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SHALE FAILURE AND CRACKING IN A SEMI-ARID AREA

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ABSTRACT: A semi-arid shale formation in the northern and central part of Saudi Arabia showed frequent near surface cracks and distress at several sites. This phenomenon was found to be of a serious risk to structures founded on or near cracks or failure zones. This study was carried out for an area where several centimeters wide ground cracks extending over more than one kilometer distance across a populated area in Saudi Arabia. The dominant subsurface formation in the area is reddish brown stiff to hard silty to clayey shale underlain by sandstone formation. The subsurface material was explored and clayey shale samples were extracted. The study included borehole drilling and test pit excavations. Soil classification and consistency tests were performed. A series of physical and chemical testing confirmed the expansive nature of the shale. The possible causes of cracks and the mechanisms of failure in semi-arid shale were covered and discussed in sufficient details. Engineering guides for buildings and construction in typical zones were presented.

Keywords: Shale; Expansive; Clay; Cracking; Semi-arid.

1. INTRODUCTION

The shale is encountered in many parts of Saudi Arabia covering major zones of the central, north and north-western parts of the country. Clayey shales and silty shales were reported in Al Ghatt, Tabuk, Tayma and Aljoaf. Works of Dhowian (1984) highlighted the expansive nature of clay shale in Tabuk. In recent years some ground cracks appeared in several locations causing concerns to municipal authorities. The phenomenon is only associated with shale zones and happened to affect existing structures. Works of Fouzan and Dafalla (2013) covered an area in Madraj near Buraida town in central Saudi Arabia. Earthquake and seismic activities were excluded of being the reason behind this phenomenon as the area does not have any history of tectonic activities and classified within zones of negligible acceleration. This work is part of the studies to investigate the physical and geotechnical nature of the shale where these cracks appeared. Deeda, a small village within the central province was chosen as the study area. Figure 1 presents the geographical location. The area geology belong to Sudair formation consisting of shale, silt, claystone and sandstone. These quaternary deposits are underlained by limestone formation of Triassic age. Cracks in the ground affected several structures and a major mosque had to be removed as a result of excessive distortion. Cracks extended over more than one kilometer causing damage to asphalt roads and other light structures.

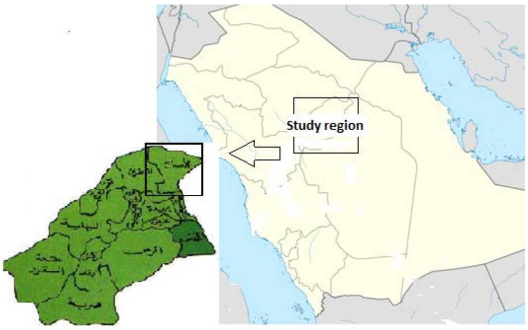

Fig. 1 Study region in Central Saudi Arabia

Fig. 2. Typical ground cracks reported in shale formation

2. GEOLOGY & GEOENVIRONMENT

The local geology of area consists of recent deposits of sand, silt and clay with occasional gravels of variable sizes. This is underlain by clayey shale material. Robelin et al (1994) presented a geological map for Deeda in which he described the underlying dolomitic sandstone as belonging to JILH formation.

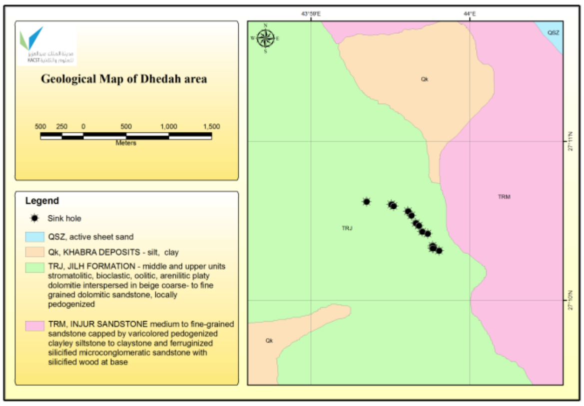

Fig 3. Geologic map of Deeda Area (Roblin et al 1994)

The expansive shale like other fat clays is very sensitive to moisture conditions. Drying and wetting are associated with shrinkage and expansion. The temperature range of Al Qassim region vary from -2 degrees in winter to 49 in summer. The annual rainfall varies from year to year with a minimum of 25mm and a maximum of 230mm. Figure 3 presents change of annual precipitation over 60 years.

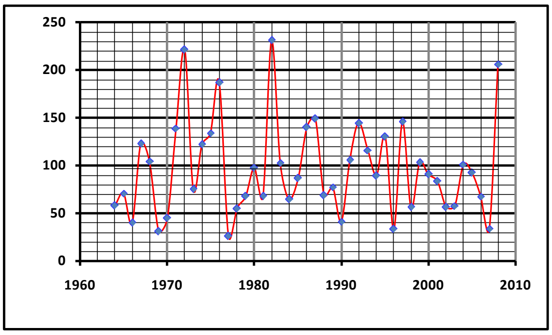

Fig. 4. Annual precipitation changes over 60 years.

3. EXPLORATION ACTIVITIES

The site was explored by advancing two boreholes within the zones of cracking down to 25 depths. Two test pits were excavated to 3m depth below ground level. Wash boring technique was employed and standard penetration tests were carried out at intervals of 1.5m. On encountering hard formation drilling was continued using double tube core barrel. Sound and intact rock cores were extracted and transported to the laboratory for further testing. As a part of this investigation seismic explorations were also conducted. Two seismic lines passing through the boreholes were tested. The geotechnical soil profile was constructed based on the outcome of boreholes, seismic data and laboratory tests.

Fig. 5. Drilling Plant on site.

Fig. 6 . Typical Shale section from the study area.

4. RESULTS AND DISCUSSION

The boreholes revealed that the site is overlain by a top soil consisting of brown to reddish brown clayey sand followed by hard sandy clay. The plasticity of clay is increasing with depth. The soil below the level of 3 to 7.5 m is classified within the CH group and this was found extending to a depth of 22.5 m. No open cavities were reported. The drilling fluid used was water. No water loss reported during drilling activities. The sandstone underlying shale formation is weakly cemented on top. The sandstone cementation is improved with depth. Recovery of soils and rock varied from zero to 100% and RQD (rock quality designation factor) varied from zero to 95%. Ground water was encountered at a depth of 24.5 m below ground level. This level is fluctuating during different season times of the year. Engineering property tests indicated SC (clayey sand soil followed by CL (clay) and CH. The fine material passing sieve number 200 varied from 25% to 94%. The liquid limit varied from 50 to 95 and the plasticity index from 30 to 48.

The siemic profile for borehole (1) indicated two main layers of sediments followed by sandstone. The top layer indicated an average depth of 3m while the second layer extended beyond 18 meters. The seismic profile for borehole 2 yielded the same but indicating 5m thickness for top soil and more than 20 m for shale or claystone.

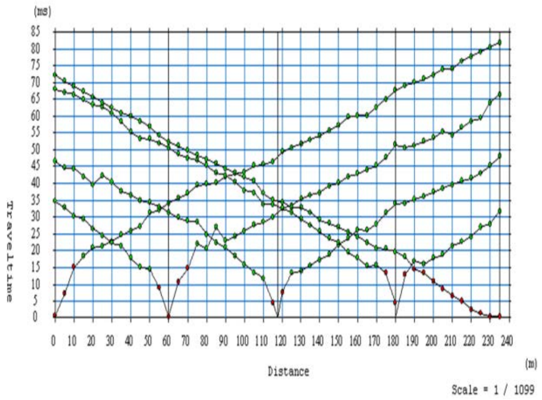

Fig. 7 Travel time and distance profile for line across BH1.

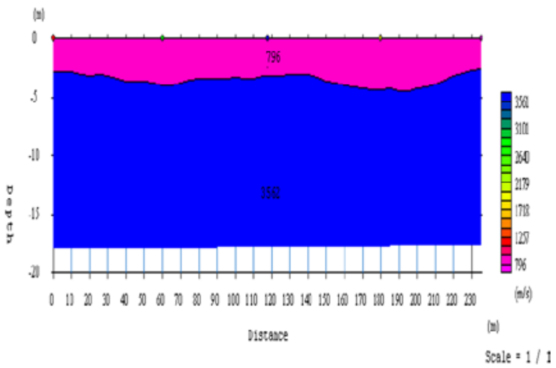

Fig 8. Geological section derived from seismic line at BH 1.

The engineering properties indicated that the subsurface material belongs to expansive clay group. The cracks can form as a result of drying and shrinkage. The cracks did not show a relative vertical movement that reflects deep failure or any signs of tectonic damage. Swelling pressure tests using odometers indicated swelling pressure of the order of 700 to 800 kPa. This figure is obtained in the laboratory for a confined small sample. The actual swelling pressure in field is far less and can be taken as one third of this value (Al-Shamrani 2003). The swell pressure for non-confined field condition of 250 kPa can be adopted. The overburden pressure for 2.5m is estimated at 50 kPa.

The chemical tests carried out for a sample taken from TP 1 indicated elements as listed in Table 1.

Table 1. Elements concentration in Deeda clay

Elements	Percentage %
Al	5.2
Ca	14.4
Fe	4
Mg	0.6
Si	33.0
Na	14.4
K	6.5

Quartz and calcium are dominant. Alminium, Calcium and Magnisium are basic components of smectite clay minerals that are associated with expansive clays.

Structures founded on typical soils shall be designed following all instructions listed in Chapter 9 of the Saudi Building Code SBC 303. However, for certain structure it might be feasible to consider pile foundations and transfer the superstructure stresses down to the sandstone formation. Light structures shall have their foundations placed at a minimum depth of 2.5m below ground level and the same time contact pressures from dead loads shall be in the order of 200kN/m^2. It is also recommended to avoid placing the foundations right on the ground crack lines. A 50m distance away from the cracks will be sufficient to avoid distress and unexpected settlement. Excavations shall extend beyond the bottom level of cracks and careful inspection must be carried out prior to placing footings within the cracks zone.

5. CONCLUSION

The shale can be subjected to serious shrinkage on drying and can introduce ground cracks. Volume changes in shale can be very serious for light structures. All foundations placed on typical material shall consider all precautions for expansive soils as set in international standards. Special reference is made to the Saudi Building Code Chapter 9. Foundations placed on expansive soils shall be based on sizing the footing dimensions in such arrangements that contact pressure due to dead loads between concrete and soil is in excess of the swelling pressure. A 200 kN/m^2 is suggested as a design value for this particular area.

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