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GEOTECHNICAL AND GEOPHYSICAL EVALUATION OF THE NEAR SURFACE FAULTS AND CRACKS IN RESIDENTIAL AREA UNDERLAIN BY SEMI-ARID SHALE

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ABSTRACT

This study was carried out following the development of abnormal faults and distresses that extend over more than two kilometers distance in an agricultural rural area to the North of Saudi Arabia. They appeared on the ground surface in the form of extended wide cracks and appeared across buildings, roads and green areas. Severe damages were inflicted to the existing structures and included cracks within the streets, the buildings and boundary walls. Geotechnical works carried out included advancing six boreholes to depths of 35 to 40 meters below grade. The subsurface soil profile was constructed and laboratory tests were carried out to characterize the shale and obtain relevant strength and swelling properties. The site was found to be overlain by a thin granular layer followed by elastic silt and/or silty shale extending 15 to 37m below top layers. The geophysical method used was the electrical resistivity using multi-electrode system of SYSCAL pro equipment. Several electrical resistivity lines were investigated across and along the crack zones. The outcome of the geophysical results was contrasted and compared to the geotechnical findings and all used to interpret the possible causes of these cracks. The electrical resistivity data were found to map the moisture profile in the area. The expansive soil is moisture sensitive and the data of electrical resistivity was found a good tool to spot areas of high and low moisture. The compiled data was found useful for evaluating the cause of damage and cracks in building construction within the distressed zone.

INTRODUCTION

Geotechnical studies are normally based on data obtained from specific points within the site. The information derived are normally representative of the general subsurface soil conditions. In certain sites where localized problems are reported it is of great importance to use an additional technique that that provide continuous mapping. The electrical resistivity was selected as a tool to investigate a site to the north west part of Saudi Arabia which suffered from unusual cracks and ground distress. Electrical resistivity is a widely used geophysical method in practice. It is found to be a quick and reliable approach to classify and measure physical properties of subsurface soil materials that are related to the ease at which electric current can pass. Rock and minerals are considered good conductors when the resistivity value is in the range of 10-8 to 1 Ωm. Non conductors can have a resistivity values in excess of 107 Ωm (Telford et al 1990) . The works of Syed Osman and Tuan Harith (2010) investigated the trends of resistivity with moisture content, frictional angle, bulk density and standard penetration tests. Increase in electrical resistivity with increase in frictional angle, unit weight and standard penetration tests was noted. In reality these three factors are inter-related and proportional to each other. This is why they produce a similar effect and influence on electrical resistivity data. The decrease in electrical resistivity is generally associated with the increase in moisture content. Works of Gil Lim Yoon and Jun Boum Park (2001) provides a good evidence for that. Kalinski and Kelly (1993) showed that electrical resistivity measurements can be correlated to the volumetric soil moisture. Due to overlapping ranges of electrical resistivity for clay, sand, loam and marl, it is strongly recommended to consider performing geotechnical and field exploration in order to confirm the findings. In this project extensive soil exploration included advancing of six boreholes to depths of 35 to 40m were performed. Laboratory studies included soil classification and engineering property tests.

SITE, MATERIALS AND EQUIPMENTS

The site covered by this study is located to the north west part of the Kingdom of Saudi Arabia. A comprehensive geotechnical investigation consisting of borehole drilling works and electrical resistivity tests was carried out to investigate the subsurface formation. The site was found to be overlain by a thin granular layer followed by elastic silt and/or silty shale extending 15 to 37m below top layers. Open test pits were also conducted to visualize and verify the soil conditions reported by using the electrical resistivity and soil boring. The fine material passing sieve number 200 was found to vary from 15% to 99% in 114 samples tested. The top soil(1.5 to 2.5m) is nearly non-plastic while the formation below this layer is (MH) highly elastic silt. Sandstone and claystone formations were encountered at a depth of 19.5m and 31m at two locations. The sandstone and claystone formation were found to continue beyond the maximum investigated level of 40m. Groundwater was encountered at variable depths due to the nature of shale. Some parts indicated water at 2m to 9m below ground level whereas at Borehole No.1 the ground water was recorded at 17.5.

Table 1. Total dissolved salts, sulfate and chloride content

Sample No.	B.H (1)	B.H (2)	B.H (3)	B.H (4)	B.H (5)	B.H (6)
Depth (m)	12.0	4.5	15.0	7.5	10.5	6.0
pH	7.1	7.3	7.3	6.9	7.1	6.9
T.D.S	1940	540	2390	2220	4940	2460
Total Sulphate ppm	400	870	530	960	1140	470
Total Chloride ppm	30	870	30	960	330	150

Drilling works were carried out using a Truck mounted drilling Rig (Mobile B 53) and test pits were performed using a hydraulic excavator. The standard penetration test was carried out at intervals of 1.5m in accordance with ASTM D1586.

The generalized soil profile for the whole site is presented in Figure 1,

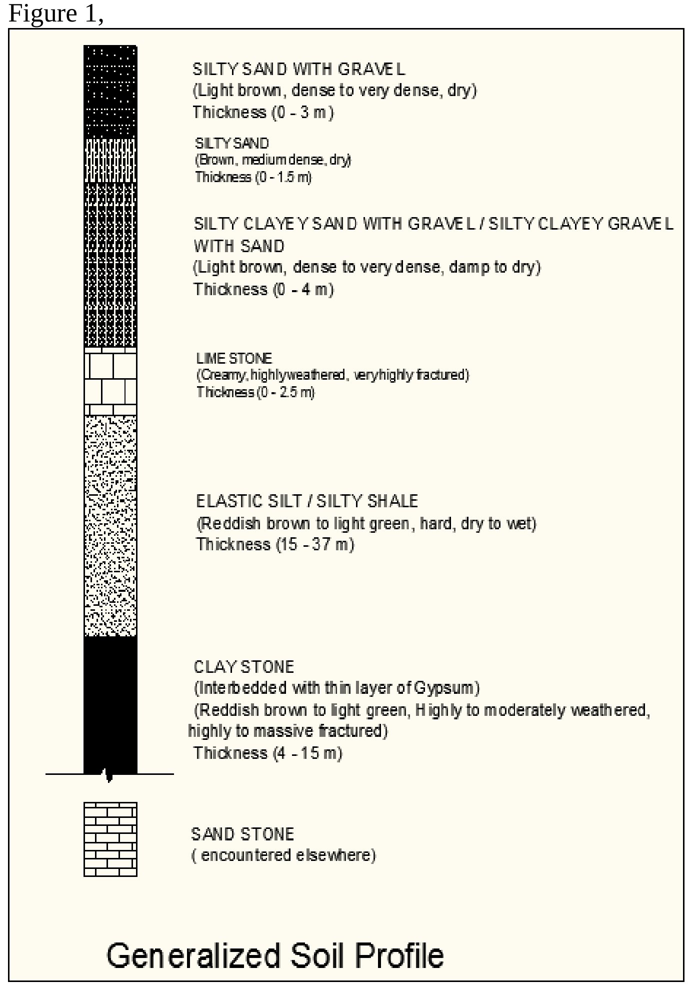

Fig.1 Generalized Soil Profile for the site, Saudi Arabia

The electrical resistivity equipment utilized in this study is Syscal R1. The system is supplied with 72 electrodes and capable of producing two dimensional sections. The manufacturer of the system stated that the output current is automatically adjusted (automatic ranging) in order to optimize the input voltage values and thus provide high quality measurement. Such systems can be useful in many applications, including salinity control, depth-to-rock determination and weathered bedrock mapping. It can also be used to determine shallow groundwater conditions (Aquifer depth and thickness). Electrodes spacing can be varied up to 10 m. The system is also capable of transferring data to the computer and can be processed using specially tailored software (Res2DInv). The system can produce contour plots of apparent and true resistivity distribution. The system is designed to work in harsh climatic conditions including temperature range from -20 to 70 ˚C.

Fig.2. Borehole and electrical resistivity lines conducted.

Fig.3 View of electrode distribution along one resistivity line.

TEST RESULTS AND DISCUSSION

This approach was intended for comprehensive investigation and to provide as many information as possible to help in evaluating the nature of distress. The geotechnical investigation revealed the presence of expansive shale with a rather high swelling pressure and swell potential. 140 kN/m^2 was reported while testing the undisturbed soil material for consolidation. The swell potential of 3.3% was reported. An SEM (scanning electron microscope) view magnified to 10000 times of one sample from the site indicated typical expansive soil form (Fig. 8).

When looking at a plot of electrical resistivity the following rules shall be kept in mind so that remarkable changes can be noted with confidence.

1- The higher the water content the lower the electrical resistivity.
2- The more the clay content the lesser the electrical resistivity.
3- The more the air voids the more the electrical resistivity.
4- The rocky formation indicates high electrical resistivity compared to clay.

The soil chemistry and salinity of stratified layers can have a significant role and influence the electrical resistivity but for a site of similar chemical components the evaluation can ignore this effect.
The chemistry of the subsurface formation as obtained for three samples selected from the vicinity of the electric resistivity lines proved to be in a small variation and the influence of salts can be neglected. The soil profile also indicated similar highly plastic silty material. Considering these assumptions the electrical resistivity data can viewed as moisture mapping in the area. However, this is found making sense when comparing the high resistivity zones to the ground water reports. The borehole 1 reported ground water at 17m depth and borehole 2 reported water at 2m depth while area near borehole 4 reported water level at 9m. The blue zones in the resistivity plots indicated lower resistivity. The outcome of this work is that the expansive substrata is subjected to variable water conditions ranging from dry state to fully hydrated. This was found affecting expansive soils and cause them to expand and contract. The uplift forces will push the soil mass to concave and fracture at specific locations.

For more confirmation of soil type and plasticity similarity a plot of plasticity index at variable soil depths was constructed. The plasticity average is 21. Top and near surface points and odd points can be ignore.

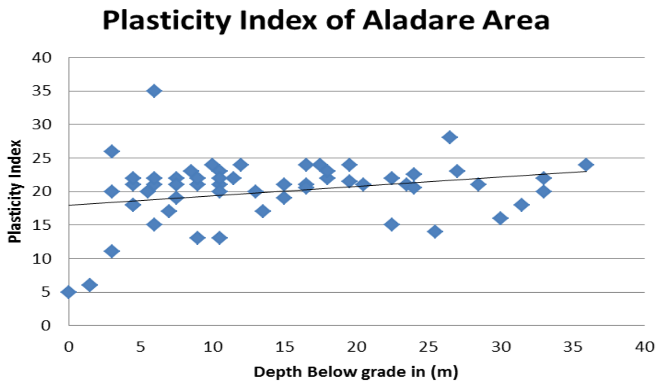

Fig 4. Plasticity index for variable depth at the site

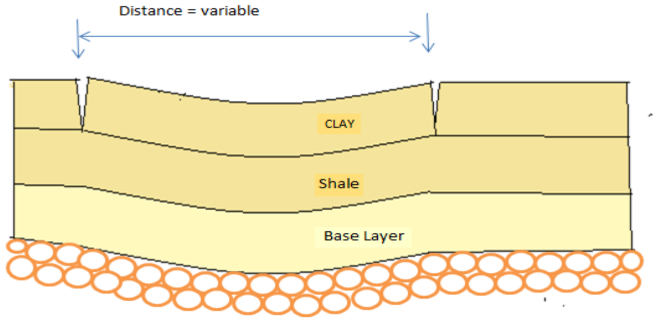

Fig.5 Mechanism of cracks formation in expansive shale

Electrical resistivity can also give the layer thickness and depth profile of underlying rock strata. The outcome of electrical resistivity was found to agree with the geotechnical investigation with regard to layering and layer thickness.

This investigation paved the way for the design engineer to choose the appropriate solutions for structures at this locality.

The ground cracks were found related to the type of soil which is highly sensitive to moisture.

Table 2. Chemical test results of the Site

Source	Depth (m)	pH	Chloride (cl⁻) %	Sulphate (SO_3) %	Pot. (k) %	Calc. (Ca) %	Alum (Al) %	Iron (Fe) %	Silicon (Si) %	Carbon (C) %
B.H (1)	27-28.5	8.94	0.02	0.01	0.05	21.0	1.40	1.37	2.34	9.90
B.H (2)	16.5	7.95	0.25	0.66	0.26	8.00	9.36	1.55	18.20	2.86
B.H (4)	31.5-33	9.09	0.07	0.12	0.07	17.00	10.70	1.60	10.90	5.50

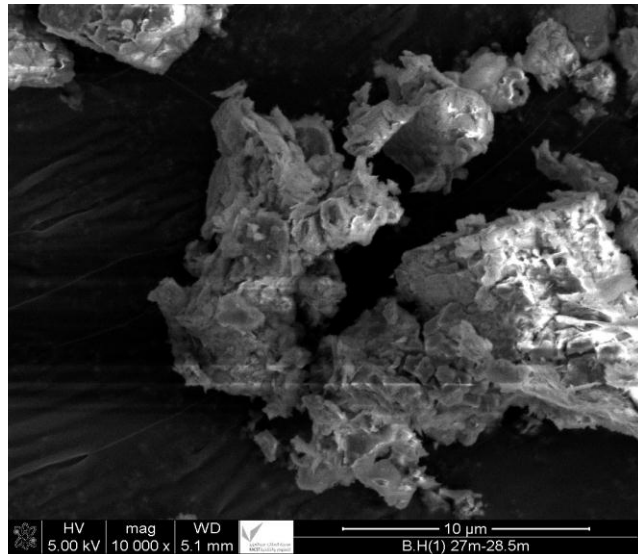

Fig 6. Typical expansive silty shale from site magnified to 10000 times.

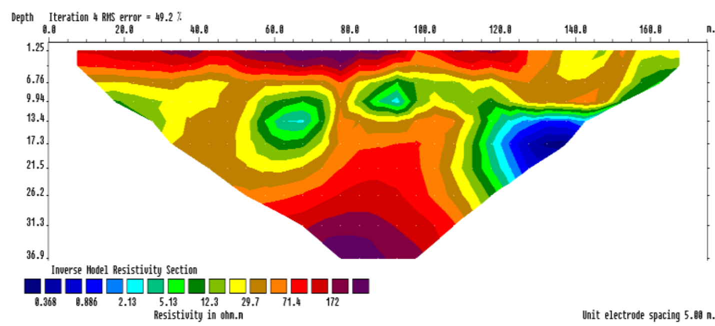

Fig. 7 Electrical resistivity Line crossing BH 1

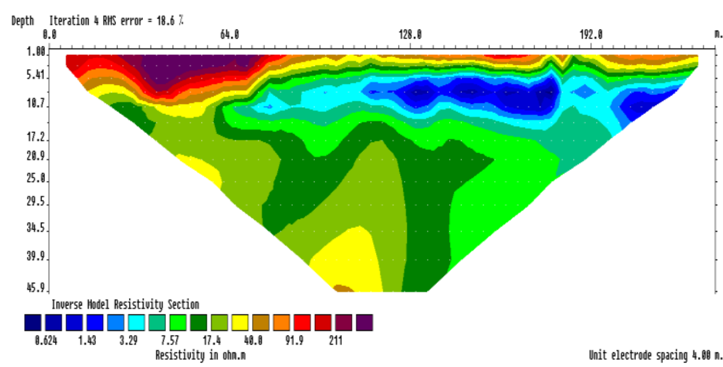

Fig. 8 Electrical resistivity Line crossing BH 2

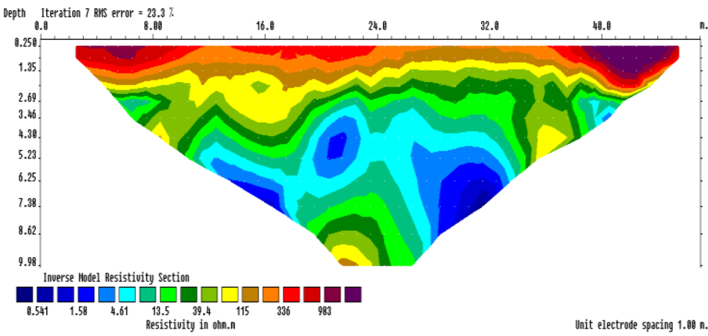

Fig. 9 Electrical resistivity Line near BH 4

CONCLUSIONS

The geotechnical investigation can be used together with geophysical methods to investigate sites of special nature.

Electrical resistivity survey can be a useful tool in assessing subsurface soil conditions. For each site it will be necessary to assess factors influencing the results. Assumptions can be made to help in evaluation of the data. This can be enabled by detailed geotechnical testing. In case a significant factor was found variable across the site then correction to the electrical resistivity values can be carried out. Electrical resistivity profiles can be a useful moisture mapping in expansive soil formation.

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