342		47	Slightly Weathered Granite
	Y2	14.5		5830.355		70	
	Y3	16		4169.278		69	
	Y4	18		2508.201		55	
BX2	S1	3		379.5182	59		Silty Sand & Clay
	S2	4.5		420.4168	34		
	S3	6		821.3155	27		
	S4	7.5		1022.2142	24		
	S5	9		1785.7357	22		
	S6	10.5		2549.2572	18		Stiff Silt with some Sand
	S7	12.		3312.7788	16		
	Y1	13.5		2399.8823		51	Slightly Weathered Granite
	Y2	15		1086.9858		75	
	Y3	18		993.4589		62	
	Y4	19.5		1086.9858		0	Highly Weathered Granite

4-2. On the Crater Rim

Data from resistivity survey lines, RL3 and RL4 (Figure 4) acquired on the crater rim show a thin overburden. The profile, RL4 which was closer to the inside crater at lower elevation than RL3, reveals a high resistivity zone for the overburden. This might be due to the presence of reclaimed soil when the area was impacted by a meteorite, which as a result, made the overburden soil on the crater rim to have a low moisture content. It has been proven by borehole record that both survey lines show a bedrock at a depth of about 10.5 m with resistivity values ranging from 2000 - 5000 Ωm. The resistivity of the bedrock decreases with depth, which indicates that the bedrock is fractured. Normally, when fracture occurs, water and sediments tend to fill the cracks thereby resulting in low resistivity. A low resistivity zone < 300 Ωm at positions 150 and 300 m along profile RL4 was observed within the bed rock, which is also due to the fractures as shown in Figure 4b.

Laboratory results obtained from boreholes BX5 and BX4, located along line RL3 and RL4 at distances 200 m and 220 m respectively, revealed that the overburden on the crater also consists of cohesive and non-cohesive soils, but mostly dominated by non-cohesive soil with a slightly lower moisture content of 10 - 20 % (Table 2). The low moisture content corresponds with the high resistivity of the overburden on the crater rim. This also accords with the findings of Hazreek et al. (2013) and Siddiqui et al. (2012), which found that high resistive soil is characterized by low soil moisture content. The cohesive soil is made up of clay and silt, while the non-cohesive is made up of sand and gravel. The bedrock on the crater rim is made up of highly fractured granite, resulting in 0 % RQD value and slightly weathered granite with RQD values of 56.0 - 86.7 %.

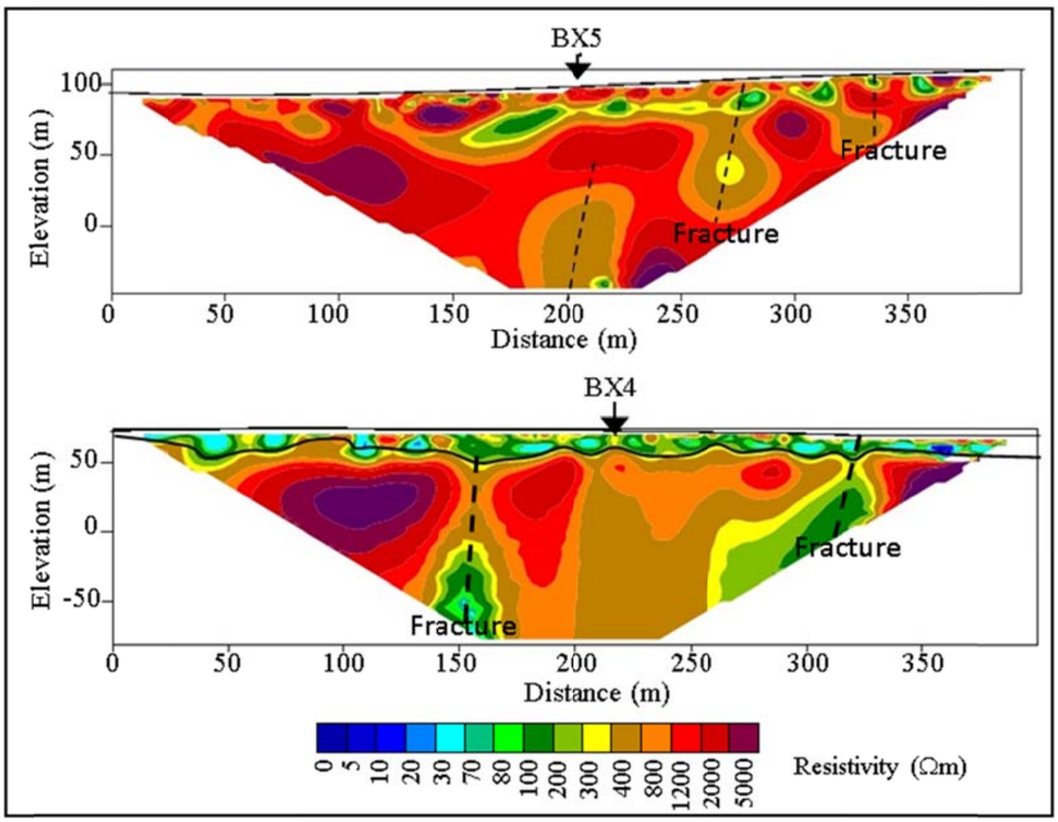
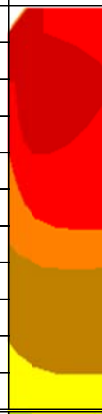
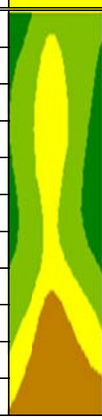


Figure 4. 2-D resistivity model of (a) RL3 and BX5 and (b) RL4 and BX4.

Table 2. Laboratory and field measurement of some geotechnical parameters of BX5& BX4.

BH No.	Sample No.	Depth (m)	ρ (Ωm) Section	Resistivity, ρ (Ωm)	Moisture Content (%)	RQD (%)	Lithology
BX5	S1	1.5		1576.8863	18		Sand, Coarse Sand & Gravel
	S2	3		2496.3071	11		
	S3	4.5		3150.2049	10		Silty Sand & Clay
	S4	6		2420.3450	11		
	S5	7.5		1352.6179	28		
	S6	9		1014.2462	29		Stiff Silt with some Sand
	S7	10.5		675.8746	16		
	Y1	12		542.3188		0	Highly Weathered Granite
	Y2	13.5		533.9716		0	
	Y3	15		500.5826		0	
	Y4	16.5		375.3741		0	
BX4	S1	1.5		304.1391	28		Silty Sand & Clay
	S2	3		339.4374	27		
	S3	4.5		375.8562	27		
	S4	6		359.0130	25		
	S5	7.5		342.1699	19		Stiff Silt with some Sand & gravel
	S6	9		356.0643	17		
	S7	10.5		431.4338	12		
	Y1	12		506.8033		63.6	Slightly Weathered Granite
	Y2	13.5		619.6277		86.7	
	Y3	15		621.5342		56	
	Y4	16.5		656.6782		0	Highly Weathered Granite

4-3. Outside the Crater

Data acquired along the resistivity line, RL5 (Figure 5) located outside the crater revealed a highly resistive bedrock (> 400 Ωm), which is overlain by a thin overburden with resistivity values < 400 Ωm. At distances 270 m - 320 m along the profile (Figure 5), the bedrock appears to be fractured or separated into two, as indicated by the decrease in resistivity. As fracture occurs within the bedrock, water seeps through the cracks, which is later filled by sediments thereby lowering the resistivity of the bedrock.

Borehole BX1 was correlated with the survey line, RL5 at distance 250 m. The borehole record agrees with the resistivity result within the range of the borehole depth (< 20 m). The laboratory test of BX1 samples shows that the overburden within the RL5 survey line predominantly consists of cohesive soils, which are made up of sandy silt and some non-cohesive soil (sand and gravel). The non-cohesive soil was found to have a relatively lower moisture content of 7 - 19 % compared to the cohesive soils with moisture content of 20 – 28 %. In accordance with the present results, previous studies have demonstrated that highly resistive soil correspond to low moisture content and vice-versa. The bedrock is made up of slightly weathered granite with RQD values of 66.67 - 91.67 % and highly weathered granite with an RQD value of 0 % (Table 3).

4-4. Simple Regression Analysis

The results from resistivity survey and Laboratory test was analyzed to produce empirical correlation between geophysical (electrical resistivity) and geotechnical (moisture content) parameter. Soil moisture content (MC) was plotted against electrical resistivity (ρ) for the impacted soils inside, on and outside the crater rim (Figures 6a, 6b

& 6c) respectively. Relationship between the two parameters shows a non-linear correlation with regression equation (Equations 4 to 6). Power curve fitting approximation was applied. A good power correlation was observed for the impacted soils inside, on and outside the crater rim with determination co-efficient $R^2 = 0.6789,\ 0.6957$ and 0.768 respectively. There was a similar trend in all the three plots (Figures 6a, 6b & 6c), mostly as the electrical resistivity of the soil decreases, the moisture content tends to increase. The finding is consistent with findings of previous studies by Syed et al. (2014) and Ozcep et al. (2009), which revealed that electrical resistivity decreases with increasing moisture content in soils. Higher moisture content facilitates conduction of electrical current through the movement of ions in pore water. This is because the moisture replaces the soil non-conducting air voids thus increasing the degree of saturation and results in decrease of electrical resistivity. The soil moisture content of the impacted soil inside, on and outside the crater can be estimated alternatively using Equations (4) to (6) respectively.

$$y = 205.1x - 0.322 \tag{4}$$

$$y = 210.27x - 0.363 \tag{5}$$

$$y = 346.09x - 0.626 \tag{6}$$

where (y) represents the soil moisture content (MC) and (x) represent the electrical resistivity (ER).

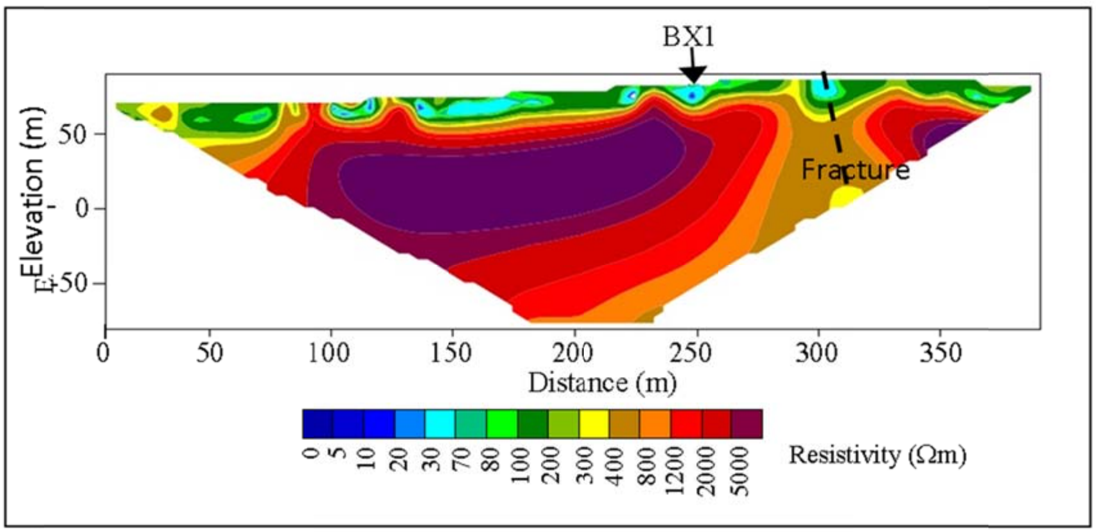
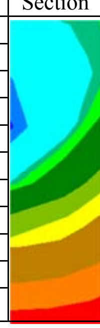
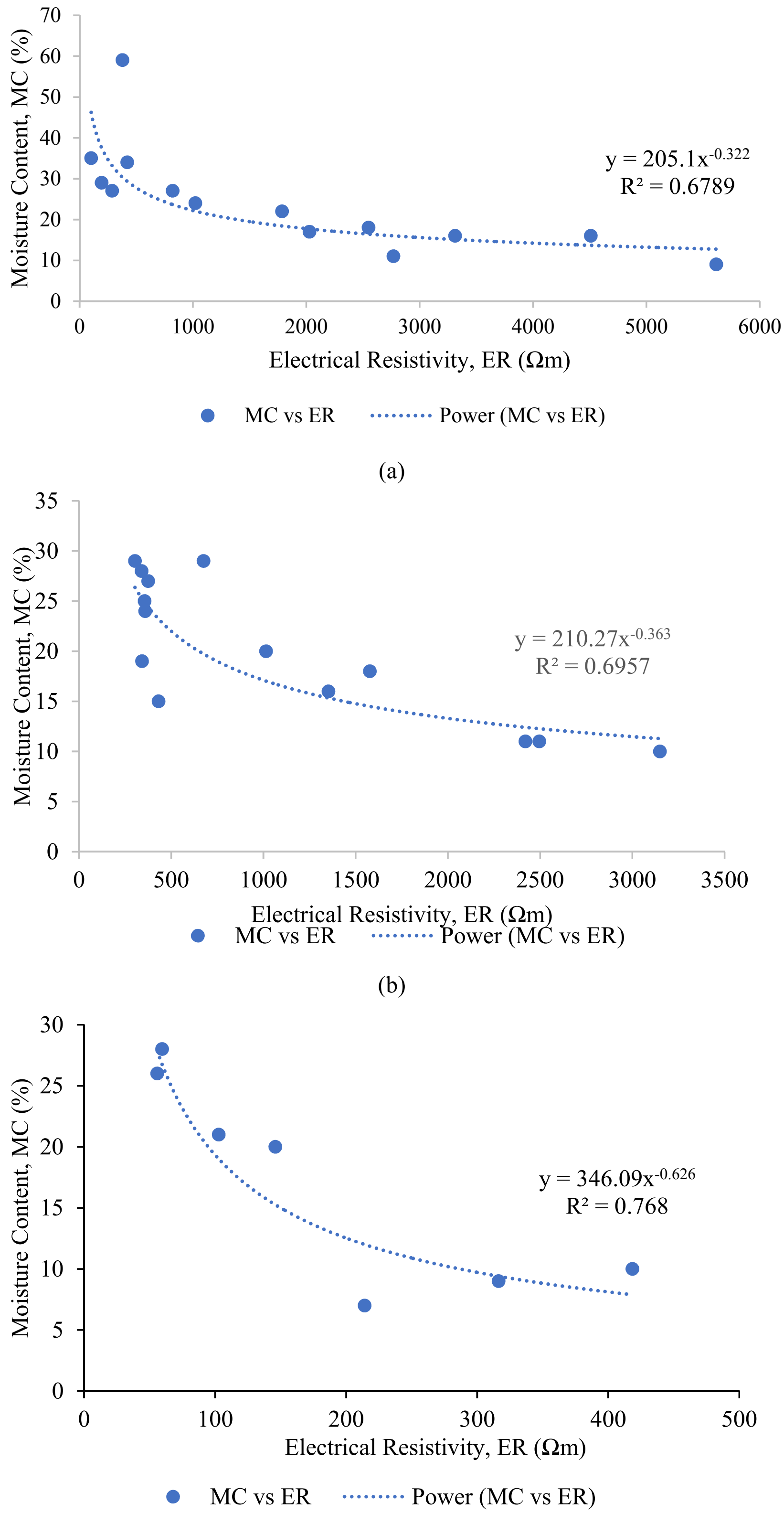


Figure 5. 2-D resistivity model of RL5 and BX1.

Table 3. Laboratory and field measurement of some geotechnical parameters of BX1

BH No.	Sample No.	Depth (m)	ρ (Ωm) Section	Resistivity, ρ (Ωm)	Moisture Content (%)	RQD (%)	Lithology
BX1	S1	1.5		55.85309	26		Silty Sand & Clay
	S2	3		59.54512	28		
	S3	4.5		102.7963	21		
	S4	6		146.0476	20		
	S5	7.5		214.169	7		Sand, Coarse Sand & Gravel
	S6	9		316.351	9		
	S7	10.5		418.5331	10		
	Y1	12		646.4743		66.67	Slightly Weathered Granite
	Y2	13.5		874.4155		91.67	
	Y3	15		1156.235		0	Highly Weathered Granite
	Y4	16.5		1545.81		0	



(c)

Figure 6. a: Moisture content with electrical resistivity correlation of impacted soil inside the crater, b: on the crater rim, c: outside the crater.

5. Conclusion

The 2-D electrical resistivity and laboratory test of soil and rock materials collected have proven to be a useful tool for the determination of the soil moisture content. It is obvious from the results obtained that the soil characteristics of the impacted area have been changed because of the meteorite impact. The outcome of the study revealed that the subsurface soil inside the crater has high moisture content (29 - 59 %), which corresponds to low resistivity values (< 300 Ωm) at depths of < 20 m. This is probably caused by the geological processes involved in the impact cratering that makes the soil to be loose and porous, thus enhancing the moisture content. The soils on the crater and outside the crater have high resistivity values (> 300 Ωm), which results in low moisture content (< 30 %). The highly resistive soil was more pronounced on the crater due to the reclaimed soil during the impact cratering. Based on the data analysis, significant correlation between the moisture content and electrical resistivity was observed. An empirical regression equation (Equations 4 to 6) established could be used to estimate the MC if the ER is known. In conclusion, a reference document for the electrical resistivity, moisture content and RQD on, inside and outside the impact crater was established to guide the engineers in designing the foundation of structures to be constructed.

Acknowledgements

The authors wish to thank the Postgraduate students and staff of Geophysics Section, Universiti Sains Malaysia for their help during the data acquisition and Centre for Global Archaeological Research Malaysia (CGAR), Universiti Sains Malaysia for sponsoring the project.

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