

# Study of cracks and fissures phenomenon in Central Saudi Arabia by applying geotechnical and geophysical techniques

Fouzan Al Fouzan · Muawia A. Dafalla

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**Abstract** This paper presents an approach to investigate the phenomenon of faults and cracks that appeared in the earth's crust surface in Al-Qassim region, Saudi Arabia. Geophysical and geotechnical methods were used together in order to evaluate these cracks and identify the reasons that led to the emergence of such phenomenon. This type of faults and cracks can normally occur due to a geological or physical event or due to the nature and properties of the subsurface material. It was intended to use two different techniques at a time, compare, and integrate the outcome of the results. The geotechnical works included advancing rotary boreholes to depths of 25 to 31 m with sampling and testing. The geophysical method used included performing 2D electrical resistivity lines. The results of geophysical and geotechnical tests showed good agreement. The use of 2D electrical resistivity was found useful to establish the layer thicknesses of shale and highly plastic clay. This cannot be determined without deep and expensive direct boring investigation or other sophisticated methods. The results showed that the ground cracks and faults were mainly caused due to the nature of the soil in the area, which is considered

as a high-risk soil type and classified within expansive soil groups. The subsurface formation contained excessive fines with high percentage of highly plastic clay materials. The volume changes due to humidity variations can result in either swelling or shrinking. These changes can have significant impact on engineering structures such as light buildings and roads. The possible mechanism of cracks formation is explained.

**Keywords** 2D electrical imaging · Soil · Fault · Ground crack

## Introduction

This paper presents an approach using combined geophysical and geotechnical techniques to study and evaluate the phenomenon of cracks and fissures, which was reported in recent years in Al-Qassim region. This approach demonstrated how both techniques could be utilized to gather useful information to determine the cause of this phenomenon. The study area is located in the modern sediments of the Quaternary Formation above the Sudair Formation, with an estimated age of early Triassic. The Sudair Formation consists of shale, silt, clay, sandstone, and clay–stone, reddish to green in color, and peppered with layers of siltstone and dolomite. The bottom of this shale is a limestone layer, which unfolds western region. In addition, the region contains active sand deposits brushes, and other deposits of gravel, which are not active.

Faults and cracks are located in an occupied area including residential buildings and a school. The area is relatively

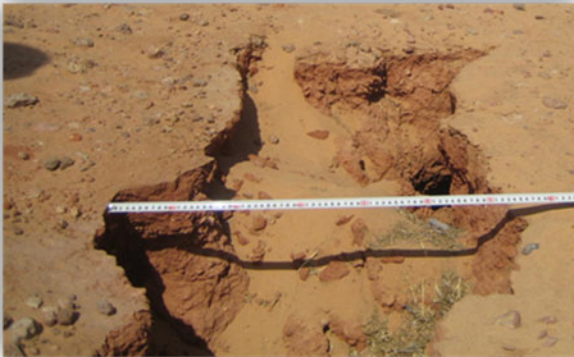
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F. Al Fouzan (✉)  
King Abdulaziz City for Science and Technology, KACST,  
Riyadh, Saudi Arabia  
e-mail: alfouzan@kacst.edu.sa

M. A. Dafalla  
BRCES, Civil Engineering, King Saud University, Riyadh, Saudi  
Arabia  
e-mail: mdafalla@ksu.edu.sa



**Fig. 1** An overall view of a crack extending more than 45 m



**Fig 2** Width of crack

**Fig. 3** An image showing the location of the 2D electrical resistivity profiles and borehole locations



low in topography compared to the surrounding region. Cracks appeared as parallel, sequential, and in a zigzag nature. The ground cracks point mostly towards an approximate east–west direction (Fig. 1). It was noticed that most of the faults and cracks appeared in the upper clay layer with thickness varying from area to another. These faults were found measuring up to 60 cm in width, narrowing, and fading in some places, while the main fault extended for more than 45 m and noted for nearly 1 m depth. The effects of these cracks appeared in the form of ground and wall distress. Cracks were taking vertical, horizontal, and tilted directions in many residential houses and the school building. The structures showing damage were located within the course and extent of these cracks (Fig. 2). In the school building, it was observed that these cracks were limited to the walls and were not present within the concrete structural units. It was also observed that 5 cm displacement in the school courtyard resulted in uneven ground movement.

Cracks and ground distress can take place as a result of two possible causes: first one is due to human interference (man-made actions) which imposes direct impact on the formation while the second one is due to natural causes.

Some man-made activities could cause these cracks. Removal of a large block of the earth crust or deep excavations is an example of human interference. Withdrawal of ground water and oil or any of soil components could cause enormous damage and initiate cracks.

Cracks occurring due to the impact of nature without human interference can be divided into two parts. The first part is directly linked to tectonic activities and the second part is linked to melting and decomposition of soil either chemically or physically when exposed to water.

Fig. 4 SYSCAL Pro system



The presence of ground cracks and fractures in the surface represents a serious concern to environmental and civil engineering researchers. The community living in the vicinity of these cracks was worried of the feasibility of using the land for any purpose. Detection and explanation of the phenomena of cracks and fractures remains a familiar task in many scientific and environmental fields (Zhou et al. 2002; Abu-Shariah 2009). Performing a full-scale geotechnical investigation, which includes excessive drilling and

laboratory testing, was found to cost a lot of money. These studies affect the area and provide a discontinuous subsurface image with few accurate data points (Maganti 2008). This technique and approach turned to be very expensive and need to be supported by other means so as to give a continuous elaborate and yet accurate information.

A much more effective and economic solution is to make use of the geophysical survey to reduce the overall amount of drilling and to improve the placement of the test borings

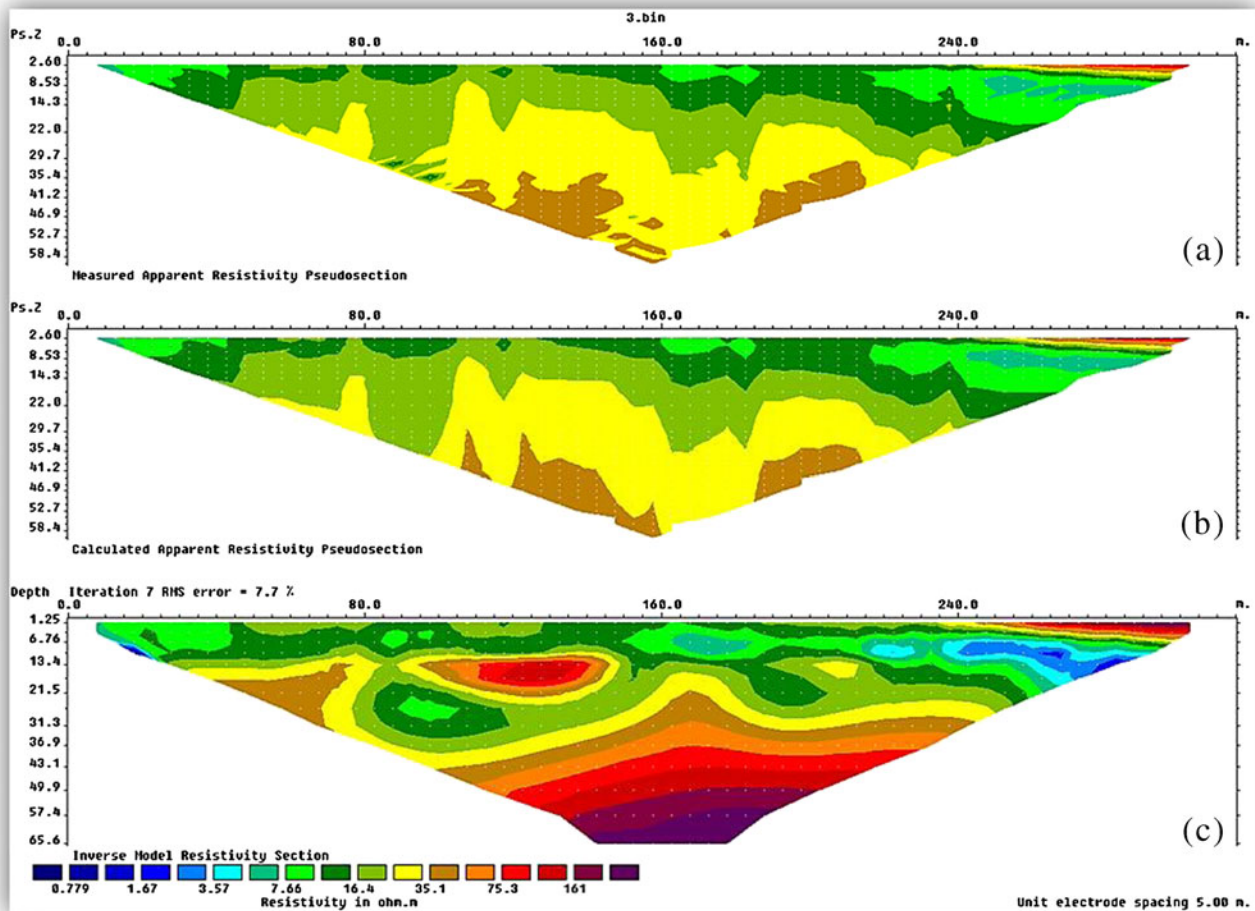
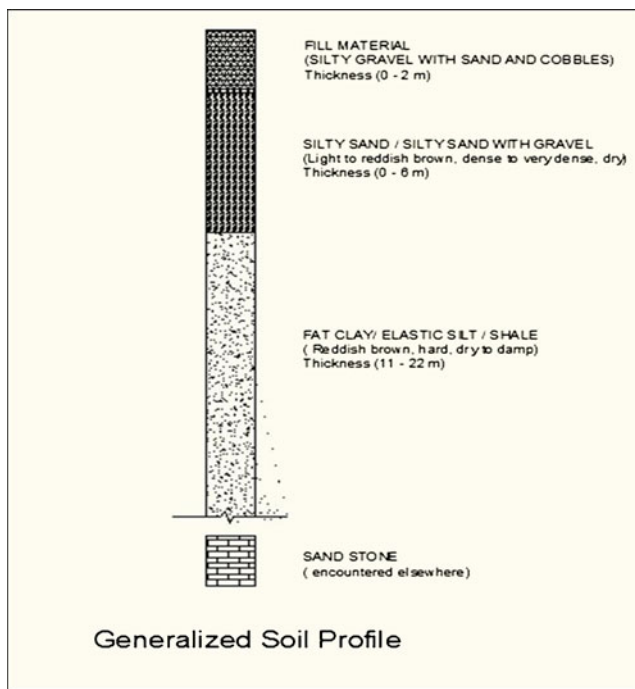


Fig. 5 2D electrical imaging inversion section for profile 3: a measured apparent resistivity of the Wenner–Schlumberger array. b Calculated apparent resistivity. c The inverse model resistivity section



**Fig. 6** A model shows a profile of the soil layers in the study area

**Table 1** Linear shrinkage tests for near surface material

Sample location	Test pit (1)	Test pit (2)	Test pit (3)	Test pit (4)
Initial mass (g)	403.9	285.6	297.6	467.7
Dry mass (g)	382.7	267.8	283.4	444
Original length (cm)	16.5	14	9.9	20
Length after drying (cm)	15.7	12.6	9.78	19.7
Linear shrinkage (%)	4.8	10	1.2	1.5

**Table 2** Chemical test results for near surface material

Carbon (C) %	Silicon (Si) %	Iron (Fe) %	Aluminum (Al) %	Calcium (Ca) %	Potassium (K) %	Sulfate (SO <sub>3</sub> ) %	Chloride (Cl <sup>-</sup> ) %	pH	Depth	Source
TP-1	2 m	7.72	0.04	0.45	0.10	5.00	3.05	0.67	32.2	1.96
TP-2	2 m	7.87	0.01	0.45	0.13	5.40	2.48	0.95	31.3	1.99
TP-4	2 m	9.06	0.01	0.01	0.07	3.00	3.78	0.52	35.0	0.69

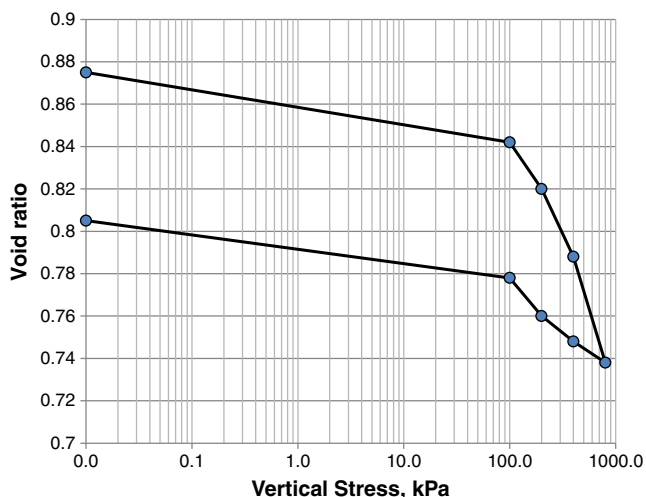
for more efficient target verification and mapping. Therefore, geophysical technique proved to be successful and economical solution in reducing the overall amount of drilling required for efficient target verification and mapping (Fig. 3) (Friedel et al. 2006; Cosenza et al. 2006).

## Methods of analysis

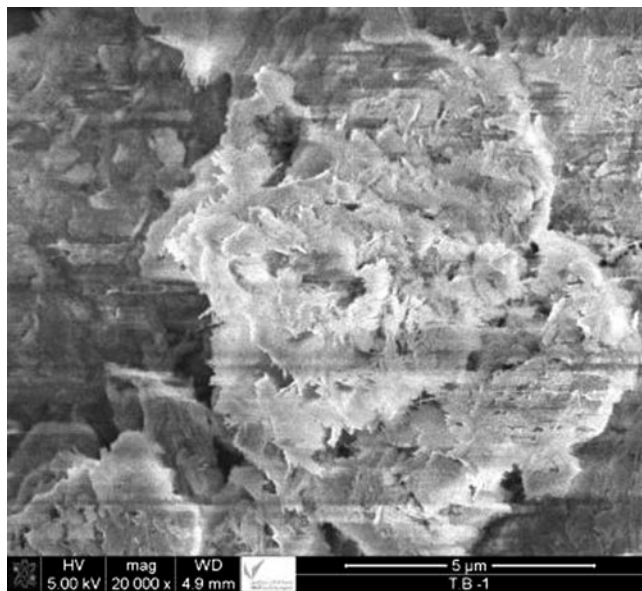
### 2D electrical imaging

The electrical resistivity imaging method was chosen in this study due to its ability to image the subsurface structure and thickness of layers. This technique has wide applications in environmental, engineering, and variable subsurface explorations (Perrone et al. 2004). It is based on the assumption that various type of bodies such as solid bedrock, sediments, cavities, or any other structures can be measurable in an electrical resistivity contrast relative to a host medium (Panek et al. 2010). The resistivity measurements and data reflect the variation between different subsurface materials. The two current electrodes inject current in the ground, the two potential electrodes measure the potential between the electrodes to calculate conductivity or resistivity, and every resistivity reading has a geological meaning. The configuration of the electrodes is called array. The electrical resistivity measurements have different configurations. The 2D electrical resistivity data have been acquired along different profiles in the most probable cracks affected areas within the site, using multi-electrode system of SYSCAL Pro (Fig. 4).

Wenner–Schlumberger array has been utilized and the unit electrode spacing was taken as 3 and 5 m along all the acquired profiles. The use of 2D electrical resistivity was found useful to establish the layer thicknesses of shale and highly plastic clay. This cannot be determined without deep and expensive direct boring investigation. The results showed that a thick layer of expansive soil, which is considered a high-risk soil type containing large percentage of highly plastic clay materials, underlies the site. Figure 5 presents the results for measured and calculated apparent resistivity as well as the inverse model resistivity section. The electrical resistivity values are expressed in colors where the vertical axis show the depth in

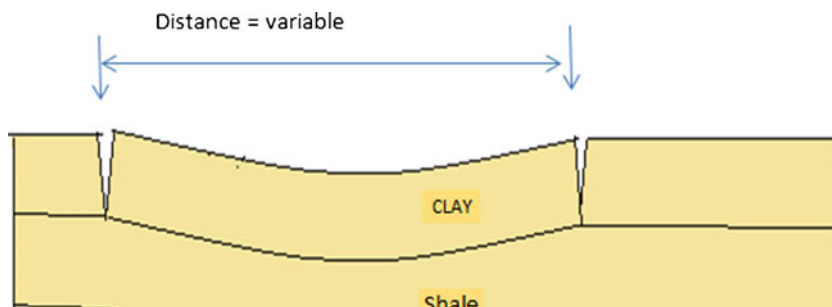


**Fig. 7** Typical compressibility characteristics of the expansive soil as obtained in an oedometer test



**Fig 8** View of the expansive soil in borehole 1 as seen in an SEM to 20,000 magnifications

**Fig. 9** Heave and crack formation within expansive soil



meter below grade and the horizontal axis shows the horizontal distance covered by electrodes. This profile has total of 80 electrodes employed in a north to south direction with electrode spacing of 5 m making up a 395-m total profile length.

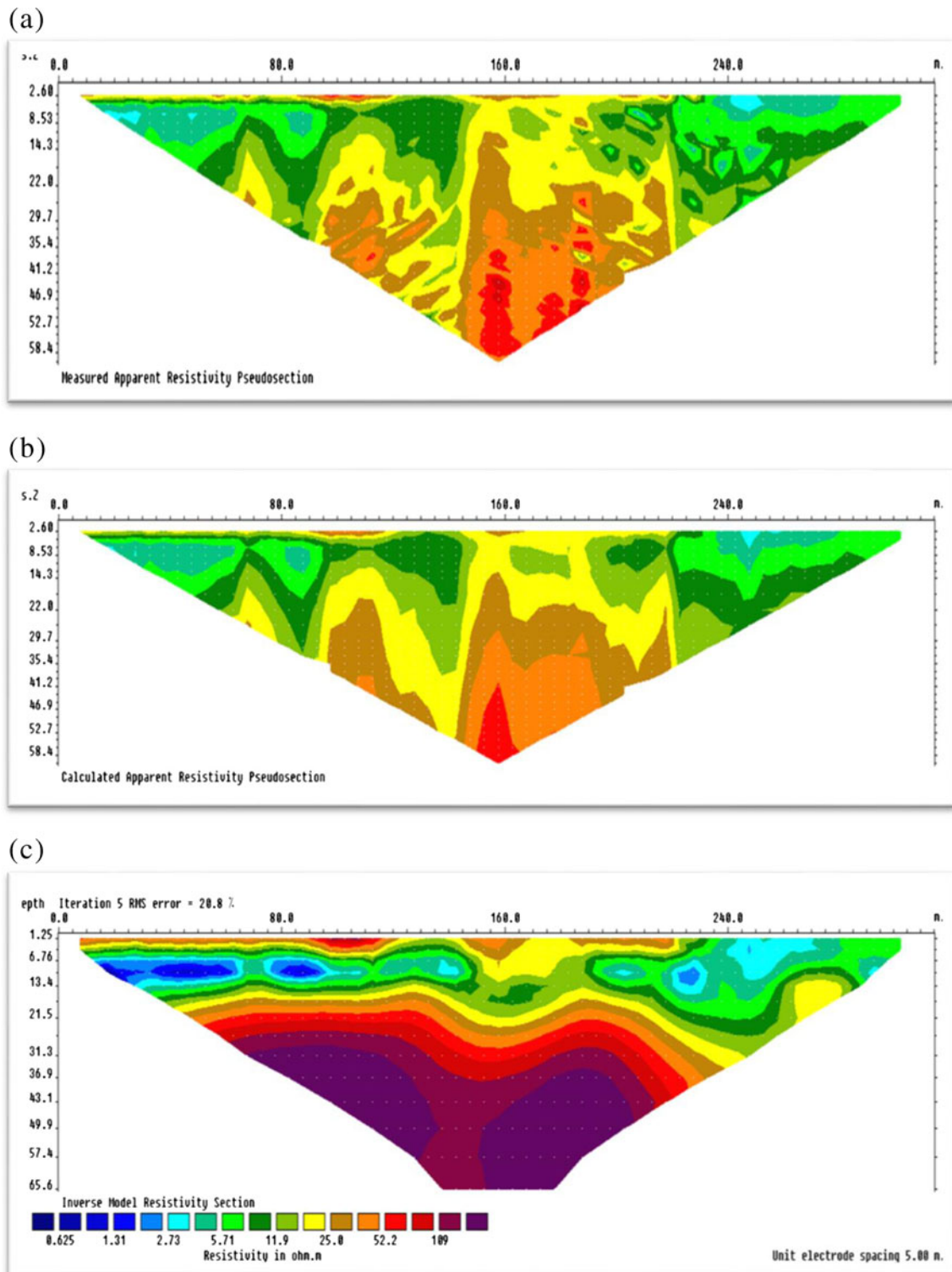
**Geotechnical methods**

The geotechnical field works carried out included four boreholes located at the most affected areas. A Mobile B53 drilling rig was used to advance four boreholes. The depth of these boreholes was kept in the range of 25 to 31 m below the natural ground level. In geotechnical practice, borehole depth is selected within the stress bulb influence zone. Normally, boreholes are extended to twice the width of footings below the foundation level. Size of foundation of up to 5 m width is possible (bridge or heavy structures). Foundation level varies from 1.5 to 5 m below grade. Twenty-five-meter depth is selected as a satisfactory depth. A single borehole was extended further 6 m to see if a layer change is within close reach.

Four open test pits were excavated close to the boreholes to 2 m depth using a hydraulic excavator. These were aimed at exploring the cracks down to a depth of 2 to 3 m below natural ground level and uncover the near surface formation. Figure 6 shows a profile of the soil layers in the study area.

**Test results**

The geotechnical investigation revealed that the site is covered with a layer of sand, silt mixed with mud, and a very small percentage of gravel. The thickness of the upper layer is varying of half a meter to 6 m followed by formations of mud of high plasticity intermixed with components of shale. The density and hardness of the clay soil increases with the depth and the soil remains highly plastic. The subsurface shale was classified within groups of CH and MH. Sandstone was encountered below the highly plastic clayey



**Fig 10** 2D electrical imaging inversion section for profile 1: **a** measured apparent resistivity of the Wenner–Schlumberger array. **b** Calculated apparent resistivity. **c** The inverse model resistivity section

shale and silty shale in a nearby site (30 km away) at a level of 30 and 35 m below ground level. The sandstone was weakly cemented and moderately weak to moderately strong. The depth to sandstone could not be reached by

the boring tests carried out (Fig. 6) but the results of 2D electrical resistivity showed the presences of this layer in a depth range between 30 and 40 m. During field works of the boring tests, the drilling shaft did not register any sudden

**Table 3** The depth and electrical resistivity values of the sandstone and clay layers at each profile

	Profile 1	Profile 2	Profile 3
Depth of the highly plastic clay layer (m)	2–12	1.5–10	2–17
Rang of the apparent Resistivity value ( $\Omega$ m)	5–15	1–10	10–35
Depth of Sandstone layer (m)	30–40	25–40	>37
Rang of the apparent Resistivity value ( $\Omega$ m)	>100	>200	>150

drop in the soil column either on the upper or lower soil. This indicated that there were no any suspected cavities within the soil subsurface formations.

The laboratory tests carried out on subsurface soils revealed high plasticity silty and clayey material. Table 1 shows the linear shrinkage tests for near surface soil material. Table 2 presents the chemical composition of the top soils encountered in test pits 1, 2, and 3.

The swelling pressure of the typical expansive soil for this site was measured as 100 kPa. The swelling pressure is the value of vertical stress required to prevent an upward movement on wetting a soil in an oedometer. ASTM D4546-08 Standard Test Methods for One-Dimensional Swell or Collapse of Cohesive Soils was adopted. The consolidation test was performed using ASTM D2435-04 Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading (Fig. 7). Figure 8 presents an SEM view of typical highly plastic soil encountered. A suggested folding system due to expansion is given in a diagram in Figure 9. When highly plastic expansive soil is subjected to wetting, it tends to heave and cause an upward rupture at specific points. The presence of expansive soils in Saudi Arabia was confirmed and documented by several researchers since more than three decades (El-Sayed 1981; Erol et al. 1981; Dhowian 1984).

The geophysical results showed subsurface strata along the survey profiles down to 60 m depth. The results showed a very good agreement with the geotechnical results; it showed that the first upper layer contains thick deposits of expansive soil. The highly plastic silt and clay having electrical resistivity in the range of 5–15  $\Omega$  is dominantly recorded for the depth between 2 and 12 m. These values continue to be reported with slight variation down to the bedrock level. The 2D electrical resistivity inversion sections showed presence of this soil type extending to variable depths. The apparent resistivity values increase with the depth to more than 100  $\Omega$ m. which indicates a sandstone layer below the clayey shale and silty shale at almost 35 m depth (Fig. 10). Table 3 summarizes the sandstone and highly plastic clay layers information based on depth and apparent resistivity values.

The test results shown here provided a range of engineering properties of expansive soil present in the site. The scanning electron microscope image showed a typical view of clay flakes commonly reported in expansive soils and clayey shale. The main focus of this study is to highlight that electrical resistivity can be used as a successful tool in establishing an efficient evaluation for subsurface soil and extent of different types of layers.

## Conclusion

This research study utilized both geotechnical and geophysical testing methods to evaluate a site subjected to fissures, cracks, and distress in Al-Qassim region in Saudi Arabia. The geotechnical study consisted of executing rotary boreholes to various depths with sampling and testing. The geophysical method carried out included performing a number of 2D electrical resistivity lines. The two approaches were found to be in agreement with regard to the type and extent of underlying soil material. The results of this study indicated the presence of highly plastic clay soil. The design of foundations for structures placed on this soil requires the knowledge of layer thickness and engineering properties of the soil. The expansive soil nature is believed to be the main cause of distress, fissures, and cracks.

The subsurface soil characterization by full-scale geotechnical investigation is not cost effective, therefore making recourse to geophysical survey reveals much more efficient, in terms of time and cost.

The geotechnical investigation using boreholes only was found not satisfactory to give all details. Electrical resistivity can give a continuous mapping and prediction of the bedrock depth. Integrating both geotechnical and geophysical approaches is found more reliable and can reduce costs of explorations.

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