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Engineering Geophysical Study for Geotechnical Investigation, Port Sudan, Red Sea, Sudan

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Abstract: ***The overall objective of the study is to locate underground anomalies in form of cavities, fractures, faults or any other anomalies that might exist within the ground subsurface makeup to a depth of 20m below existing ground level using multi-geophysical techniques in term of microgravity and Electrical Resistivity Tomography to meet the requirement of building construction in the project area. Topographically the area is bounded by altitudes as high as 4m in the southern and eastern part and 0m in northern and western and central parts (above the main sea level) towards the east direction. Apparently the terrain surface of the project area is covered by silty and fine-grained sediments of the Sabkha formation. Eight lines of microgravity and Electrical Resistivity Tomography were collected at the proposed site. The interpretation of three lines of gravity data from the proposed site is presented in this work. In each line a small anomalous low value was identified. These may represent week zones in the subsurface. However these anomalous values could also be the result of a local dip in bedrock surface, a variation in the density of bedrock, or a variation in the density of the overburden. Considering the boreholes and ERT sections the formations from top of bed rock to 20m depth in the site are mainly slightly to moderately weathered. The siltstone between 8 and 12m approximately are highly weathered and fractured.***

Keywords: Microgravity, Electrical Resistivity Tomography, Sabkha, density.

1. Introduction

The Red Sea region is interesting for geologists, and geotechnical engineers in constructions. The regional geology (Fig. 1) was carried out by [1]; [2] reported that the modern rock shoreline sedimentary environment is a hostile one and range of high – energy processes characterize these shorelines. The designation of weathering depositional companion model of the karst formation in the Red Sea coast of Sudan had been done by [3], [4] and [5]. For solving engineering, geological, hydrogeological and environmental tasks, geo-electrical methods are routinely applied. However, almost the investigations were used the engineering geophysics in term of mirco-gravity and geo-electrical methods in different types of coast formations. In contrast, several geotechnical characteristics of soil could be evaluated by using engineering geophysics and the correlated with depth and other parameters [6].

Very rare geotechnical publications in Sudanese coast on continental shelf even hazard map for engineering purposes, planning and/or development never take any researcher interest. In contrast, intensive investigations have been done on the eastern Red Sea coast. Geotechnical problems as chemical stabilization in Sabkha and formations were studied by [7].

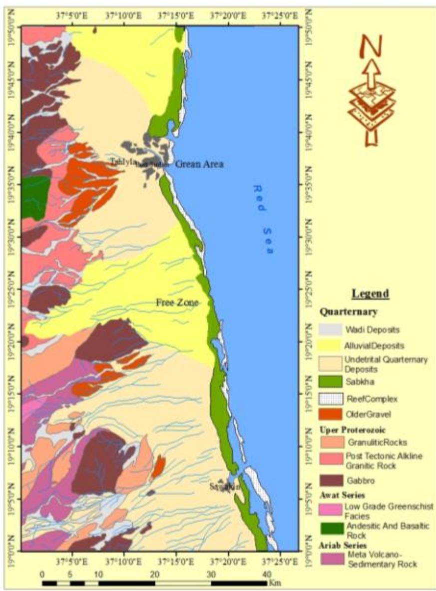

Figure 1: Regional geological map of the study area

2. Site Location and Description

The study area is located in the southern Port Sudan (Fig. 2).

The site was selected by the Administration of Engineering Projects Department-Sudan Ports Corporation. Multi engineering geophysical technique were measured in mixed alluvial marine deposits on continental shelf in term of micro-gravity and electrical resistivity tomography (ERT).

This paper provides details of the work undertaken, the objectives and the results of the surveys, conclusion, figures and maps categorizing the site with respect to the presence of week zones/anomalous ground and recommendation for preliminary foundation design and construction.

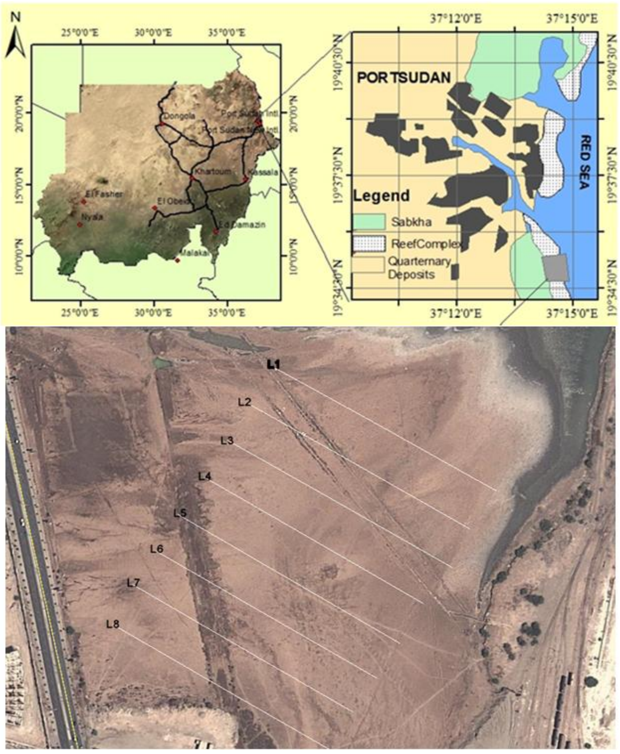

Figure 2: Location map, shows the boreholes positions

3. Objective of the study

The overall objective of the study is to locate underground anomalies in form of cavities, fractures, faults or any other anomalies that might exist within the ground subsurface makeup to a depth of 20m below existing ground level using multi-geophysical techniques (Microgravity and Electrical Resistivity Tomography (ERT)) to meet the requirement of building construction in the project area. However the specific objectives included the following:

- Location/identification (by coordinates) of potential sites of week zones/anomalous.
- Upon locating of such potential sites, assessment of the depth/length/width in terms of positioning and anomalous classification with due consideration to the project needs.
- Suggestion of alternatives potential sites in terms of accessibility.
- Recommendation for preliminary foundation design and construction.

4. Methodology

4.1 Micro gravity survey Data Acquisition

Gravity lines were collected at the proposed site. Eight lines were collected, coincident with Lines L1, L2, L3, L4, L5, L6, L7, and L8 of the associated ERT survey at the site as shown in the location map in (Fig. 2).

Data were collected at 5 m spacing and precise elevation at each measurement station was acquired by the surveyors.

Voids are anticipated to correlate with short length scale decreases in the gravity values. These anomalies are expected to be only one or two stations long. A decrease in the gravity value may also result from variations in bedrock surface, variations in bedrock density or variations in density in the overburden.

A Scintrex CG-3 Autograv gravimeter, employing a fused quartz spring system, was used at the site. This instrument has a resolution of 1 μGal with standard deviation less than 5 μGal. Residual long-term drift is quoted at less than 0.02 mGal per day.

4.2 ERT Data Acquisition

Wenner (Alpha Array) configuration was used during the whole survey. A total 8 ERT lines within 10m line spacing and 2m electrode spacing were recorded (Fig. 2). The total number of ERT points is 710.

The surface along the acquired lines was made of Sabkha. The injection current was kept between 50 and 300 mA during the acquisition phase. This was achieved by changing the voltage of the battery source.

Part of our QC System is related to acquisition and processing of the acquired data. Generally the original data acquired by technicians and operators have to be checked and cross checked.

4.3 Topographically

Topography Survey was conducted prior to the geophysical survey, using GPS RTK. Wooden sticks were set every 50m over the geophysical lines to indicate the Gravity and ERT line locations. Then a measuring rope with clearly marked marks every 2m was used between the wooden sticks to place the electrodes exactly on location.

Topographically the area is bounded by altitudes as high as 4m in the southern and eastern part and 0m in northern and western and central parts (above the main sea level) towards the east direction. Apparently the terrain surface of the project area is covered by silty and fine-grained sediments of the Sabkha formation.

5. Results of the Study

5.1 Micro Gravity Data Processing and Interpretation

The gravity field measured at the earth's surface is a function of latitude, elevation, surrounding topography, earth tides, instrument drift and subsurface density variations. To derive the gravity field due solely to density changes within the subsurface, the effects of the remaining parameters must be stripped away. The effects of latitude and elevation are typically larger than those of subsurface features which, in turn, are usually larger than those of tides, drift and adjacent topography.

Progressing from equator to the poles, gravity field values change by about 5 Gal. Modern gravity meters are designed to measures very small relative changes in the ambient gravity field between survey points or at a single location over a period of time. In order to convert surveyed gravity data to absolute gravity values, a gravity control point where absolute gravity is known must be incorporated into the survey. For the present survey, no such absolute gravity control points were available, so relative gravity field values are presented. There is no requirement, therefore, to calculate the expected absolute gravity for the known sample latitude.

To correct for changes in elevation between sample locations, gravity field values are reduced to a datum, usually sea level. This is achieved by first repositioning the station to the plane of the datum. The effect of the material in the vertical column between the station and the datum (i.e. mass excess or deficiency) is then removed, producing what is referred to as the Bouguer gravity value (Fig. 3).

The earth's gravity field is subject to tidal variations caused by external forces exerted on the earth by the sun and moon. These effects are smoothly varying and slow to manifest and are, therefore, included in the correction for instrument drift. Over time, the null or zero position of the gravimeter drifts because of creep in the internal spring. This effect can be accounted for by reacquiring measurements at selected stations. Instrument drift over a known period of time can then be quantified and a correction applied to each reading.

In total, 8 lines were collected at the proposed site (Fig. 3). The results for three of these lines (Lines 1, 4 and 8) are presented here.

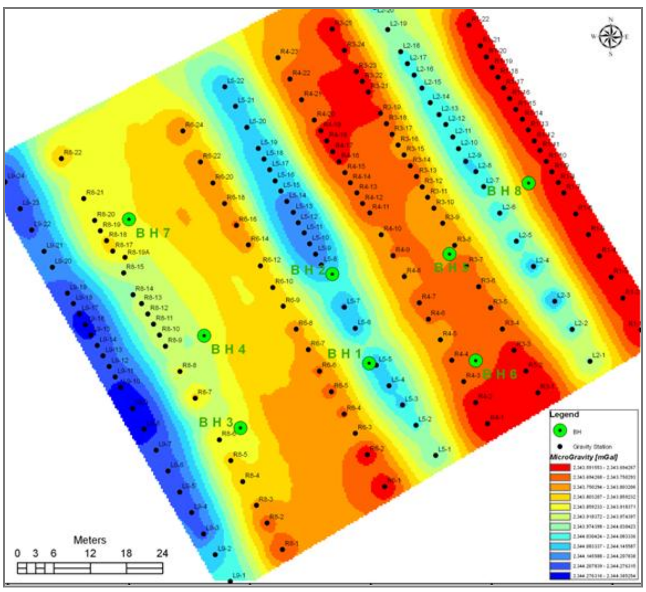

Figure 3: Microgravity image of the study area, gravity stations are shown in black dots

Line 1

The results for Line 1 are shown in Figure (4). The line consisted of 22 stations. The gravity meter was returned to Station 1 at the end of the survey and reading re-collected. Using the variation in readings, a drift correction was applied to the data. Tide and Bouguer corrections were also applied.

The results from Line 1 show increasing values to the east. This could be the result of denser bedrock, or shallower bedrock. An anomalous low value can be seen at a station 35-38 as indicated by the red oval in Figure 3. It represents a dip in approximately 0.05m Gal.

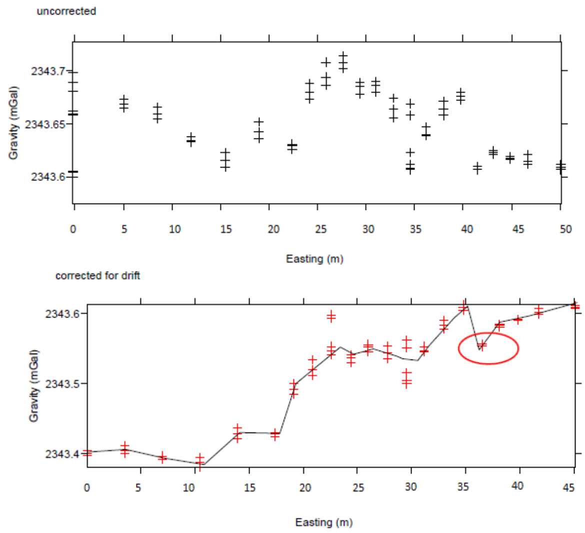

Figure 4: Microgravity cross section on line 1

Line 4

The results for Line 4 are presented in Figure (5). Line 4 consisted of 23 stations. The gravity meter was returned to Station 1 at the end of the survey and reading re-collected. Using the variation in readings, a drift correction was applied to the data. Tide and Bouguer corrections were also applied.

The results from Line 4 also show increasing values to the east. This could be the result of denser bedrock, or shallower bedrock. An anomalous low value can be seen at a station 40 as indicated by the red oval in Figure 4. It represents a dip in approximately 0.07m Gal.

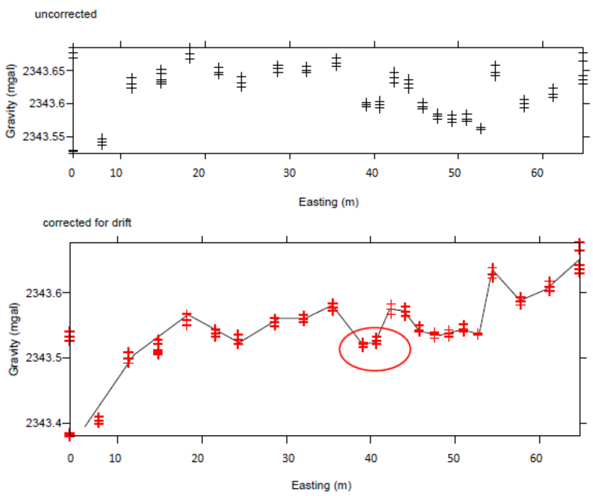

Figure 5: Microgravity cross section on line 4

Line 8

The results for Line 8 are presented in Figure (6). Line 8 included 22 stations. The gravity meter was not returned to Station 1 at the end of the survey. Therefore it was not possible to do a drift correction on the data. However, as the length scale of any anomalies of interest is much shorter than that of the drift, it is not anticipated that this will hamper the interpretation. Tide and Bouguer corrections were applied.

An anomalous low value can be seen at a station 51-53 as indicated by the red oval in Figure 5. The anomaly is approximately 0.1 mGel below background.

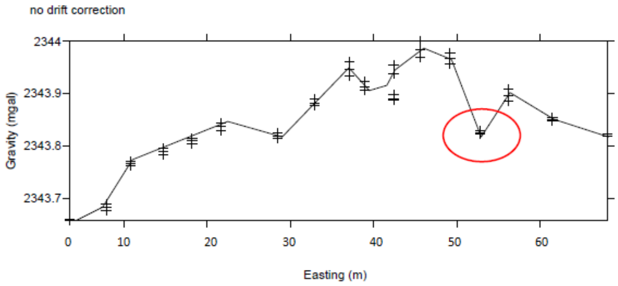

Figure 6: Microgravity cross section on line 8

5.2 ERT Data Processing and Interpretation

The processing and interpretation of the data was carried out using RES2d-3d software. The auto-CAD drawing software was used to plot the sections and 3D geo-model will be conducted to locate week zones/anomalous zones using integrated GIS and PARADIGM gOcad tools.

4 iterations were selected for the Least Squares inversion subroutine on each line during the process. After the second iterations the Root-Mean-Squared (RMS) error changes slightly and was distributed between 3 to 7% and was decreased gradually after the forth iteration

The data is presented in a form of sections displaying the distribution of apparent resistivity along the line. The horizontal axis will be the location of the survey points on the surface, while the vertical axis will represent the approximate depth with the color scale representing the apparent resistivity values plotted in colors. Figures (7, 8 and 9) shows one example of ERT survey sections

ERT Section on Line 1

As shown in figure (7) the apparent resistivity from existing ground surface to the depth of 8m are in-continuous in the horizontal direction along the line. The resistivity values vary from 5.0 to 40 Ω.m approximately. These layers are corresponding to sand, silty sand and silt which were witnessed by existing boreholes.

The lower apparent resistivity part between station 40 and 56 is mainly consisted by silt. This part was marked by red to pink colors in the sections. From 8 to 20m the apparent resistivity values distribute from 17.5 to 35.0 Ω.m. The apparent resistivity values increase gradually with the depth increasing.

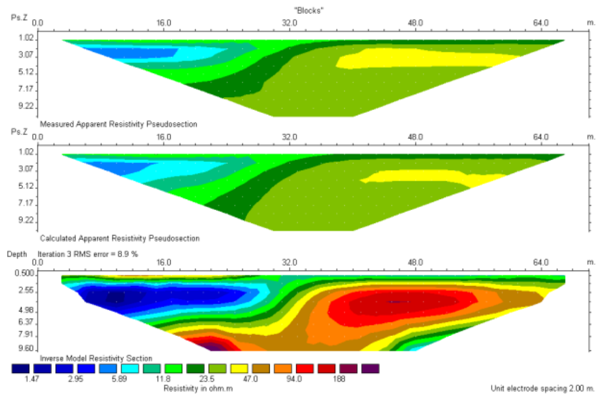

Figure 7: ERT Resistivity Section of Line 1

ERT Section on Line 4

As shown in figure (8) a high apparent resistivity zone is revealed between depth of 7 and 11m approximately and from station of 26 to 38 in the horizontal direction along the line. The apparent resistivity value of this zone is 45 to 50 Ω.m and marked by cyan color.

The apparent resistivity value is higher than surroundings, which means that the formations in this part have more spaces and filled by air. Considering the boreholes we conclude that this high resistivity anomaly is related to highly fractured and weathered siltstone.

From depth of 11 to 18m the apparent resistivity values decrease from 50 to 7.5 Ω.m. The resistivity is undulated and changing continuously along the horizontal direction of the line. From depth of 18 to 20m the apparent resistivity values increase from 10 to 17.5 Ω.m.

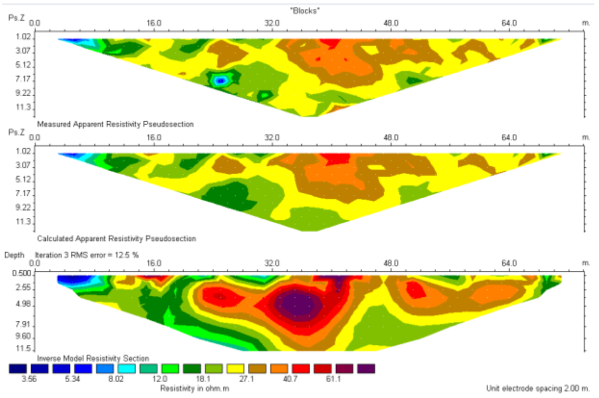

Figure 8: ERT Resistivity Section of Line 4

ERT Section on Line 8

As shown in figure (9) a high resistivity layer is revealed between the depth of 2 and 4m along the line. The apparent resistivity values of this layer are between 30 and 120 Ω.m. This layer is undulated and in-continuous along the line, which is probably caused by irregular, dry and hard formations in the shallow near the ground surface.

From depth of 4 to 8m in the section the apparent resistivity values vary from 1 to 7.5 m. This layer is marked by dark red and red colors. This layer is mainly consisting of silt and silt sand which were revealed by Canadian Geo boreholes. From 8 to 20m the apparent resistivity values increase from 7.5 to 150 Ω.m approximately.

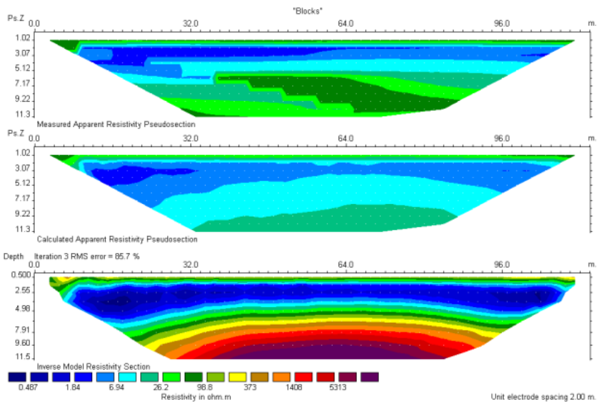

Figure 9: ERT Resistivity Section of Line 8

It is noted that the average apparent of resistivity values of formations between stations 0 and 55 in the horizontal direction and from depth of 12 to 20m are higher than the formations which are at the same depth and from station 55 to 118. This higher apparent resistivity zones are marked by dark blue.

According to our experience groundwater could be drawn towards the surface by capillary action and evaporates in the upper subsurface due to the high temperatures in port Sudan. Hence, the formations above ground water table contain vapor. The more fractured strata contain more vapors. It will show lower apparent resistivity values in the same strata.

Based on above explanation the (dark blue) higher average apparent resistivity formations contain less vapors. Considering the existing boreholes these dark blue formations are probably related to slightly weathered and fractures.

The similar apparent resistivity phenomena could be found on lines L2, L3, L5, L6 and L7 and can be interpreted as above. It worth mentioning that the siltstone near the sand layer is highly fractured and the sand and silt could creep and lose under the Exogenous Geological Process. This could cause the settlement of ground surface in the future.

5.3 Property Modeling

Stochastic methoda are applied for modeling the distribution of physical properties. Scaled up ERT data and trend data were used as input. For each property of all cells are given a value. The well and trend values distributed in the volume have been defined by the 3D grid. Stochastic physical property models are generated in gOcad based on the Sequential Gaussian Simulation method (sGsim).

Apparent resistivity models have been generated in depth; the intention was to use the model in the static and dynamic modeling. Figure (10) show 3D a model of apparent resistivity generated form ERT calibrated data and wells marker. As indicated by the legend, the black colour is the minimum apparent resistivity probably buried channel/cavities/anomalous. The method of Sequential Gaussian Simulation (sGsim) was used. The required correlation coefficients between ERT data and resistivity formation constructed from well data, ranging from -0.20 to -0.25.

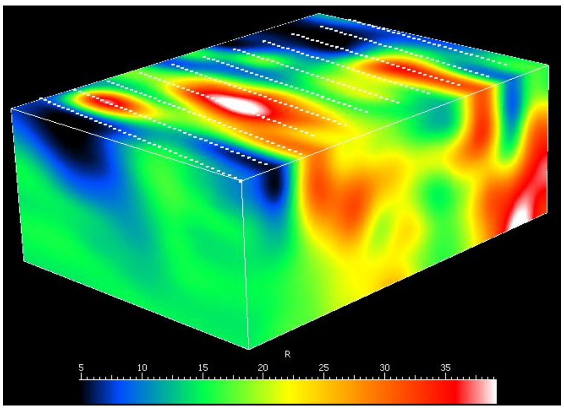

Figure 10: 3D model of resistivity simulated with Sequential Gaussian Simulation (sGsim). As indicated by the legend, the black color represent cavities/anomalous.

3D Resistivity sections in depth have also been constructed for line 1, 2, 3, 4, 5, 6, 7 and 8, and two 1ayers below ground surface as shown in figure (Fig. 11) below. The apparent resistivity estimated by simple kriging. The 3D sections are indicative of apparent resistivity with depth in the area. In each figure, resistivity range is from 5 to 40 Ohm.m.

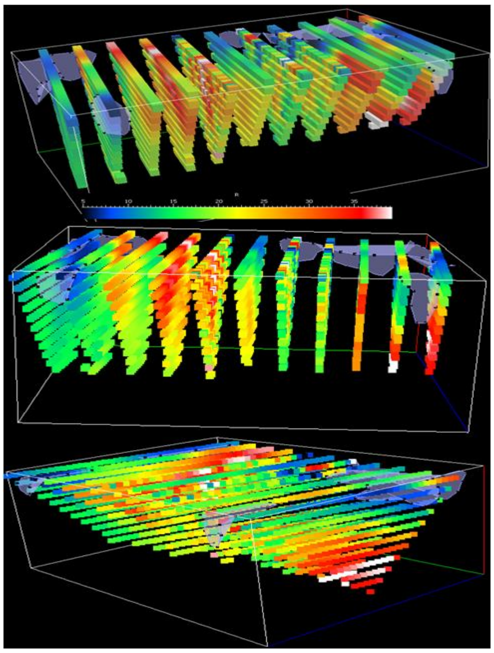

Figure 11: 3D Resistivity sections estimated by simple Kriging in depth 22 m below ground surface respectively, the black and to blue light is the target underground cavities/anomalous zones.

6. Conclusion

- The interpretation of three lines of gravity data from the proposed site is presented in this work. In each line a small anomalous low value was identified. These may represent week zones in the subsurface. However these anomalous values could also be the result of a local dip in bedrock surface, a variation in the density of bedrock, or a variation in the density of the overburden.
- No obvious cavities were detected under the geophysical lines using the ERT method.
- Considering the boreholes and ERT sections the formations from top of bed rock to 20m depth in the site are mainly slightly to moderately weathered. The siltstone between 8 and 12m approximately are highly weathered and fractured.
- It should be noted that the sand and silt could creep and loose under the Exogenous Geological Process (raining is the main reason) to cause the settlement of ground surface in the future.

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