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Expansive Soil Properties in a Semi-Arid Region

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Abstract: The expansive soils in semi-arid regions are of great concern to design and geotechnical engineers. Range and variations of geotechnical properties of soils are very useful for appropriate design. Saudi Arabia; a semi arid region attracted the attention of researchers and practicing engineers over the last three decades following the rapid urbanizations in different parts of the country. Advanced testing equipments were made available for this study. The research group conducted joint visits with high officials from different municipality authorities to survey the problem and study the extent of damage to various structures. The areas visited included Al Ghatt, Al Zulfi, Al Hofuf, Um Al Sahik, Al Qatif, Tabuk, Tayma and Al Qaleeba. Single and two storey buildings, boundary walls, pavements and asphalt roads suffered significant damage in many parts of the visited locations. This paper presents the outcome of survey and a general review of previous works carried out for swelling clays in Saudi Arabia. Engineering properties for typical soil formation are presented.

Keywords: Clay, cracks, damage, expansive soil, light structures, Saudi Arabia

INTRODUCTION

This study presents the works of Bugshan Research Chair in Expansive Soils in King Saud University. Bugshan Research Chair in Expansive Soil (BRCES) was established to help with problems associated with expansive soils throughout the Kingdom of Saudi Arabia. Advanced instruments based on the most recent technology in the subject of unsaturated soils were made available. The work presented in this study is part of the research dedicated to the behaviour of Saudi Arabian expansive soils.

Saudi Arabia is one of the countries severely affected by problems associated with expansive soils. It is located within an arid to semi-arid zone where temperature in hot summer desiccate the subsurface soils and causes dry to semi dry near surface formation. Water is introduced to the subsurface soil through different forms. These include waste water disposal, storm water, and rising ground water table. Rain water is common in the central, north and north-west regions of the country during the winter. Damage due to expansive soils in Saudi Arabia is estimated to hundreds of millions US dollars annually. Tabuk region is the most suffering part of the country where the problem is a nightmare for the administrative, municipality officials and legal authorities.

Saudi Arabia is a large country located within an arid and semi-arid zone, spanning over North latitudes from 20° to 30° and East longitudes from 34° to 50°. The subsurface soil formation is dominantly desert sand intermixed with alluvial deposits of silt, clay and gravel mostly eroded from parent rock formation. Extensive clay and clay rich soil were reported along the valleys and depressions. Clay shale is encountered exposed or at a shallow level for most of the North and North-West parts of the Kingdom. Four different forms of swelling material were encountered throughout the country; the first form is shale material, the shale is a fine grained weak rock composed of sedimentary deposits mainly clay or silt, oriented and laminated, flaky in nature, often referred to as silty shale or clayey shale. The mineralogy of the shale includes basic clay and non-clay minerals. This type is abundant in Tabuk, Al Joaf, Al Ghatt and Tayma regions. The quality of shale varies from place to place. Very hard in Tayma and weak to highly fractured at Al Ghatt District. The second form is calcareous clay material; the calcareous clay material is calcium carbonate rich clay, sedimentary deposits mainly encountered at the east coast and eastern parts of Saudi Arabia. This clay is found as thin to thick layers with interbeds of sand or calcareous deposits. The mineralogy of the clay includes smectite group minerals, calcite, quartz, and other non-clay minerals. This type is abundant in the area of Al Hofuf and Al Qatif regions. The third form is the greenish silty clay; the green silty clay material is a sedimentary deposit overlying the ingenious rock to the west and North West of the Kingdom. Thickness of this formation may go beyond 20 m. This is encountered at Al Medina Al

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Munawara and its surroundings. The main minerals reported for this clay include quartz, feldspar, smectite, calcite, kaolinite and chlorite. The fourth form is the reddish silty clay; the red silty clay material is a combination of windblown and alluvial deposits. This particular type of clay is reported in the southern region. This is mainly encountered at Sharoura and Najran. Minerals of quartz and feldspar as well as basic clay minerals make up the reddish silty clay of Saudi Arabia. This type is not limited to the southern part and can be noted in scattered spots within the kingdom.

The objective of this work is to provide a broad coverage of expansive soils in the country and highlight essential geotechnical and engineering properties needed for design and construction

This study is aimed to furnish the geotechnical designers with guide figures for preliminary design and increase the awareness of potential problems related to expansive soils in different parts of Saudi Arabia.

EARLIER STUDIES IN SAUDI ARABIA

The first studies on expansive soils were carried out by the Ministry of Housing and Public Works laboratories when investigating a claim from Al Ghatt house owners who noticed unusual cracks appearing on newly constructed villas. The buildings subjected to distress were funded by the Saudi Real Estate Development Fund. Shortly after this, publications on expansive soils in Saudi Arabia started to appear; Erol and Dowian (1982) were among the first to work on expansive soil in the kingdom of Saudi Arabia. These works were first published in a symposium held by King Saud University in 1981. This event hosted many publications about expansive soils in different parts of the kingdom. Erol *et al.* (1981) published some works on the expansive soils of Al Medina Al Monawara. El-Sayed (1981) introduced the swelling and collapsing behavior of Al-Mobaraz town in Al-Hofuf region.

Dowian (1984) brought the subject of expansive clay in Saudi Arabia to the fifth international conference in Adelade, Australia. Ruwaih (1987) presented a general study on expansive soil in Saudi Arabia in the sixth international conference in Delhi, India. The most comprehensive and wide spread study is the one conducted by Dowian (1990). Research on the expansive soil received wide attention in King Saud University, King Fahad University for Petrolium and minerals in Dhahran and also in King Abdulaziz University in Jeddah. The geotechnical practicing firms in Riyadh were also involved and many studies were conducted by Dames and Moore, Al Rajehi Hydrosoil, Rasheed Geotechnical and Material Engineering and others. The works of Abduljauwad (1994), Abduljauwad *et al*. (1998), Taha (1992), Al-Muhaidib (1998, 2010), Al-Muhaidib and Abdulla, (2003, 2008), Al-Muhaidib *et al*. (2000), Shamrani (2007), Al-Shamrani and Al-Muhaidib (1999), Al-Shamrani and Dowian (2003), Al-Shamrani *et al*. (2010), Al-Sharidah (2008), Azam (1997), Azam *et al*. (2000), Erol and Dowian (1990), Al-Sabtan and Abdullah (2005), Aiban (2006) Dafalla (2004), Dafalla and Al-Shamrani (2008, 2010) and Dafalla *et al*. (2009, 2010) constitute a considerable addition to the knowledge of expansive soil in Saudi Arabia.

VISITS CONDUCTED AND RESEARCH STUDIES

Al Ghatt and Al Zulfi: The Bugshan research team consisting of geotechnical experts and researchers arranged a visit to Al Ghatt district in February 2008. The president of the Municipality of Al Ghatt and local engineers briefed the team on the history of problems associated with expansive soil and pointed out the most trouble areas and the general practice adopted by contractors and engineers. The subsurface formation at Al Ghat is overlain by brown silty sand material with gravel and gypsiferous material followed by olive green clayey shale and silty shale. The mineralogy studies indicated limited amount of smectite group minerals but rich of kaolinite and Illite. Dowian (1990) claimed that montmorillonite was not reported. Al Muhaidib (1998) also confirmed the absence of montmorillonite in Al Ghatt shale. This finding is questionable since it is only based on X-Ray diffraction. It is quite common that the smectite peaks are missed out due to interferences or low peak intensities. Explanation of expansion in the absence of smectite minerals can be attributed to release of loads of over-consolidated clays or other minerals that may indicate some swelling on wetting. The high suction alone cannot be considered sufficient to cause expansion. Puppala (2008) claimed that expansive soils treated with cement and lime are of high suction but shows no swelling. Future studies were planned to utilize quantitative x-ray analysis and chemical composition to verify this subject.

Among the most affected buildings in Al Ghatt is a shopping centre which was abandoned immediately after completion. Serious cracks appeared in many parts of the structure and repeated maintenance proved unsuccessful. The main access road to Al Ghatt suffered from frequent damage and had to be maintained on a regular basis. Many residential buildings were deserted due to cracking. Misalignment and total failure of boundary walls was found common in old Al Ghatt plots. In this paper we can present broad ranges for soil properties as obtained by tests carried out in BRCES information by other researchers and practicing geotechnical firms.

Recent construction in Al Ghatt involved the use of rigid foundation system (Al-Muhandis and Kurdi, 2000) and deep soil replacement for a grand mosque in the old town (Municipality Reports). These structures were found intact and free from distress. However, the approach used in the two mentioned cases is rather expensive and found fit for the governmental authorities but hardly tolerable to local house owners.

Al Zulfi: Al Zulfi is close to Al Ghatt and the shale formation was reported in the central area of the town. A history of damage to Al Zulfi Emirate building and Al Zulfi old hospital was a subject of legal dispute between the contractors and the client. Very limited studies were carried out by the Ministry of Housing and public works as quoted by Ramadan (1994). The impact of expansive soil in Al Zulfi is much less than Al Ghatt and received minimum attention. The visit by Bugshan (2008) chair team to the areas of concern confirmed the presence of expansive soils. Most affected areas include the town center and Alaziziyah district (Ad Doaish). The properties as observed from by Al-Khatib (2008), a final year student in civil engineering were presented in a research title: Swelling Characteristics of Al-Zulfi Soils. The data for Al Zulfi is very limited and ranges as given for Al Ghatt could be used.

Al-Hofuf: The areas reported expansive soil problem in the eastern province included Al Mubaraz and Al-Hofuf (Lat 25˚22 N Long. 49˚50'). The calcareous clay present in the province is influenced by the marine deposits. The Hofuf formation covers extended area around the Hasa oasis. It consists of calcareous sand, marl and sandy clay. Other formations in the area include Bahr Formation consists of carbonate rocks and quartz sand. This also applies to Dammam formation which is mainly carbonate rocks with some marl clays at its lower part. An extensive MSc. Study carried out by Redwan (1991) in King Fahad University for Petrolium and Minerals covered some parts of Al Ihsa mainly AL Mubaraz (Al Khars, Al Hamidia and Al Mansouriya) and Hofuf city. (Al Naathel, Al Salihiah and Mahasin). The results reported in this study gave unusual high values for the swelling pressure. This may be due to the testing set up or approach used. A 2400 kPa swelling pressure is unlikely when considering field measurements. Such high values can be misquoted when trying to bring back the sample to its initial void ratio in an expansion-compression oedometer cell.

Bugshan Research team visited Al Ihsa region (Hofuf) and carried out some test pits at different areas. These are; Al Yahia District, Al Nuzha, Bo Sahbal and Water tank farms areas. The history of problematic sites included the Technical college Building at Al Mubaraz, Al Razi School at Al Yahia District and various other buildings: (Misfir, 2008) (BRCES) a final year student in King Saud University carried out a research on Characterization of AL-Hafuf Clay.

Al Qatif: Bugshan (2008) research team visited Al Qatif and held several meetings with Qatif Municipality Authorities and Safwa Municipality regarding the occurrence of expansive soil in the area. The officials pointed out that Al Qatif housing project and Al Qatif hospital and Um Al Sahik district are the most affected areas. The green clay of this area was known to the local since long time and they used it as a traditional detergent and as a barrier for water canals and also administered orally for some health conditions. Its nature as a destructive subsurface formation was revealed recently when studies carried out by the staff of King Fahad University for Petrolium and minerals. Redwan (1991), Abduljuwad (1994), Aiban (2006), Azam (1997) and Azam *et al*. (2000) are among those who explored the engineering properties and mineralogy of this area.

Um Al Sahik: BRCES team headed to Um Al Sahik and surveyed the damage and cracks in the suburb of Safwa. The Safwa municipality engineers explained that cracks appeared within one year of construction. Two types of highly swelling clay was noted; greenish clay and brown highly plastic clay. This clay occurs as thinly bedded layers close to the ground surface. Some residents tried deep foundations and basements. This was found to work better than normal isolated pads used to support two storey structures.

The properties of Um Al Sahik are not different from Al Qatif clay but the green clay is more expansive than the brown clay.

Tabuk: The Bugshan research team visited Tabuk city located in the North West of the kingdom. Tabuk suffered more than other towns or cities in the country. Damage seen in Al Maseef, Al Nahdah and Al Rowda districts is estimated in hundreds of millions US dollars. Luxury villas, modern built schools and mosques were subjected to upheaval forces which resulted in serious cracks, tilting and twisting. The problem was known since late 70s of the 20^{th} century. Works of Dowian (1984) and Dowian *et al*. (1990) highlighted the behavior of silty shale and clayey shale of the area. Al-Sabtan and Abdullah (2005) conducted a comprehensive study covering greater parts of the city. The swelling parameters were measured utilizing the standard oedometer test and modeled by multiple linear regressions. In a move to study foundation alternatives Dafalla *et al.* (2010) investigated the rigid foundation system. The partial soil replacement method was also investigated in Bugshan Research Chair and a final year student (Al-Omar, 2008) presented a research titled: Soil Replacement Technique for foundations on Expansive Shale.

Tayma: The Municipality of Tayma met with the Bugshan (2008) research team and explained how the town suffered from the expansive soil. The area allocated for governmental administrative buildings and Al Rowda district are the most affected parts of the town. The Municipality building, the police building and the government insurance buildings were example of the severe damage. Light structures were subjected to cracks of various sizes from minor hair cracks to wide alarming cracks. One of the main causes of these troubles is the absence of a proper sewage system in the town. Waste water was discharged into soak away pits and directed towards foundations. It was noticed that ground water levels are fluctuating from close to surface in winter time and far below 15 m in summer times. Dowian (1990) investigated some shale from Tayma. BRCES team performed some test pits and sampling from key locations in the town. Al-Sharari (2008) a final year student studied the engineering properties and characteristics for shale material obtained from a new hospital and a road in Al Rowda district.

Al Qaleeba: Al Qaleeba is located mid way between Tayma and Tabuk hosting an important policing centre along Tabuk Medina road. The ministry of Education reported high swelling properties for a school complex in 1990 and decided to go for a very expensive solution which involved soil replacement for nearly 4 m. The residents' houses in the area are mostly single story buildings. Cracks in boundary walls and houses were clearly visible. The asphalts roads show different types of crack and signs of continuous asphalt maintenance which created serious driving problems.

Al-Enizy (2008), (BRCES) a final year student conducted a research titled: Characterization of AL-Quleeba Expansive Shale. The geotechnical properties are not different from Tayma shale.

Al Medina clay: BRCES team was aware of Al Madinah expansive clay; earlier studies were carried out in King Saud University in 1981. According to a publication by Al Muhaidib (1998) the types of clay in Al Medina Almunawara can be classified in two types; a green clay and white clay. The ranges given here are based on limited data published and local geotechnical practice.

Hail clay: Local practicing companies encountered some villages within Hail area with expansive clay. Most of this clay is a transported sedimentary deposits resulting from erosion of the Shale encountered in the area. This material is mostly of low plasticity. A typical material tested by Dafalla (2004) is used to show the properties for Hail clay.

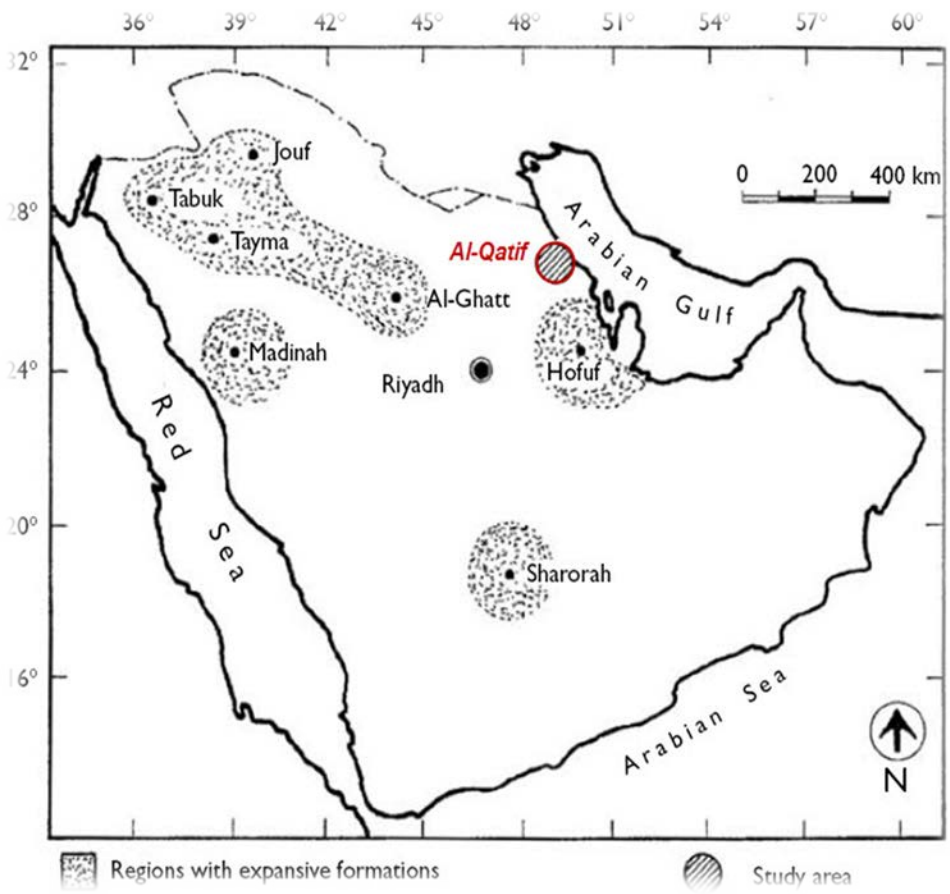

Fig. 1: Expansive soil zones in Saudi Arabia (Abduljauwad *et al*., 1998)

Fig. 2: Twist and distortion-Al Ghatt

Fig. 3: Typical boundary wall crack-Tabuk (Al Rowda)

Fig. 4: A building and boundary wall-Um Al Sahik

Fig. 5: Typical road damage-Al Ghatt

Fig. 6: Deserted two storey building-Tabuk (Al Masif)

Fig. 7: A single storey house subjected to damage at Tayma

Fig. 8: A single storey house subjected to damage at Al Qaleeba

Fig. 9: A house at Alyahia district-Hofuf

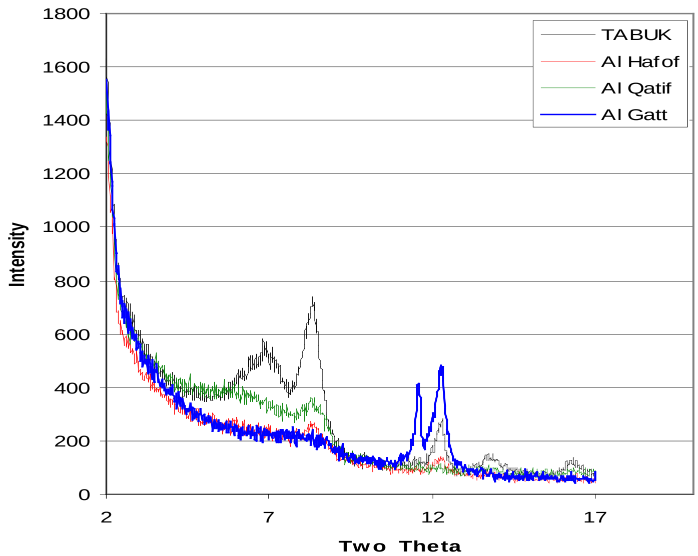

Fig. 10: X-ray diffraction-four Saudi soils

Sharora clay: Sharora is located to the south of the kingdom of Saudi Arabia at the border to Yemen. Geotechnical studies carried out for some projects indicated reddish clay of medium to high plasticity. Works of Al Muhandis Nizar Kurdi consulting engineers for Sharora Power Plant confirmed this occurrence. Al Muhaidib (1998) published some properties for Sharora clay. These are linked with some data from local geotechnical contractors and works of Ruwaih (1987) to establish the properties range for the clay in Sharora.

Al Joaf clay: Al Joaf is located towards North West of Saudi Arabia. Bugshan Research team did not visit this area at present but areas of Tabarjal and Sakaka were reported to have some shale and expansive clays. Ruwaih (1987) published some properties of Al Joaf clay.

Other areas: Areas with expansive clays in the kingdom of Saudi Arabia included many localities which are rarely mentioned in the literature. Based on information not published and the experience of the Authors the following locations can be added to the list: East of Riyadh (*Khashm Alaan)*, Al Asiyah (*Ein bin Fuhaida*) and Al Qassim area (various suburbs with thin shale layers).

Figure 1 presents a map showing regions with expansive soil formation in Saudi Arabia. Figure 2 to 9 present example of damage as reported from different places.

MINERALOGY OF EXPANSIVE SOILS IN SAUDI ARABIA

As part of this survey mineralogy investigations were conducted on selected clays. Qualitative determinations on minerals responsible for heave were carried out. The x-radiation is produced when high energy cathode rays rip electrons from a target element placed in the anode of an evacuated tube. The wave length produced is short and is dependent on the target material. The radiation involves two components known as kα and kβ. Screens were used to filter kβ for simplification. Crystal spacing can be determined by x-rays of a single wave length. Bragg (1913) introduced the equation known as Bragg equation:

$$n\lambda = 2d \sin \theta \tag{1}$$

where,

n = An integer

d = The distance separating planes

The common radiations used in x-ray crystallography are produced by Cu, Co, Fe and Cr tubes. Powder prepared samples from Tabuk, Al Hafof, Al Ghatt and AlQatif were tested. The diffractometer records are shown on Fig. 10. The calculated d-spacing can be obtained to a reliable accuracy. The diffractometer profiles show several overlapping in the zone $2\theta = 4^\circ$ to $2\theta = 8^\circ$. In this zone we can observe the smectite group or montmorillonite where d = 15 Aº. Other minerals may be present in this area. These include but not limited to; Vermiculite (d = 14 Aº), Cholrite, (d = 14 Aº) and Illite and Mica (d = 10 Aº).

From the X-ray diffraction results it can be confirmed that expanding minerals belonging to smectite groups are present in all four Saudi clays under study. Peak intensities indicate that mineral proportions are different but detailed quantitative study is beyond the scope of work for this research.

EXAMPLES OF DAMAGE

Failure due to expansive soil problems took many forms in the areas diagnosed as of potentially expansive nature. Uplift and twisting boundary walls for the residential villas is very common. This type of failure was reported frequently and found associated with water leakage or waste water disposal. Crack or failure intensity was found mild to medium in some areas and severe to very severe in other areas. Failure due to expansive soil problem was classified by the authors as given in Table 1.

The most damage is related to light structures. Boundary wall, asphalt pavements, irrigation canals and ground floor slabs are examples. When the swelling uplift is high two storey buildings may not be exerting satisfactory stresses. Utilizing raft foundation for some structures may distribute the load over a greater area and increase the risk of uplift and cracks.

Table 1: Classification of failures due to expansive soils

Class of failure	Description
Mild	Distortion in the form of partial uplifting with minor crack seen only in close vicinity (1 to 2 mm)
Medium	Diagonal cracks in the order of 2 to 5 mm, minor wall tilting
Severe	Displacement and disintegration of structural units cracks in the order of 5 to 10 mm tilt observed
Very severe	Displacement and disintegration of structural units, cracks in the order of centimeters. Major tilt and misalignment

Table 2: Al Ghatt clay properties

Description: Olive green clay shale to silty shale, symbol (USCS): CL, CH and ML	Property range for Al Ghatt soils	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	18.5	19.0
Water content wn, %	5.0	19.0
Liquid limit, LL, %	40	70
Plastic limit, PL, %	20	35
Plasticity index, PI	20	30
Shrinkage limit, SL, %	12	22
Percent sand, %	-	10
Percent silt, %	15	70
Percent clay, %	15	60
Specific gravity, Gs	2.70	2.78
Swelling pressure kN/m^2	40	300
Swell percent	0.8	2

Table 3: Al Hofuf clay properties

Description: Brown calcareous silty clay with sand symbol (USCS): CL, CH, ML and MH)	Property range for al Hofuf soil	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	14.5	18.5
Water content wn, %	3.0	15.0
Liquid limit, LL, %	40	65
Plastic limit, PL, %	20	25
Plasticity index, PI	15	40
Shrinkage limit, SL, %	12	23
Percent sand, %	5	25
Percent silt, %	15	70
Percent clay, %	10	40
Specific gravity, Gs	2.65	2.70
Swelling pressure kN/m^2	60	300
Swell percent	0.5	2.5

Table 4: Al Qatif clay properties

Description: Brown calcareous green and brown clay, symbol (USCS): CH and MH	Property range for al Qatif soils	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	10	14
Water content wn, %	15	40
Liquid limit, LL, %	120	160
Plastic limit, PL, %	30	60
Plasticity index, PI	90	100
Shrinkage limit, SL, %	9	15
Percent sand, %	0	5
Percent silt, %	15	50
Percent clay, %	50	90
Specific gravity, Gs	2.50	2.60
Swelling pressure kN/m^2	200	1000
Swell percent	2	20

Table 5: Tabuk clay properties

Description: Brown to green clay shale to silty shale, symbol (USCS): CL, CH and ML	Property range for Tabuk soils	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	18.5	19.5
Water content wn, %	3.0	19.0
Liquid limit, LL, %	40	75
Plastic limit, PL, %	20	35
Plasticity index, PI	15	40
Shrinkage limit, SL, %	12	24
Percent sand, %	-	10
Percent silt, %	15	70
Percent clay, %	15	70
Specific gravity, Gs	2.70	2.78
Swelling pressure kN/m^2	50	250
Swell percent	0.8	2

Table 6: Tayma clay properties

Description: Greenish brown to clay shale to silty shale, symbol (USCS): CL, CH and ML	Property range for Tayma soils	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	18.5	19.5
Water content wn, %	3.0	19.0
Liquid limit, LL, %	30	60
Plastic limit, PL, %	20	45
Plasticity index, PI	10	25
Shrinkage limit, SL, %	12	24
Percent sand, %	-	5
Percent silt, %	15	70
Percent clay, %	15	70
Specific gravity, Gs	2.70	2.78
Swelling pressure kN/m^2	50	200
Swell percent	0.8	2

Table 7: Al Medina clay properties

Description: Greenish brown to clay shale to silty shale, symbol (USCS):CL, CH and ML	Property range for Al Medina soils	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	12	18
Water content wn, %	25	60
Liquid limit, LL, %	60	120
Plastic limit, PL, %	40	70
Plasticity index, PI	20	50
Shrinkage limit, SL, %	12	28
Percent sand, %	-	10
Percent silt, %	15	50
Percent clay, %	15	65
Specific gravity, Gs	2.70	2.75
Swelling pressure kN/m^2	50	250
Swell percent	0.8	2

Table 8: Hail clay properties

Description: Brown silty clay to silty shale, symbol (USCS): CL and ML	Property range for Hail soils	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	14	18
Water content wn, %	16	28
Liquid limit, LL, %	28	48
Plastic limit, PL, %	10	30
Plasticity index, PI	8	28
Shrinkage limit, SL, %	36	56
Percent sand, %	-	10
Percent silt, %	15	50
Percent clay, %	19	39
Specific gravity, Gs	2.70	2.75
Swelling pressure kN/m^2	25	50
Swell percent	0.1	0.5

Table 9: Al Joaf clay properties

Description: Brown silty clay to silty shale, symbol (USCS): CL and ML	Property range for al Joaf soils	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	17	20
Water content wn, %	5	30
Liquid limit, LL, %	29	49
Plastic limit, PL, %	18	28
Plasticity index, PI	11	21
Percent sand, %	-	10
Percent silt, %	15	50
Percent clay, %	24	44
Specific gravity, Gs	2.70	2.75
Swelling pressure, kN/m^2	25	50
Swell percent	0.1	1

Table 10: Sharora clay properties

Description: Reddish brown silty clay, symbol (USCS):CL, CH and ML	Property range for Sharora soils	
	Avg. min.	Avg. max.
Dry unit weight, γd, kN/m^3	17	20
Water content wn, %	5	25
Liquid limit, LL, %	39	59
Plastic limit, PL, %	15	25
Plasticity index, PI	24	34
Percent sand, %	-	10
Percent silt, %	15	50
Percent clay, %	25	45
Specific gravity, Gs	2.70	2.75
Swelling pressure kN/m^2	50	200
Swell percent	0.1	2

Photographs given in Fig. 2 to 9 highlight some damage reported by Bugshan Research Chair team during site visits.

Table 2 to 10 presents generalized property ranges for expansive clay for different parts of the Kingdom of Saudi Arabia.

CONCLUSION

This survey was aimed at providing increased awareness among practicing geotechnical engineers and public in semi-arid areas to the risks associated with construction on potentially expansive soils and presents a current count on areas with reported problems. Index properties and ranges for swelling pressures and swell percent expected are given. A generalized guide for classifying damage is presented. Examples and forms of failure as reported by Bugshan Research Team are presented.

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