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Evaluation of engineering properties of soil in Al Butayn, Mudarraj Al Qassim and Turubah - Hail Saudi Arabia

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EVALUATION OF ENGINEERING PROPERTIES OF SOIL

IN

Al BUTAYN, MUDARRAJ Al QASSIM AND TURUBAH – HAIL

SAUDI ARABIA.

By

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ABSTRACT

Fractures, sinkhole, building cracks, and ground subsidence have spread in many regions of the Kingdom of Saudi Arabia, some of which are related to seismic activity, others due to the presence of unstable soils (collapsing soils and Expansive soils) and others because of faults, while others result from drawing groundwater at great rates. The current study has several facts related to the formation of cracks and landslides, including:

1) A general study of geomorphology and geology of the study areas.

2) The causes affecting the formation of cracks and subsidence.

3) Detailed geomorphological and geological studies of the locations of fissures and subsidence.

4) Geotechnical studies to the work of some trenches and boreholes in the locations of Fractures, sinkhole, building cracks, and ground subsidence, collecting samples and conducting some laboratory experiments to determine the properties of the soil and subsurface rocks in these sites.

5) Determining the causes of ground cracks through analyzes of samples and proposing them required to reduce them in the future, and clarifying the main causes for the appearance of these cracks and landslides.

6) Recommendations to reduce the occurrence of cracks and ground subsidence in the future, the most important of which are: Measure of water pumping, drainage operations from the surface and underground reservoir in the affected areas.

7) Through an evaluation of the properties of soils, it was found that most of the factors prove that this soil has a potential for swelling ranging from weak to high.

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1. INTRODUCTION

1.1. OBJECTIVE OF THE RESEARCH

The objective of the study is to evaluate and determine the properties and characteristics of Identifying the expansive soil properties and geotechnical properties of the study area. Geotechnical properties of the materials (soil and rocks) in any project is an essential task to help in structural design of the areas. In addition, evaluations of the different geological hazards in the project areas can be a great help in order to avoid any impact on the project.

For these reasons, evaluation of geotechnical properties of the surface and subsurface earth materials is necessary to provide more information that is relevant to the needs of engineers and evaluation of different geological hazards that could effect the project area. These evaluations help determine the causes of cracks, sinkhole, settlement, and/or swelling.

This evaluation of the soil properties in the Al Butayn, Mudarraj in the AL Qassim area, Turubah – Hail, and the assessment of the degree of damage.

The main objectives of this study can be summarized as follows:

- Identification and classification of soils that can be expanded and distributed.
- Evaluation of the characteristics of this type of soil in the affected area.
- Assessment of ground cracks damage in the area, and causes of expansion.
- Recommendations to reduce material damage.

1.2. DEFINITION OF EXPANSIVE SOILS

Expansive soils owe their characteristics to the presence of swelling clay minerals. As they get wet, the clay minerals absorb water molecules and expand. As they dry, they shrink, leaving large voids in the soil (J. David Rogers, Robert Olshansky, and Robert B. Rogers). These clay minerals are called elongated minerals in the sense that they can absorb water and increase in volume. When soil contains a high proportion of these minerals, the probability of a large volume increases in appropriate climatic conditions.

In this case, soils are called multiple expandable soil, expandable clay soil, or hearable soil. If the soil is exposed to a hot climate, it loses its water content and shrinks, creating gaps in the soil that help penetrate the water if it is available inside the soil and is extended again.

This is also called shrink-swell soil. In this report, this type of soil will be extended. Clay minerals can affect the properties of any soil if it is more than 5% of the total soil weight. The most common soil where the phenomenon of expansion and contraction occurs is the montimorillonite if it is pure, where it expands to increase the size of fifteen times the original size is it dry, but these soils are not pure in nature and are usually mixed with other types of clay minerals It has fewer qualities in volume change. Therefore, it is rare to have soil more than one and a half times the size of dry soil, but enough to cause severe damage to buildings.

1.3. MECHANICAL OF EXPANSIVE AND SWELLING SOIL

The expansion of the soil contains quantities of clay minerals from the smectite group and others whose structure allows for water absorption when a change in moisture content occurs (Carter and Bentley, 1991). This increases its size and thus expands; the greater the absorption of water, the greater the soil size increases. The reason for the chemical adsorption of water by clay minerals for water is due to the osmosis pressures resulting from the difference in the chemical voltage between the free water in the soil fabric and pore water in double diffusion layers formed around the outer surfaces of negatively charged clay minerals (Parker et al., 1977).

These double propagation layers are the result of the electrostatic forces of attraction between the cations found in the soil water and the negatively charged clay granules. Therefore, the property of the soil swell follows the clay minerals science (Seed et al., 1961 & 1962).

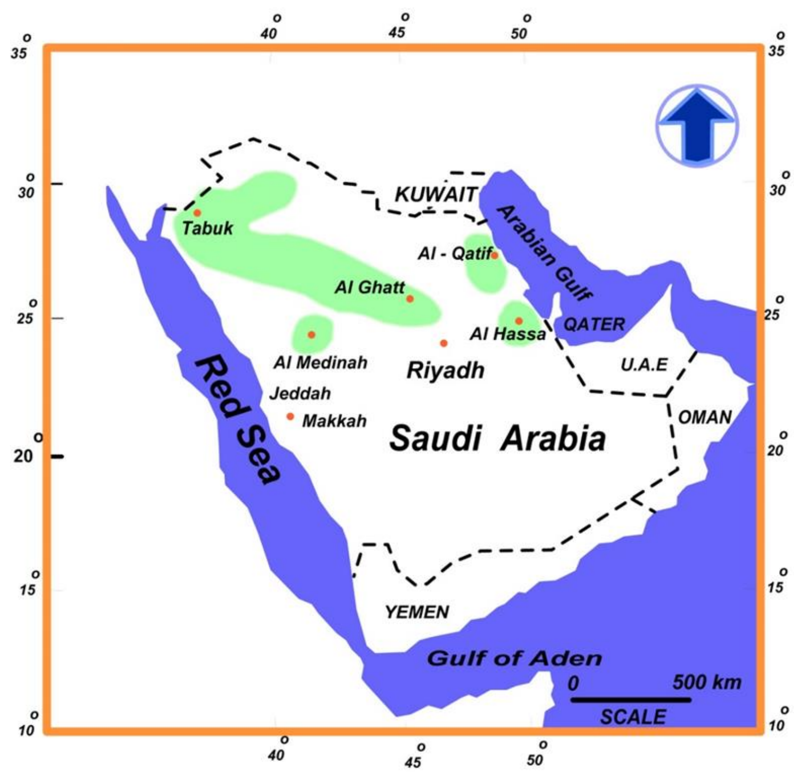


Figure 1.1 Distribution of expansive soils recognized in Saudi Arabia (from Dhowian et al., 1985)

1.4. FACTORS AFFECTING EXPANSIVE SOIL

The mechanism of the expansive clay soil is generally influenced by three main factors (Gromko, 1974). Each worker contributes to a certain degree of increase in size, and each factor controls a number of influencing elements, so stretching is described as a complex process. These factors include clay mineralogy, environmental conditions (e.g. severity of wet-dry cycles, and effective stress acting upon the soil.

1.4.1. Expansive Soil Properties. The expansion potential of the clay minerals depends on clay mineralogy and availability of moisture. The mineralogical variables the homogeneity of clay minerals and their respective percentages, initial dry density, soil texture, flocculants, dispersion, plasticity, and grain size. A number of elements play an important role in stress conditions compared with the degree of expansion, such as cohesion, age of the mud, thickness, and depth of cover (effective stress). The degree of expansion depends on the relationship between the type of mud and water minerals, which influence soil suction and salinity.

1.4.2. Types of Clay Minerals. One of the most important factors in the identification of expansive soil mixtures is the increase in volume that is fundamentally controlled by soil mineralogy and effective confinement. Kerr (1959) concluded that 15 metals can be mineralized by their attraction to pore water containing positively charged cations. Many workers have noted in their studies of different metals the degree of expansion exhibited by clay. Most workers agree that the physio-chemical properties of clay minerals and the relative proportions of said minerals in any given soil controls the potential increase in volume and the expansion pressure that might be exerted, as described in Mitchell (1976) and Sobhi (1981).

Other studies have highlighted the effect of cation exchange capacity (CEC), which is defined as the degree of soil absorption and substitution of cations, which depends on the negative charge of clay platelets, which attracts water molecules through dipolar attraction. The greater the negative charge, the more water molecules that can be adsorbed. Over the last 60 years various workers have concluded that the effect of substituting ions in clay soils containing minerals with swelling potential exhibited volume changes that exceeded the degree of polymorphism in the presence of water (Rosenqvist, 1959; El-Sobhy and Mazen, 1983; El-Sobhy et al., 1985). They have shown that mineralization is one of the basic ways reducing soil expansion.

Researchers use simple tests such as Atterberg Limits and free swell as proxies for mineral composition. Montmorillonite and fermicolite minerals are ideal metals that enhance soil volume change, while alalite and kaolinite minerals are characterized by relatively small volume change. Volume change may occur if the size of its granules is very accurate (Grim, 1968; Mitchell and Raad 1973; Mitchell, 1976). I don't know what you are trying to say here: Clay granules are produced by heating clay sufficiently to expand its structure and bake it like a ceramic material; typically called "expanded clay granules." They usually possess very low density so are used as lightweight concrete aggregate. These granules do not absorb moisture.

1.4.3. Soil Water Chemistry and Moisture. Soil moisture levels vary across building sites because of the following factors:

- Coefficient of rainfall variability between wet and dry climatic seasons,

- Efficiency of runoff collection, conveyance, and discharge distance from structures or pavements

- Proximity of impervious surfaces, such as pavement, sidewalks, patios, roofs, retaining walls, etc.

- Antecedent soil moisture, which depends on cumulative precipitation over previous 60 days, direct evaporation, and evapotranspiration trees or vegetation.

In most countries, deficiencies in the sewage system as well as leakage of potable water from pipes into the ground are also capable of becoming unexpected “point sources” of soil moisture, which can promote differential swelling and heave. In addition, the rise and fall of shallow groundwater levels can lead to significant changes in soil moisture due to capillary rise in the vadose zone.

The chemical composition of soil pore water can reduce the rate of expansion by increasing the concentration of cations. Okasha (1988) showed the effect of the solution found in the voids of the soils in urban settings and within caverns based on their expansion behavior. It showed that the rate of expansion and pressure in soil mixed with fresh water was higher than the rate of expansion for the same soil mixed with salt water. The main reason is due to the high concentration of cations in salt water.

1.4.4. Plasticity. Soils that exhibit plastic behavior in a large range of moisture content have a high probability of expansion. Other factors determine the extent to which the soil can increase in size.

1.4.5. Soil Structure. The shape and distribution of the clay particle and the method of distributing the spaces between these particle as well as the water properties in the soil and the concentration of ions and electrical properties have a direct effect on the expansion process. In addition, it was found the depth of the stretchable layer, which leads to behavior to the extent of movement on the surface of the earth, affects the degree of expansion. The quantity and quality of cohesion in cohesive clay reduces the degree of expansion.

1.4.6. Dry Density. Higher dry density indicates a little space between the grains or particle, increasing cohesion and creating high likelihood of increasing volume (Chen, 1975). Vacuums absorb part of the expansion as it occurs, causing a large increase in volume when wet with water compared to low density soil with the same amount of initial moisture. This is because the high dry density of the soil has a large surface area, and therefore the water absorption is very high, leading to a large value of free swelling**.**

1.5. ENVIRONMENTAL CONDITIONS

1.5.1. Initial Moisture Condition. Clay soils have a balanced water content when the soil's water possibility is zero. Water susceptibility increases when the water content falls short of the required equilibrium ratio. Therefore, dry soils have high susceptibility to water absorption from soils with the same composition but high water content. Thus, increased gluttony to absorb water means increased stretching or increased swelling pressure.

Dry soils will increase in size to a higher degree than wet soils due to the direct relationship between the water content between the granules and the processes of water absorption by the soil. The probability and degree of expansion can be defined by the contraction limit as well as the Atterberg limits (Attneyer 1955, Kantey and Brank 1952, Seed et al. 1962).

1.5.2. Moisture Variations. The changes in moisture in the active zone near the upper part of the profile primarily define heave. It is in those layers that the widest variation in moisture and volume change will occur (Johnson 1969).

1.5.3. Climate. The changes in the amount of rainfall and evaporation rate significantly affect the soil water content as well as the depth of the seasonal range affected by moisture. Seasonal soil expansion is highest in hot climates affected by intermittent periods of low rainfall (Holland and Lawrence, 1980).

1.5.4. Groundwater. The shallow level of the groundwater extends the soil with a moisture source, thus helping to expand. The changes groundwater level by constructed drains and canals have the same effect or more.

1.5.5. Drainage and Artificial Water Sources. The surface drainage features, such as ponding around a poorly graded house, foundation, provide sources of water at the surface; leaky plumbing can give the soil access to water at greater depth. (Krazynski 1980, Donaldson 1965).

1.5.6. Vegetation. Plants absorb water from the soil and evaporate part of it. This reduces soil moisture through evaporation and leads to an increase in soil moisture content by changing plant density (Buckley, 1974).

1.5.7. Permeability. The permeability of clay soils is very low and can significantly increase the formation of cracks because of soil dryness. Permeability helps to speed water movement within the soil, increases the speed of volume increase, and promote faster rates of swell (Wise and Hudson, 1971) (De Bruijn 1965).

1.5.8. Temperature. High temperatures cause humidity to resort to cold areas under buildings and installations, which exacerbates the problem (Johnson and Stroman, 1976).

1.6. CLASSIFICATION OF EXPANSIVE SOIL

Geotechnical properties and soil properties such as the following can be set in the laboratory:

1. Grain size distribution.
2. Consistency limit.
3. Swelling.
4. PH.
5. Cation exchange capacity.

The swelling potential of the expansive soil is usually classified as very high, high, medium, and low (Seed et al. 1962). Classified the soil to be stretched by plasticity index only (Table 1.1). Gromko (1974) classified stretched soil based on the percentage of soil grains passing through a Sieve 200 and the limits of strength (Table 1.2). On the other hand, Dakshanamanthy and Raman (1973) made a chart (Figure 1.2) based on the relationship between the liquidity limit and the plasticity coefficient, on which the soil is classified as expandable based on the effort to swell very high, high, medium and low. Van der Merwe (1964) used the plasticity coefficient and the percentage of clay particles in the soil to classify the stretched soil, as shown in (Figure 1.3).

Table 1.1 Expansive soil classification based on plasticity index (After Chen 1988).

Swelling Potential	Plasticity Index
0-15	Low
10-35	Medium
20-55	High
55<	Very High

Table 1.2 Expansive soil classification based on the manual of tests

Percentage Passing No. 200 sieve	Liquid limit (%)	Shrinkage limit (%)	Plasticity index (%)	Degree of expansion
95 <	60<	15<	35>	Very High
60-95	40-60	10-16	25-41	High
60-30	40-30	7-12	15-28	Medium
30>	30>	11>	18>	Low

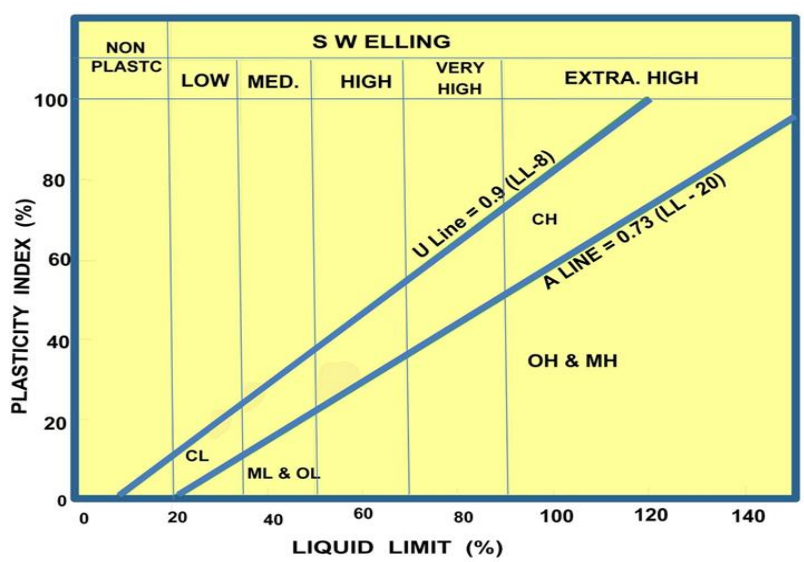


Figure 1.2 Plasticity chart.

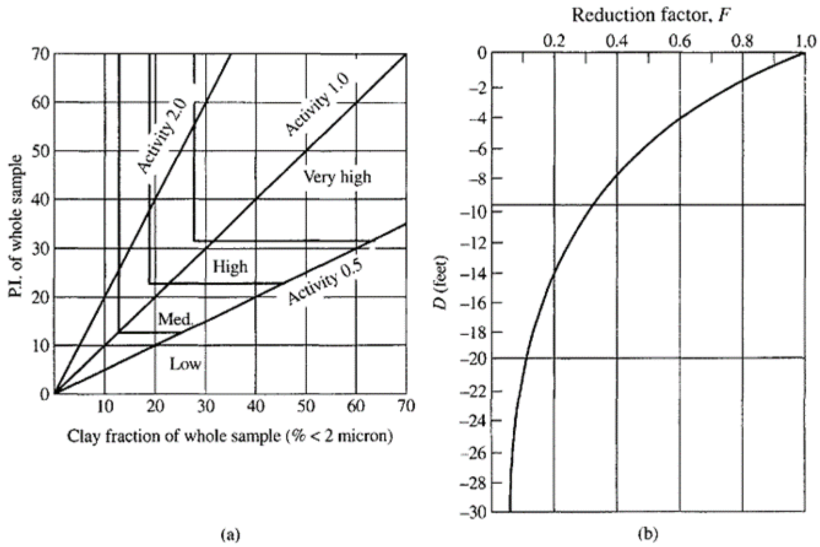


Figure 1.3 Relationships for using Van Der Merwe's prediction method:
(a) Potential expansiveness and (b) reduction factor (Van der Merwe, 1964).

Seed et al. (1961) used the results of the unrestrained swell tests to make a classification of the expansive soil as shown in (Table 1.3). Holtz and Gibbs (1954) considered colloid content, plasticity index, shrinkage threshold, and percentage of swelling as the basis for soil classification, as shown in Table 1.4.

Table 1.3.Classification of degree of expansion by USBR (Seed et al. 1961).

Swelling Potential	degree of Expansion
0-1.5	Low
1.5-5	Medium
5-25	High
25<	Very High

Table 1.4.Expansive soil classifications based on colloid content, plasticity index, and shrinkage limit. After Holtz and Gibbs (1956).

Colloid Content (% minus 0.0001mm)	Plasticity index (%)	Shrinkage limit (%)	Probable expansiopn (% total volume change)	Degree of expansion
> 28	>35	>11	>30	Very High
20-31	25-41	7-12	20-30	High
13-23	15-28	10-16	10-20	Medium
<15	<18	>15	<10	Low

Very important properties of clay minerals the cationic substitution required for balance of charges on the surface of the clay minerals. This property is called replacement cationic capacity cation exchange capacity and expressed per unit milliequivalent of 100 grams of dry mud (Mitchell, 1976). The cation replacement capacity was used to define the clay minerals, as shown in Table 1.5.

Table 1.5. Cation Exchange capacity (Mitchell, 1976).

Clay Mineral	CEC (meq/100g)
Kaolinite	3-15
Illite	10-40
Montmorillonite	80-150

1.7. DAMAGES DUE TO EXPANSIVE SOIL

In general, if the volume expansion of the foundations in the site exceeds 5%, will cause damage to a varying percentage of the installations unless the foundations are specially designed to cope with this.

According to some statistics, the physical damage to the structures on the expansion soil outweighs the damage caused by floods and earthquakes combined. These facilities include buildings, roads, bridges, pipelines, and all rigid structures.

The problems caused by this type of soil depend largely on the pressure changes under the origin from one place to another, because of differential movement under the same building.

As well as the change of soil, level in the same place up and down depends on seasonal changes. Soil is subjected to this seasonal vertical movement up to depths of about two meters (active range). When a structure is established over a relatively large area (a large building or road), seasonal changes in the moisture content may fade under the center of building due to rain but it is concentrated around the limbs and its surroundings.

1.8. LOCATION AND ACCESSIBILITY OF STUDY AREA

(Area 1) Al Butayn is located in the Qassim area, north of the city of Breda, about 50km, Farms and freshwater streams surrounding it. (Area 2) Mudarraj city is located in the north of the Qassim area on the Qassim-Hail road and is located at a distance of 100 km to the northwest of Buraidah city (Area 3) Turubah city lies about 140 km to the northeast of the city of Hail (Figure 1.4).

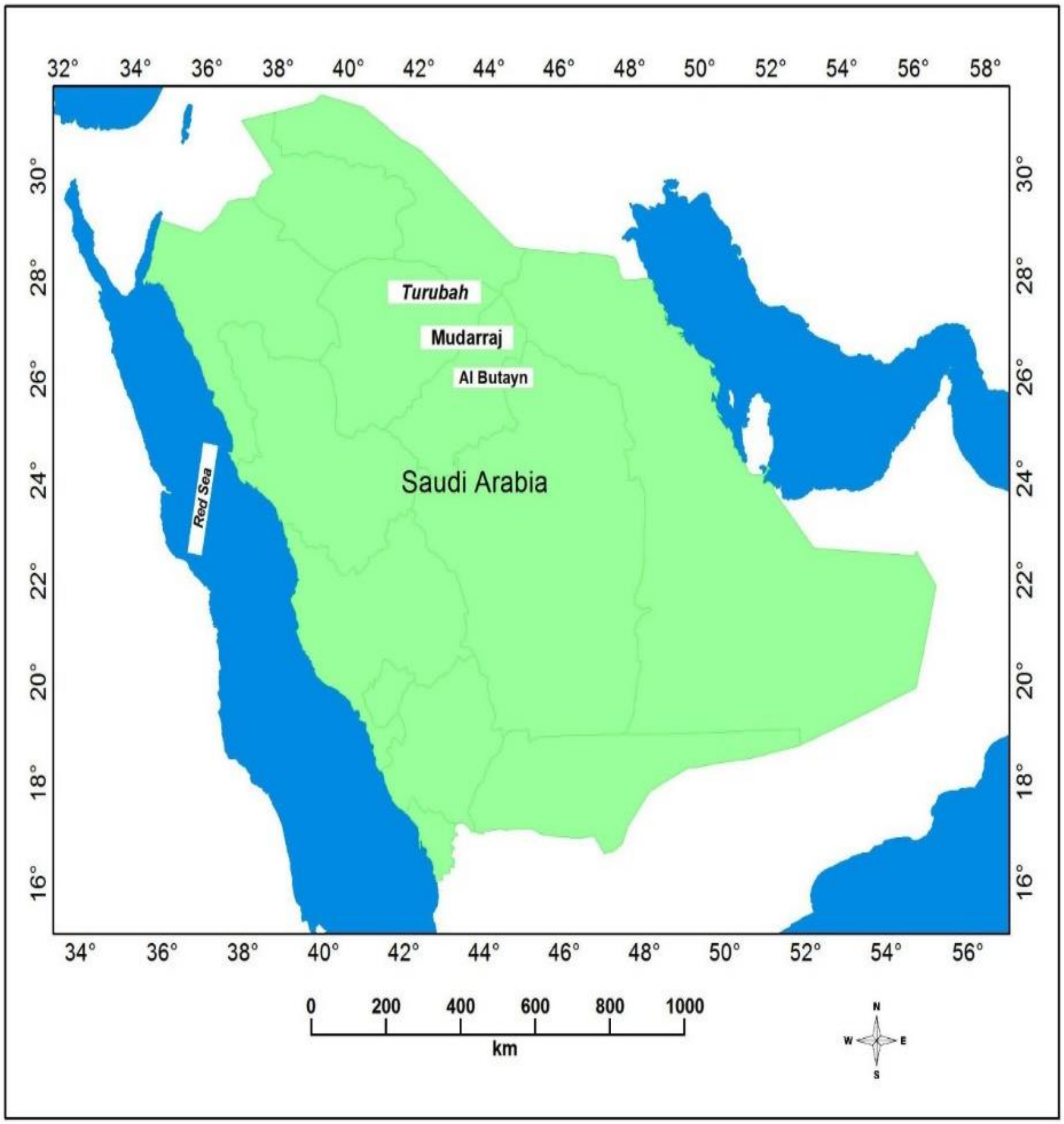


Figure 1.4 Map of location of studies area

2. TOPOGRAPHY AND GEOLOGY

2.1. TOPOGRAPHY OF (Al BUTAYN)

Al Butayn is located between 625 m and 651 m above sea level. Farms areas surround Al Butayn town in all respects. It passes small valley through Al Butayn city; name it Al-Sarot, which flows into the northern part of the region, in addition to small valley name it Al-Waib, which is located in the Umm Al-Ril farms (Figure 2.1).

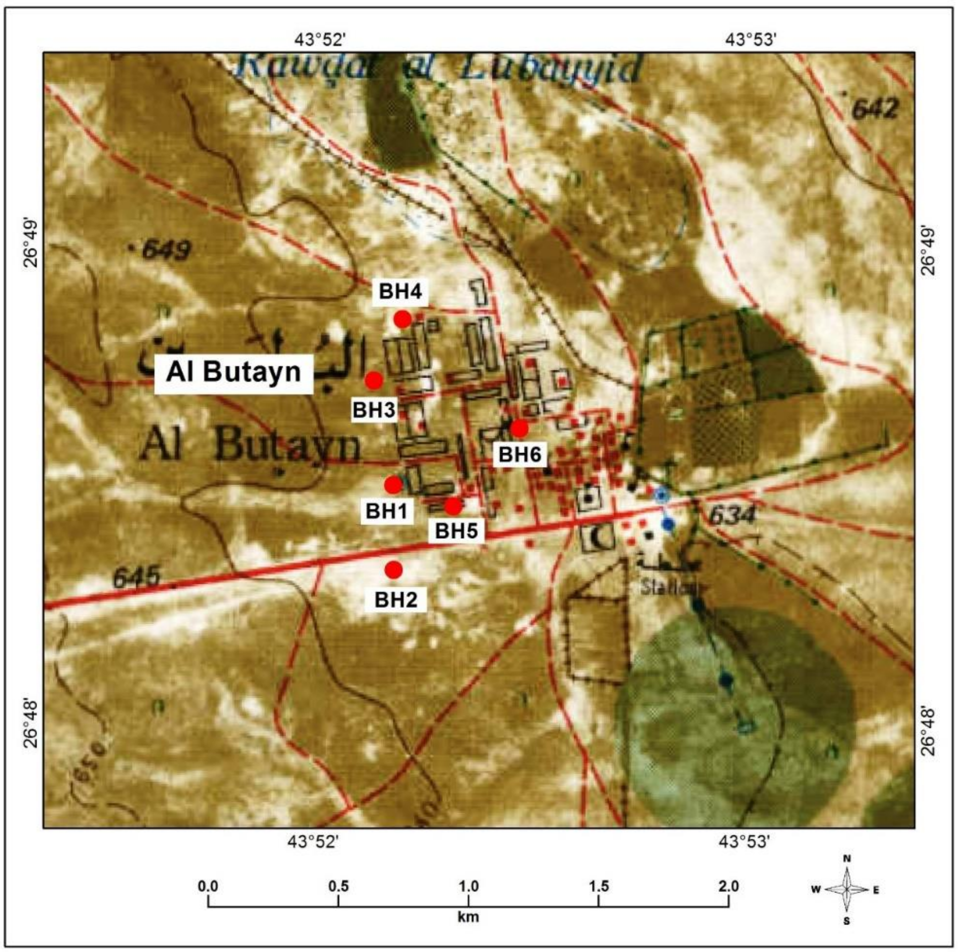


Figure 2.1 Topography map of Al Butayn city.

2.2. REGIONAL GEOLOGY OF (AL BUTAYN)

The Al Butayn area consists of many geological. These units are arranged from the earliest to the oldest as follows:

1) Sedimentary cover: These sediments are located around the town of Al Butayn except to the north and northeast of the town. These sediments are divided into two parts: active gravel sediments (Qsga) and inactive inertial sediments (Qsgn). These sediments are characterized by light brown color and are composed of gravely limestone and sand.

2) Sediment deposits these sediments occupy the streams of valley that descend from west to east and take the symbol (Qal). There are two villages of Al Butayn area: the first is located south of the town of Al Butayn, and the second extends from the northwestern part of the area until it reaches the northeastern edge of Al Butayn. These sediments are composed of different sizes of gravely limestone and gravely sand.

3) The deposits of Al khbra are denoted by the symbol (Qk). These deposits are located in the southeast, south-west, and far northwestern parts of the geological map of the Al Butayn. These sediments consist of brown mud and silt, as well as a thin slice of windy sand covering the surfaces of some of these areas.

4) Deposits of plain flood and pelvic silt and take symbol and are denoted the symbol (Qay). These sediments are located in the low areas facing the end of estuaries and valleys located in the southeast corner of the map Al Butayn geological. These sediments consist of sand, clay and some semi-rounded gravel to round.

5) Wind sediments: these sediments cover a large areas surrounding Al Butayn, specifically to the east and northeast. These sediments move from the north and northwest to the south and southeast at different sedimentary rates depending on wind power,

vegetation density, moisture content, and grain size. These deposits are shown in yellowish light brown and are the size fine to medium grain size with good gradation. These sediments consist mainly of quartz, which represent the largest percentage of quartz, along with to the feldspar, heavy metals such as Hornblende, and other secondary metals.

These deposits appear in the form of a (Qess) covering the flat areas and are characterized by a small thickness, representing a transitional phase between the development and formation of sand dunes and their eventual disappearance.

6) Hard limestone crust (Qdcx) are located in several areas, where they appear in the extreme southwestern part of Al Butayn geological map and in the east and southeast of Al Butayn village.

These sediments appear near the Al Butayn village, extending from the northwest to the southeast.

These sediments represent the oldest deposits present in the region. These sediments are beige and consist of large, medium-sized gravel, sand and some limestone. These sediments are composed of Agafar formations of the Triassic Period.

7) Agafar is formation and takes the symbol of (Tab). These sediments are located in the southwestern part of the geological map of the Al Butayn. These sediments consist of different clay sandstone and limestone or marine clay. This rock was deposited during the Triassic Period.

8) The Sidir clay formation is given by the symbol (TRs). The rocks of this unit often overlap with the rocks of the Al Butayn village (TRks) unit, which extend from the northwest to the southeast of the region through the village of Al Butayn and exist without interference in the majority of the western part of the village.

The rocks of this clay stone and gypsum-bearing stone are characterized by red and light green color in a class sequence.

In some places, thin layers of dolomite and red sandstone are shown in red or brownish red. In some places, the rocks of this solid limestone crust consist of large, medium-sized gravel and sand of the four-era.

This rock, formed during the early Triassic period, was deposited in the lowlands located between the limestone rocks of the Khuf Formation.

9) The Khuf Formation consists of four sedimentary units of the Triassic Periods; only one member is exposed to the upper part of the area, which is Khartim.

The member rocks of Khartim (TRkk) are exposed in the far western, northern and northeastern parts of the Al Butayn geological map, but in the rest of the areas where they are found they appear intertwined with the rocks of the Sidir clay.

In some places, this rock consists of a solid calcareous crust made up of large to medium-sized gravel and sand of the quadruple.

The rock of this formation is congruent with rocks composed of a clay. The rocks of this formation were deposited during the Late Permian and Early Triassic Periods (Figure 2.2).

The structural Geology of the (Al Butayn). In the area around the Al Butayn has many faults and geological structures take different directions such as North-West-South-South-East, Northeast-South-West, Northwest-South-East, and East-West.

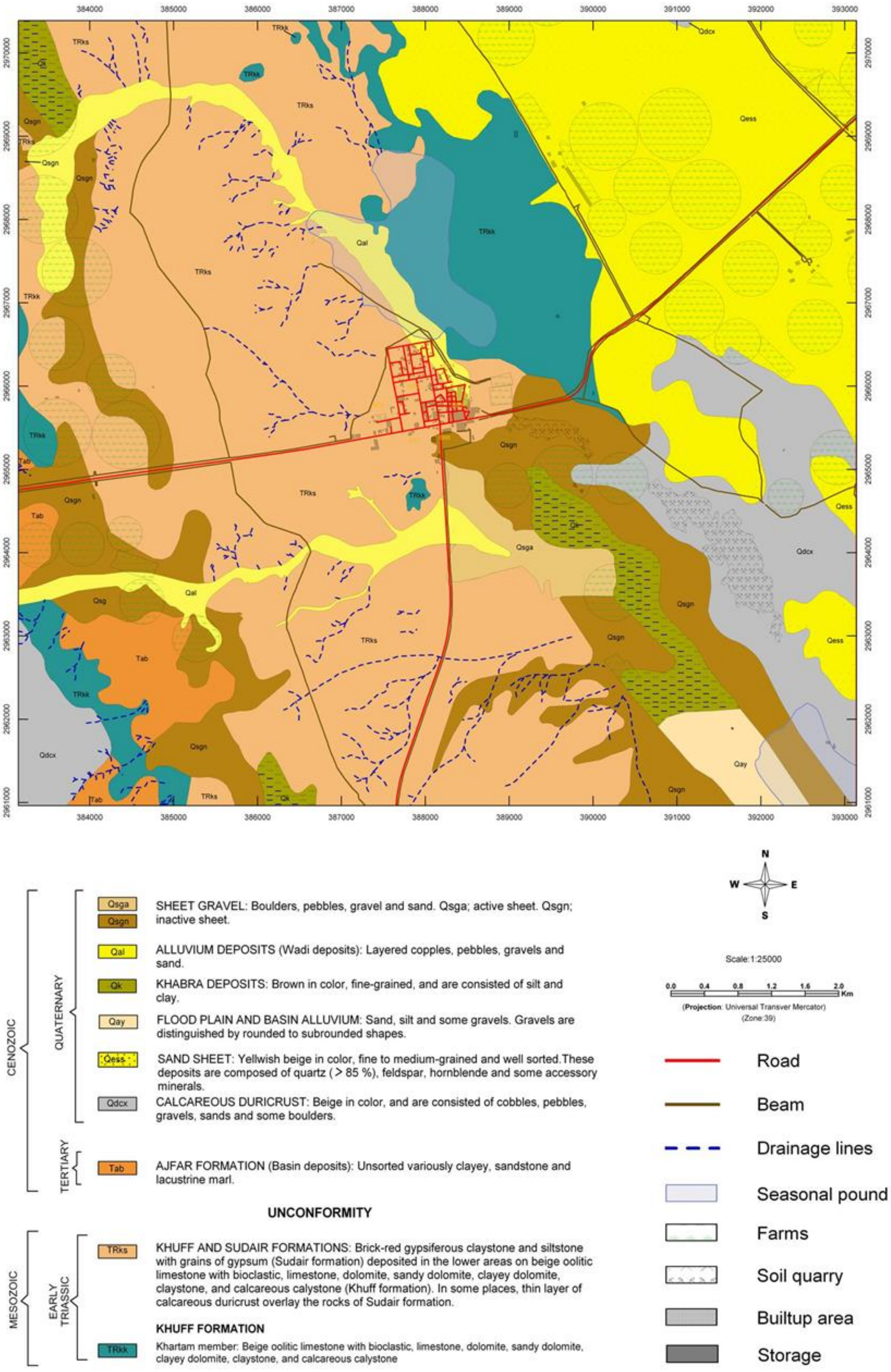


Figure 2.2 Geological map of Al Butayn.

2.3. TOPOGRAPHY OF (MUDARRAJ)

From topographic maps (Figure 2.3), the elevations of the Mudarraj area is between 647 meters and 700 meters above sea level. There are many farming areas around the Mudarraj city. There is a small valley pass through the area across the Palim valley east of the Mudarraj.

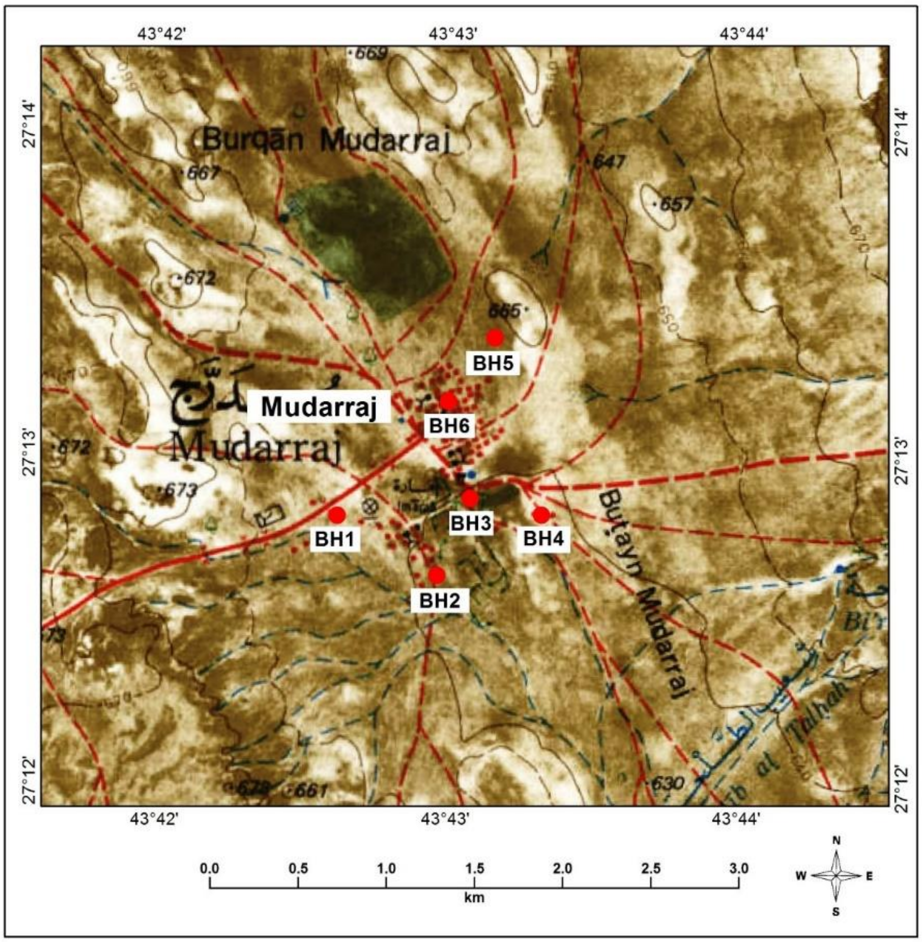


Figure 2.3 Topography map of Mudarraj city.

2.4. REGIONAL GEOLOGY OF (MUDARRAJ)

The geological maps of the Mudarraj area (Figure 2.4)show of a set of geological units arranged from the earliest to the oldest as follows:

1. Sediments of Al khabra, take the symbol Qk. These deposits are located in the northeastern and southeastern parts of the geological map of Mudarraj and north of Mudarraj city. These sediments consist of brown silt and mud, as well as a thin layer of windy sand covering the surfaces of some of these areas.

2. Windy sediments cover large areas of the region. Almost half of the area of the geological survey map, in particular the eastern part, is covered. These sediments move from the north and northwest to the south and southeast at different sedimentary rates, depending on wind power, vegetation density, moisture content and grain size. These deposits are shown in yellowish brown on the map and are the size of the fine-to-medium and fine-grained grains. These sediments consist mainly of quartz, which represents the largest percentage, along with feldspar, heavy metals such as Hornblende, and other secondary minerals. These deposits appear in the form of Qess which coveres the flat areas and is characterized by a small thickness, representing a transitional phase between the development and formation of sand dunes (Qes) and their eventual disappearance.

Solid limestone crust is denoted by the symbol Qdcx. These deposits are located in several areas, mostly in the western part of the geological map of Mudarraj and small circular areas in the north and at the bottom of Jelah formation outcrop. These deposits appear in the Mudarraj extending from the northwest to the southeast. These sediments represent the oldest deposits in the two regions. These sediments are light brown and consist of large, medium-sized gravel, sand and some limestone. These sediments are composed of Agafar of the Triassic Periods.

The Jilh formation consist of three sedimentary units: upper, middle and bottom. The rocks of the upper and middle units, symbolized by TRJ, appear because of the difficulty of separating them on the scale of this map and in the far northeastern part of the geological map near the city of Mudarraj. The rocks of these two units consist of dolomite clay stone, light brown clay fragments, dolomite stone, and limestone. The rocks of the lower unit are located east of the city of Mudarraj, extending from the northwest to the southeast of the area and tilting to the northeast by about 5 deg. The approximate height of the Jullah formation outcrop measured from above to its base is about 30 m. The rocks of this unit are formed from top to bottom by sandy dolomite, fragments of dolomite, yellowish brown dolomite containing quartz granules in its lower part, and mudstone with greenish brown silt. These rocks form rock masses falling on the slopes in some parts of the outcrop. These sandstone rocks are characterized by red, fine-to-medium grading. Sandstone rocks cut off channels of gravel that lag behind the exposed rocks. This rock was deposited during the intermediate Triassic period to the Late Triassic period.

The Sidir clay formation is denoted by the symbol TRs, and the rocks of this formation are typical of the area west of the Mudarraj. In some places, thin layers of dolomite, red sandstone or reddish brown, and some of the places, this rock consists of a solid limestone crust composed of large, medium-sized gravel and sand of the Quaternary Period. This rock formed during the early Triassic period, was deposited in the lowlands located in between the limestone rocks of the Khuf formation.

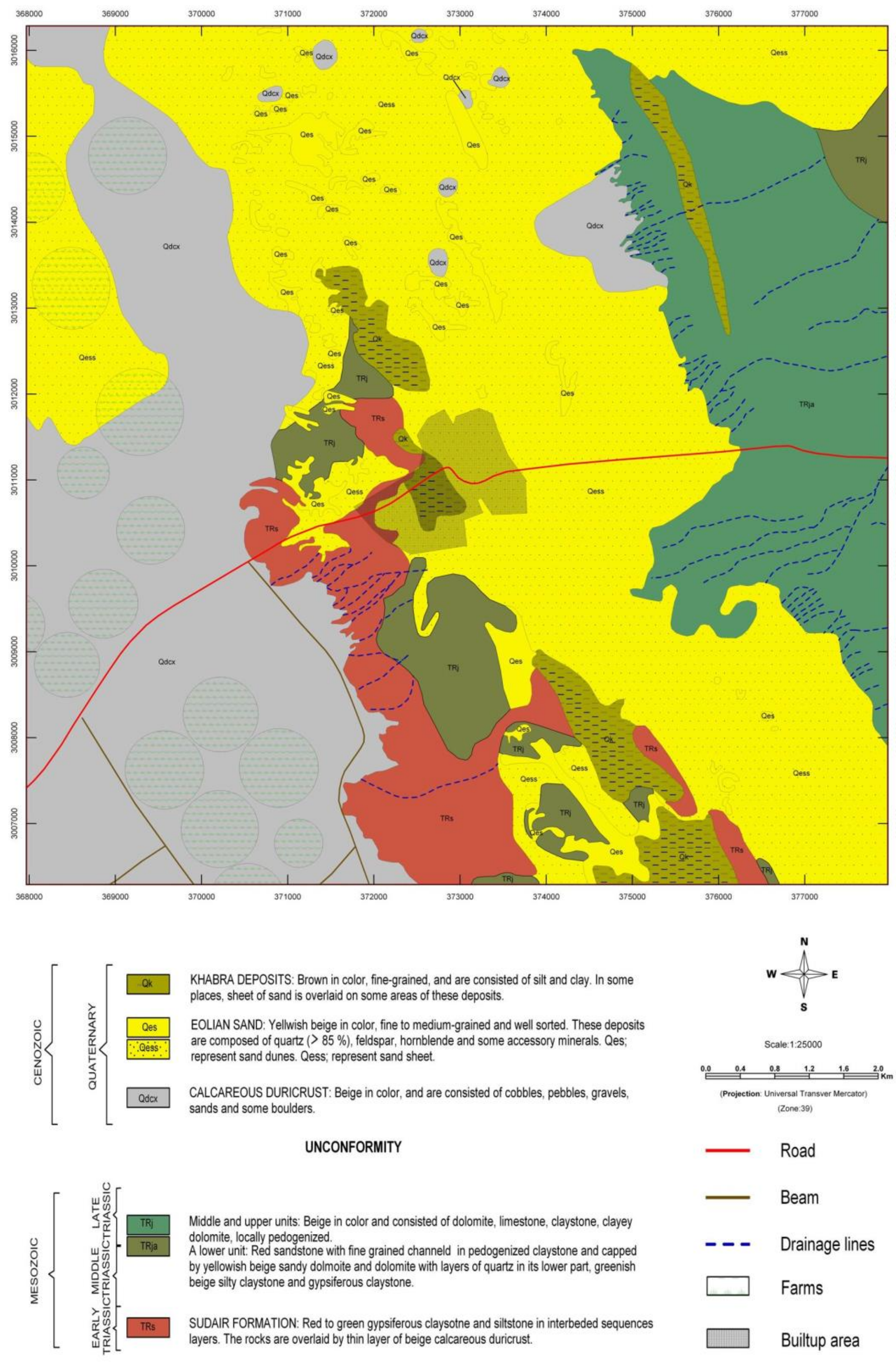


Figure 2.4 Geological map of Mudarraj city.

Figure 2.5 Show the outcrop of Mudarraj study area.

The Structural Geology of the (Mudarraj). The area around the Mudarraj city has many faults and geological structures that take different directions such as; north to northeast, south to southwest, northeast to southwest, and few structures that go from east to west and northwest to southeast.

2.5. TOPOGRAPHY OF (TURUBAH)

The topographic maps show (Figure 2.6) the area surrounding Turubah, located about 140 km to the north-east of the city of Hail at an elevation 700 m above sea level. residential areas surround the area.

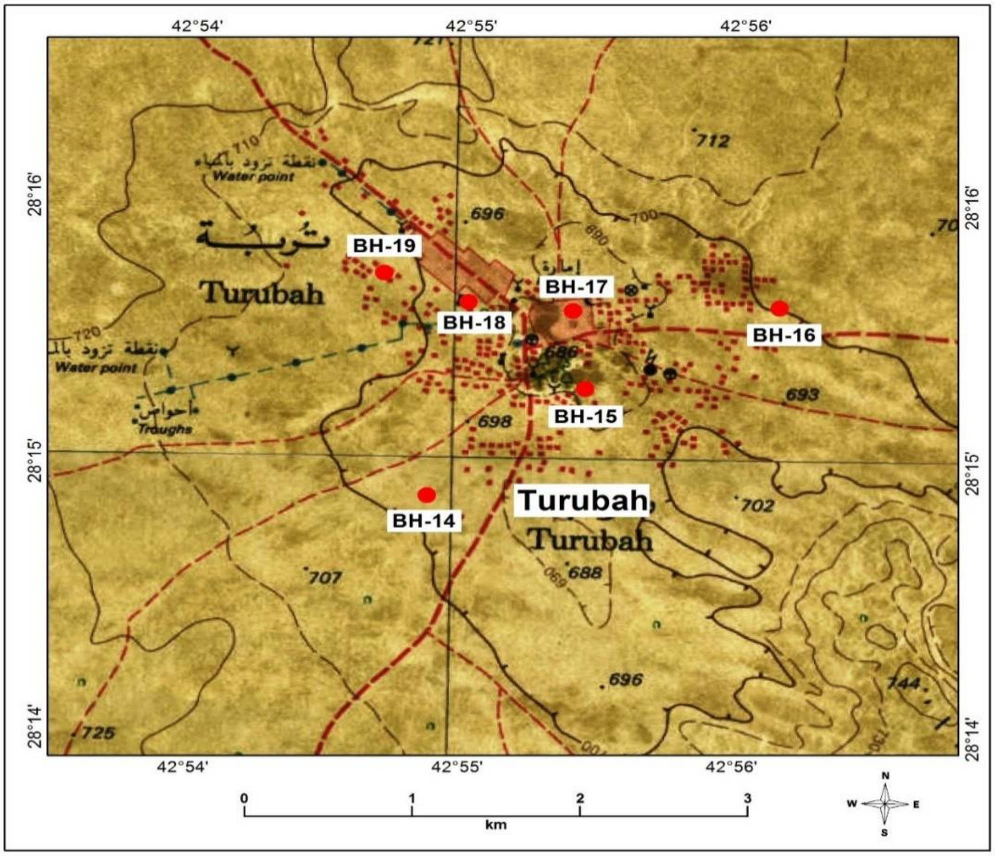


Figure 2.6 Topography map of Turubah city.

2.6. REGIONAL GEOLOGY OF (TURUBAH)

The geological maps of the Turubah show a group of geological units (Figure 2.7).These are described from the earliest to the oldest as follows:

1. Sand dune sediments are dented by the symbol Qdz. These sand deposits are of the Barchans sand dune type and have a fine grainsize.

2. Sediments of inactive sand dunes are given by the symbol Qdy. They are sandy sediments that are inactive longitudinal sand dunes and the fine grainsize.

3. Active sand deposits are given by the symbol Qsz. These sand deposits cover large areas in the form of butterflies and have a fine grainsize.

4. The calcareous duricrust deposits are Odcy, which is a hard shell sediment that contains fossilized, remains of irregular shaped limestone fragments, in limestone sand, composed of calcareous sand-based sediments containing marginal bubbles, limestone and calcareous limestone. These deposits have a fine grain mixture.

5. Magma member it takes the symbol Kw3 and is a stone of mutual clay stone with a stone green kaolin and fine-grained sandstone.

6. The Jilh formation takes the symbol TRJ and is made up of limestone, clay limestone, and organic limestone.It has a gray to pink color.

7. Khuff Formation takes the symbol (Pk), which is the deposits of Laterite and limestone rocks pink to yellow.

The Structural Geology of the (Turubah). The structural geology of the area around Turubah city has no obvious faults or other structural cracks based on the analysis of the geological maps of the region.

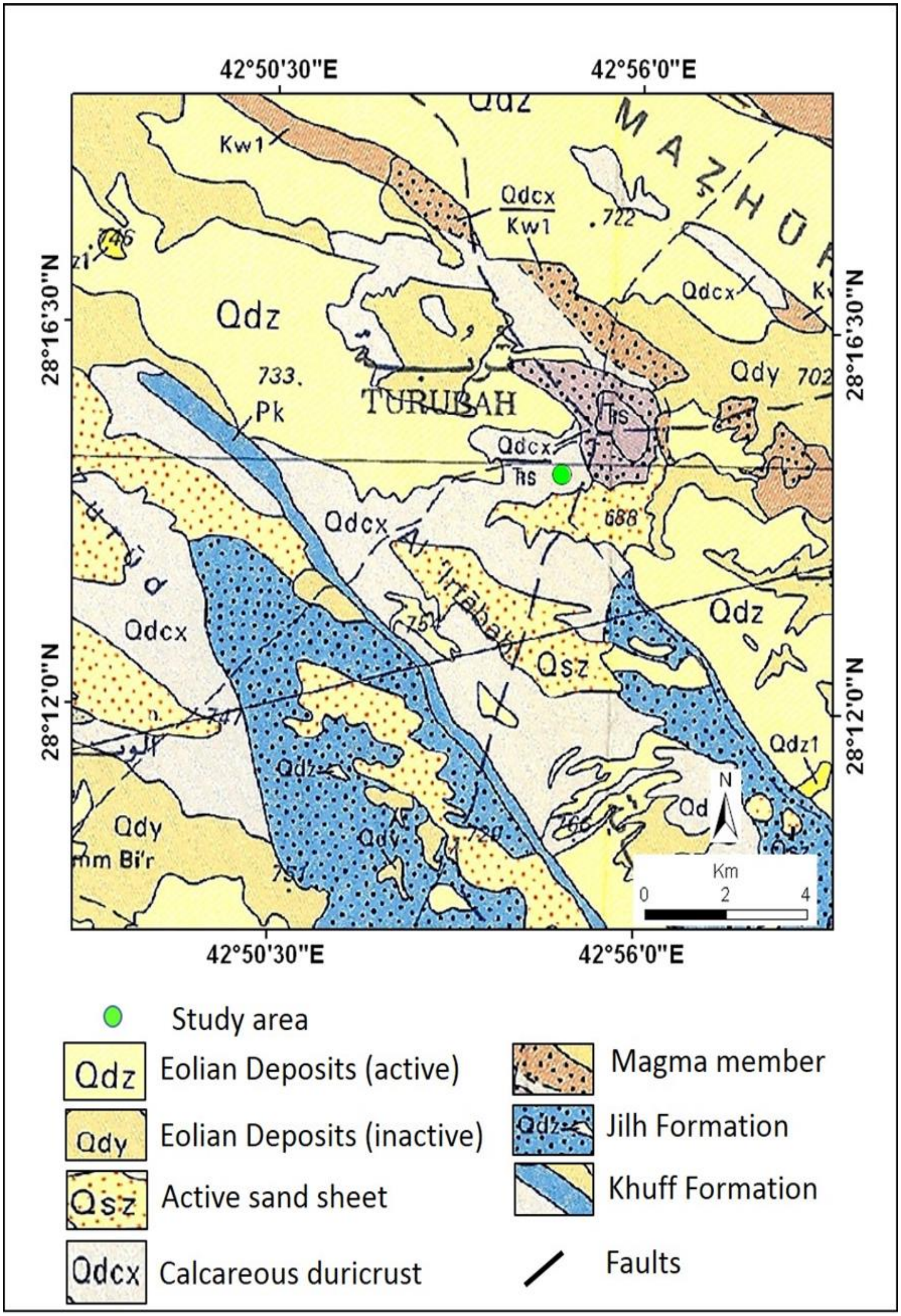


Figure 2.7 Geological map of Turubah city.

3. METHODOLOGY

3.1. INTRODUCTION OF METHODOLGY

This study was based on the collection of data and previous studies, surveys of cracks and fissures, then the work of an integrated fieldwork program in light of the study of cracks and geological erosion in the region. Using modern techniques, detailed field studies, geotechnical studies and sub-surface areas sampling by trenches.

At this stage, exploration visits to the study areas were taken to inspect for cracks and land erosion, identify mechanisms and methods of project implementation, and to gather pictures of cracks and erosion. (Figure 3.1, Figure 3.2, Figure 3.3, Figure 3.4, Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.8 and Figure 3.9).

Compilation of previous reports on the region and reports on the study of cracks and subsurface in different areas within Saudi Arabia, geological maps, topographic maps. Landsat image in addition to reports of cracks and corrosion in the world and knowledge of research methods used in the study of different types of cracks and erosion of land.

Figure 3.1 Cracks on wall house buildings at the Turubah city areas.

Figure 3.2 Big cracks on wall school buildings at the Mudarraj city areas.

Figure 3.3 Big cracks on buildings at the Mudarraj city areas.

Figure 3.4 Significant cracks on buildings at the AL Butayn city areas.

Figure 3.5 Some types of cracks and fissure at the studies areas.

Figure 3.6 Some types of cracks and fissure at the Turubah city areas.

Figure 3.7 Sinkhole at the studies areas.

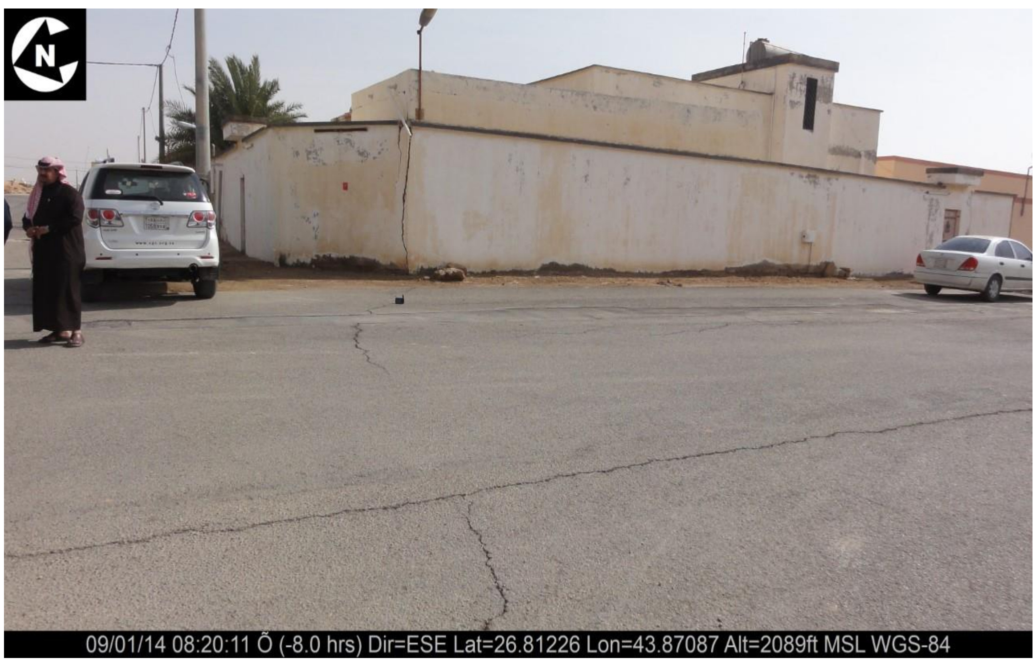


Figure 3.8 Some types of cracks on buildings and street at the AL Butayn city areas.

Figure 3.9 Some types of cracks on buildings and street at the studies areas.

3.2. FIELD INVESTIGATIONS

The detailed field studies have many different objectives, such as to determine and draw the extension cracks and determine the general direction and location of cracks by using a GPS device, identify the dimensions of erosion, collect different information, to reduce the spread of these cracks and erosion of land in different locations and collect information about them. Additionally, pictures were taken of each location in the study area and information was collected from residents of these areas about the time of occurrence and expansion. Borehole drilling locations and sampling opportunities were determined.

3.3. GEOTECHNICAL STUDY

The geotechnical studies are all works related to the exploration of the site include study of soil, sediments, groundwater, analysis and interpretation of information to predict the behavior of soil when building on them, .these studies are very important in the design and implementation of the buildings, It was implemented in two preliminary and final stages. A heavy rig was used in both phases of the field, which had the ability to drill solid soils from dry clay and extract samples from the first meter to a depth of 10 meters. The excavation areas were evenly distributed to observe soil changes in the three dimensions of each site. The drilling was accompanied by a description and classification of the soil and a recording of the depth of the groundwater in the form of drilling records (Figure 3.10).

Figure 3.10 A photos of the excavator used to make the drilling boreholes.

3.4. ROCK QUALITY DESIGNATION (RQD)

The rock quality designation is one of the most important parameters used in the classification of rock masses for engineering purposes. It is a modification to the core recovery and it has been defined by Deere and Miller (1966) in an attempt to quantify discontinuity spacing as the following equation:

$$RQD = \frac{\text{Length of intact cores} > 100\text{ mm (4 inch)}}{\text{Length of core drilled}} \times 100$$

An emperical formula has been introduced by Palmstrom (1982) for determining the RQD on the basis of the number of joints in a cubic meter in an outcrop as follow:

$$RQD = 115 - 3.3\ Jv$$

Where: Jv is the total number of joints per m3.

RQD value will be equal to 100 when Jv < 4.5. (Table 3.1) illustrates the descriptive terms, values and symbols for the RQD.

Table 3.1 Descriptive terms and symbols of RQD values (after Deere and Miller, 1966).

Descriptive T	RQD%	Symbols
Very Good	90-100	R1
Good	75-90	R2
Fair	50-75	R3
Poor	25-50	R4
Very Poor	< 25	R5

3.5. LABORATORY TESTS METHODS

The laboratory tests were performed on selected samples from the boreholes and surface pits upon the program of testing provided by the engineer. The ideal laboratory program is very important to determine the geological engineering properties for the studies area. Also the Laboratory tests will provide the engineer with sufficient data to complete an economical design.. The following tests were performed according to American Society for Testing and Materials (ASTM) Standards:

- ASTM D 2216-98, Standard Test Method for, "Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass".

- ASTM D 4318-00, Standard Test Method for, "Liquid Limit, Plastic Limit and Plasticity Index of Soils".

- ASTM D 422-02, Standard Test Method for, "Particle-Size Analysis of Soils".

- ASTM D1140-00, Standard Test Method for," Amount of Material in Soils Finer than the No. 200 (75 um) Sieve".

3.5.1. Grain-size Analysis. This test is performed in two stages: sieve analysis for cohesive less soils and hydrometer analysis for fine-grained soils (cohesiveness soils). Soils containing both types are tested in sequence. The material passing sieve number 200 (0.075 mm or smaller) will be analyzed by hydrometer.

3.5.1.1. Sieve analysis. This test provides a direct measurement of the particle size distribution of a soil by causing the sample to pass through a series of wire screens with progressively smaller openings of known size. The amount of material retained on each sieve is weighed. This test is performed based on ASTM D 422-02.

3.5.1.2. Hydrometer. This test is based on stokes law. The diameter of a soil particle is defined as the diameter of a sphere which has the same unit mass and which falls at the same velocity as the particle. Thus, a particle size distribution is obtained by using a hydrometer to measure the change in specific gravity of a soil-water suspension as soil particles settle out over time. Results are reported on a combined grain size distribution plot as the percentage of sample smaller than, by weight, versus the log of the particle diameter. The hydrometer test has been specified in accordance with ASTM D 1140-00.

3.5.1.3. Moisture content. The moisture content is defined as the ratio of the weight of water in a sample to the weight of solids. The bulk sample is weighed, and then oven-dried to a constant weight at a temperature of about 230° f (110° c). The weight after drying is the weight of solids. The change in weight, which has occurred during drying, is equivalent to the weight of water. For organic soils, a reduced drying temperature of approximately 140° f (60° c) is sometimes recommended. Tests shall be performed in accordance with ASTM D 2216-98.

3.5.2. Atterberg Limits. The Atterberg limits are a basic measure of the critical water contents of a fine-grained soil:

3.5.2.1. Liquid Limit (LL). The liquid limit is determined by ascertaining the moisture content at which two halves of a soil cake will flow together for a distance of 0.5 inch (13 mm) along the bottom of the groove separating the halves. Liquid limit test is performed in accordance with ASTM D 4318-00.

3.5.2.2. Plastic Limit (PL). The plastic limit is determined by ascertaining the lowest moisture content at which the material can be rolled into threads 0.125 inches (3.2 mm) in diameter without crumbling. Tests shall be performed in accordance with ASTM D 4318-00.

3.6. FREE-SWELL TEST

One of the tests that can determine the degree of expansion of the mud is the experience of free-swell test. In this test, the sample is placed in the odometer and is allowed to expand freely under a load of 7 KPa by moistening it with water.

The amount of swelling is calculated after the end of the swelling by dividing the change in the height of the sample by the original height of the sample before swelling multiplied by one hundred. Loads are then added to the sample to be returned to their original height and the swelling pressure is calculated by dividing the total loads by the surface area of the sample.

Another test is to calculate the free swelling of the soil by placing (10) cm3 of dry soil passing through the sieve number (40). Very slowly to the cylinder inserted with a capacity of 100 cm 3, and fill it with water , note the size of the soil until the size is fixed, and the amount of swelling is determined by the formula next: Free Swell Index, (%)

$$= \frac{Vk - Vd}{\mathrm{Vk}} \text{ x } 100 \text{ .}$$

4. RESULTS AND ANALYSIS

4.1. BOREHOLES LOCATION AND DESCRIPTION OF LOG SAMPLE OF AL BUTAYN AREA

In the Al Butayn area there are six boreholes (BH01 to BH06) were drilled at a depth of 9 to 15m in the (Figure 4.1) and the coordinates of the boreholes are shown in (Table 4.1). The Boreholes were distributed along the study area to identify sub-surface and horizontal and vertical variations as well as taking samples and conducting all the required analyzes to determine the natural and geotechnical properties of sub-surface soil.

From the analysis of the Boreholes, it was found that the subsurface relay in the layers area of the Al Butayn is characterized by the following:

Red mud deposits and red mud deposits with few sand characterize the numbers 1, 2 and 3, while white sand deposits or brown sand with red clay characterizes the upper parts. The middle area of the study area, which boreholes BH4 and BH5 contains red clay; sometimes it is gray in color with some sand and may appear in the form of sand deposits with a little clay. The BH6, located in the third area, is characterized by the presence of sand deposits with gravel and no mud deposits.

However, some sand may appear mixed with mud deposits at the top. The percentage of gravel ranged from 0.3% to 21.6%. The percentage of sand ranged from 29.8% to 96.8%. The percentage of silt ranged from 0 to 17.3% and the clay percentage ranged from 0 to 71.7%. The value of the Cc gradient is between 0.02 and 0.6 and the Cu coefficient varies from 7.42 to 6.91. The LL liquidity limit, the PL plasticity unit, and the PI plasticity index ranged from 0 to 55%, from 0 to 29% and from 0 to 26%, respectively.

The classification of the USCS soil system has the following characteristics: clay with sand (CL), sand with mud or mixture of sand and silt (SC), poor sand sorting (SP), clay with sand that has the potential to explode (CH)), Sand with silt and gravel (SM).stratigraphy in the Al Butayn region is shown in (Figure 4.2) and (Table 4.2).

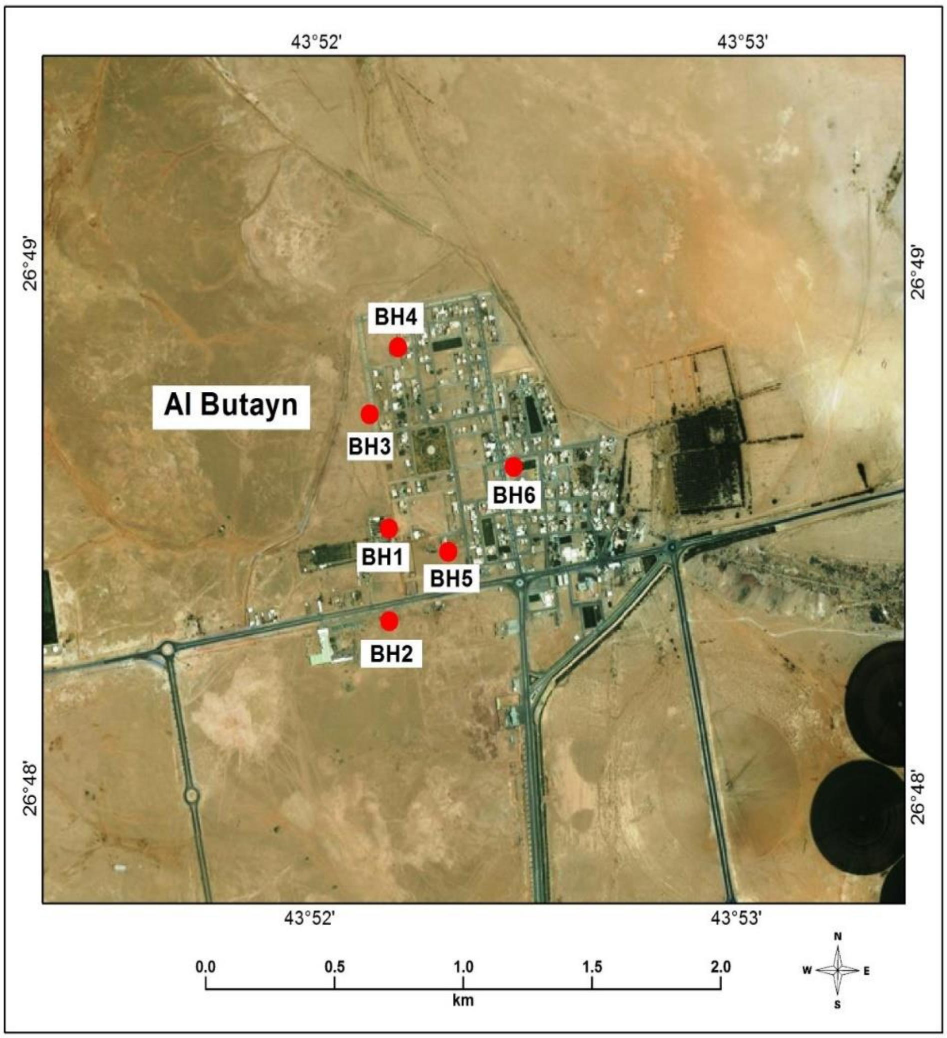


Figure 4.1 A map showing the distribution of boreholes in Al Butayn area

Table 4.1 Coordinates of boreholes in Al Butayn area

BH.No	Depth of Drilling **(m)**	Al Butayn area Borehole location	
		longitude	Latitude
BH1	9	43° 52' 10.7" E	26° 48' 30.1" N
BH2	10	43° 52' 10.9" E	26° 48' **1**9.5" N
BH3	9	43° 52' 7.86" E	26° 48' 43.1" N
BH4	9	43° 52' **11.8**" E	26° 48' 50.8" N
BH5	9	43° 52' 19.1" E	26° 48' 27.5" N
BH6	15	43° 52' 28.2" E	26° 48' 37.3" N

Figure 4.2 The stratigraphic of the layers in the Al Butayn area.

Table 4.2 Sedimentary Sequences in the boreholes and Properties of the Rock Classes in the Al Butayn area.

Borehole No .	Discreption	Discreption	UCS (MPa)	RE C%	RQD %
BH1	0-1.5 Sand deposits and gravel	1.5-9m Red mud, High cracks	0	0	0
BH2	0-4.5 Sand deposits and gravel and a little clay	4.5-10m Red mud, High cracks	0	0	0
BH3	0-1.5 red mud and sand with little gravel	1.5-9m Red mud, High cracks	0	0	0
BH4	0-3 Sand deposits and gravel 3-4.5 Sand deposits and gravel and a little clay	4.5-9m grayish green Mud High cracks	0	0	0
BH5	0-1.5 Sand deposits and gravel 1.5-3 Sand deposits and gravel and a little clay	3-9m Red mud, High cracks	0	0	0
BH6	0-15 Sand deposits and gravel	non	0	0	0

Geotechnical properties of the mud layer in the Al Butayn area study by sampling from the subsurface layers are show the results as following:

1- The results of the analysis of the degree of the shrinkage limit of soil and mud according to the Atterberg limits of the following:

The percentage of clay in the samples ranges from 0 to 71.7% (low to high-feces).

The liquidity limit for soil and rock samples ranges from 28% to 57% (low to high).

The Plasticity Index in soil and clay rock samples ranges from 9% to 26%, from low to moderate to high.

2. Results of the free-Swell test were unrestrained swell, showed that the value of soil and clay samples ranged from 0.45 to 1.32, from low to moderate to high.

3 - By testing the Swell Overburden Test, the undisturbed samples of mud rocks found that the value ranges from 2.14 to 2.7 kg/cm2 and these values are very high and indicate that the mud soil is expansive soil.

4.2. BOREHOLES LOCATION AND DESCRIPTION OF LOG SAMPLE OF MUDARRAJ AREA

The Mudarraj area there are six boreholes (BH01 to BH06) were drilled at a depth of 9-12 m in the study area (Figure 4.3) and the coordinates of the boreholes are shown in (Table 4.3).The boreholes were distributed along the study area to identify the subsurface and their horizontal and vertical changes, as well as sampling and conducting all the required analyzes to determine the natural and geotechnical properties of the subsurface soil.From the analysis of the boreholes in the study area, it was found that the subsurface rotation in the layers area of the Mudarraj is characterized by the following:

Most of the subsurface contain clay rocks ranging from red to gray to green. They appear at a depth of 1.5 meters and sometimes are 6 meters deep and continue until the end of the boreholes. The upper parts are composed of sand deposits that take many colors including red, white, brown and yellow mixed with mud and gravel deposits. The percentage of gravel in the sediment and clay rocks of the area of the Mudarraj area ranged from 0 to 41.4%, the sand percentage ranged from 1.3% to 93.4%, the silt percentage ranged from 1.6% to 33.2% and the clay percentage ranged from 1.6% to 88.3%. The Cc gradient value ranges from 2.88 to 16.67 and the Cu coefficient is from 0.41 to 1.12. The liquidity limit (LL), plasticity (PL) and plasticity index (PI) were found to vary from 0 to 57%, from 0 to 29% and from 0 to 31%, respectively. With the USCS classification, the soil is characterized by the following names:

Sand with mud or mixture of sand and silt (SC), poor sand sorting (SP), clay with sand (CH), gravel with silt and sand (GM). Stratigraphy in the Mudarraj region is shown in (Figure 4.4).

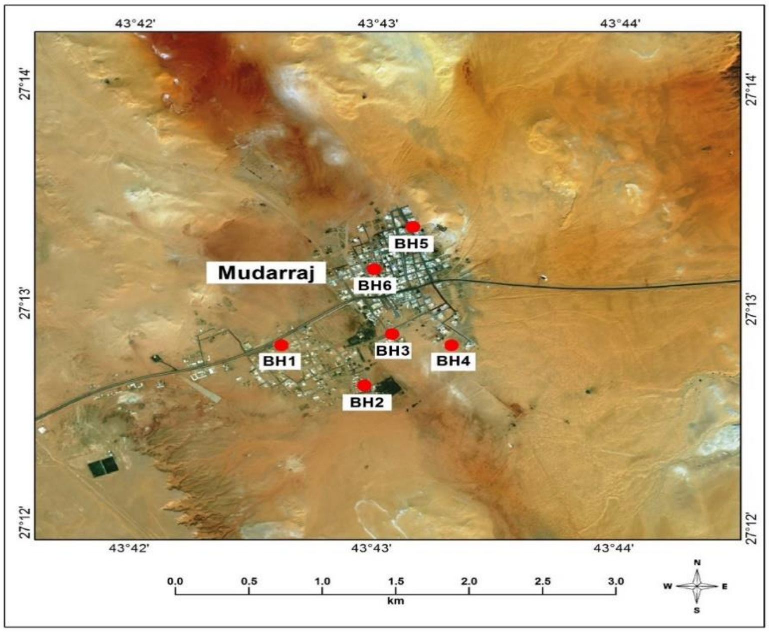


Figure 4.3 A map showing the distribution of boreholes in Mudarraj area

Table 4.3 Coordinates of boreholes in Mudarraj area.

BH.No	Depth of Drilling **(m)**	Area Borehole location	
		longitude	Latitude
BH1	10	43° 42' 37.14" E	27° 12' 49" N
BH2	9	43° 42' 57.8" E	27° 12' 38.2" N
BH3	12	43° 43' 4.5" E	27° 12' 52.3" N
BH4	9	43° 43' 19.2" E	27° 12' 49.4" N
BH5	9	43° 43' 9.3" E	27° 13' 21.7" N
BH6	9	43° 42' 59.8" E	27° 13' 10" N

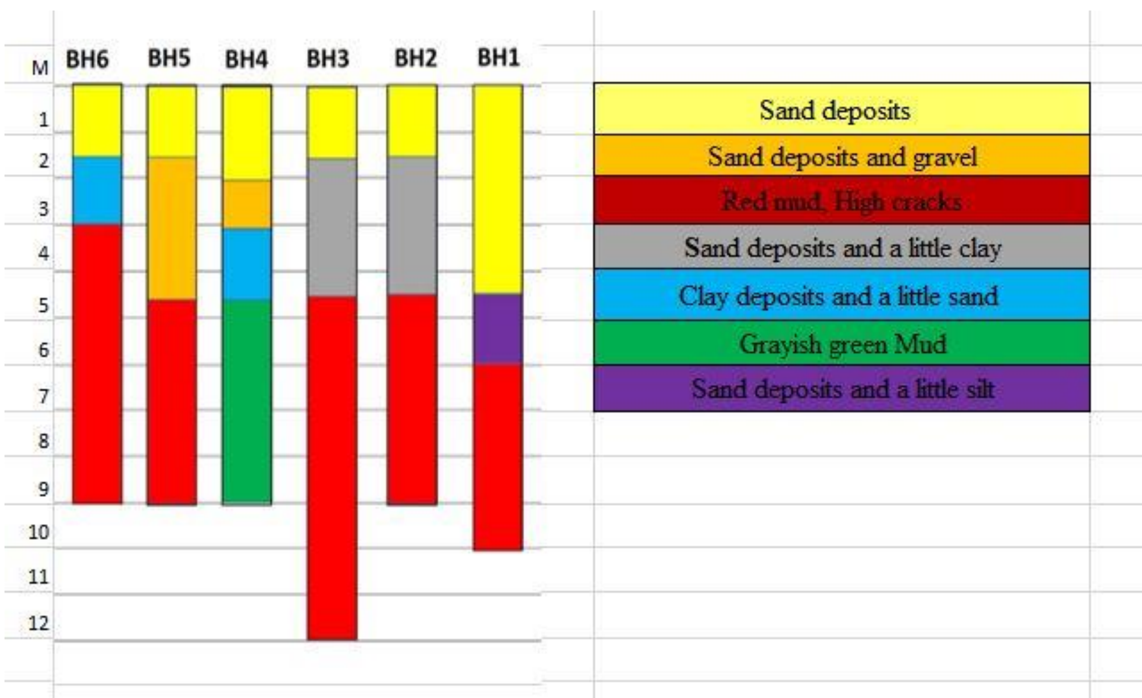


Figure 4.4 The stratigraphic of the layers in the Mudarraj area.

Table 4.4 Sedimentary Sequences in the boreholes and Properties of the Rock Classes in the Mudarraj area.

Borehole . **No**	Discreption	Discreption	UCS (MPa)	REC %	RQD %
BH1	0-4.5 Sand deposits 4.5-6 Sand deposits and a little silt	6-10m Red mud, High cracks	0	0	0
BH2	0-1.5 Sand deposits 1.5-4.5 Sand deposits and a little clay	4.5-9m Red mud, High cracks	0	0	0
BH3	0-1.5 Sand deposits 1.5-4.5 Sand deposits and a little clay	4.5-12m Red mud, High cracks	0	0	0
BH4	0-2 Sand deposits 2-3 Sand deposits and gravel 3-4.5 clay deposits and a little sand	4.5-9m grayish green Mud High cracks	0	0	0
BH5	0-1.5 Sand deposits 1.5-4.5 Sand deposits and gravel	4.5-9m Red mud, High cracks	0	0	0
BH6	0-15 Sand deposits 1.5-3 clay deposits and a little sand	3-9m Red mud, High cracks	0	0	0

Geotechnical properties of the mud layer in the Mudarraj area study by sampling from the subsurface layers are show the results as following:

1. For the analysis of the degree of swelling according to the Aterberge limits found:

a) The percentage of clay in soil and clay rock samples ranging from 1.6% to 88.3%, from low to high parasitic outbreak.

B) The liquidity limit for soil samples and mud rocks ranges from 51% to 57% and the soil is classified as highly polluted.

C) Plasticity coefficient in soil and clay rock samples ranges from 25% to 31% and is characterized as Moderate to high.

2. For the free-Swell test, the results of the unrestricted swell tests were used for the classification of the soil. The results showed that the free- Swell value of soil and clay samples ranged from 0.13 to 2.18, from Low to high.

3 - The test of the Swell Overburden Test of mud rocks found that the value ranges from 2.14 to 3.16 Kg/cm2 and these values are very high and indicate that the soil clay muddy soil.

4.3. BOREHOLES LOCATION AND DESCRIPTION OF LOG SAMPLE OF TURUBAH AREA

In the Turubah area there are six boreholes (BH14 to BH19) (Figure 4.5) were drilled at a depth of 15m in the study area. The coordinates of the boreholes are shown in (Table 4.5).The boreholes were distributed along the area of the study to identify the subsurface and their horizontal and vertical changes, as well as taking the samples and conducting all the analyzes required to know the natural and geotechnical properties of the sub-surface soil.

From the analysis of the boreholes in the study area, it found that the subsurface rotation in the layers area of the Turubah is characterized by the following:

The analysis of the boreholes revealed that the subterranean sequence at the earth cracks site in Turubah is characterized by the boreholes BH14,BH 15, BH16, BH17, BH18 and BH19 contain sedimentary layers of gravel deposits with sand, clay with sand, sand with silt, sand, , which is composed of limestone, and sandstone.

Sediment layer is a granular sediment in some of the boreholes, consisting of gravel with poor graded sand, sand poor graded, deposits of silt and clay with sand, which are as follows:

A) Clay with sand and a color from red to green, limits are given as follows, liquid limit values ranging from (45-46), plastic limit values (25-26), and elasticity coefficient Plastic index (19-21) According to the USCS division, these sediments take the symbol CL.

B) Sand with mud, the values for the limits are given as follows: Liquid limit values ranging from 14-23, plastic limit values ranging from 5-11, 8-12) According to the USCS division, these sediments take the symbol SC,

C) Sand with mud, silt, values for the limits as follows: Liquid limit (22), plastic limit (15) and plastic index (7). According to the USCS division, these sediments take the symbol SC-SM.

D) Sand with silt, values for the limits as follows: Liquid limit (56), Plastic limit (35) and Plastic index (21). According to the USCS division, these sediments take the symbol MH.

2) A rock layer characterized by the following:

A) The mud rocks brown color, very weak, highly cracks, ranges from 0 to 70, which is very poor to reasonable. The ratio of samples recovery ranges from 60% to 100%. The strength of the rocks (UCS) ranges between 0-6.1. MPa.

The sub-surface mudstone rocks gave the Swell Overburden Test ranging from 0.023 kg / cm2 and 0.82 kg / cm 2,

B) Sandstone rocks are characterized by a small grains and yellowish color, sandstone quality is as zero, which is very poor, the recovery of samples ranges from 60% to 80%, the rock strength is very weak.

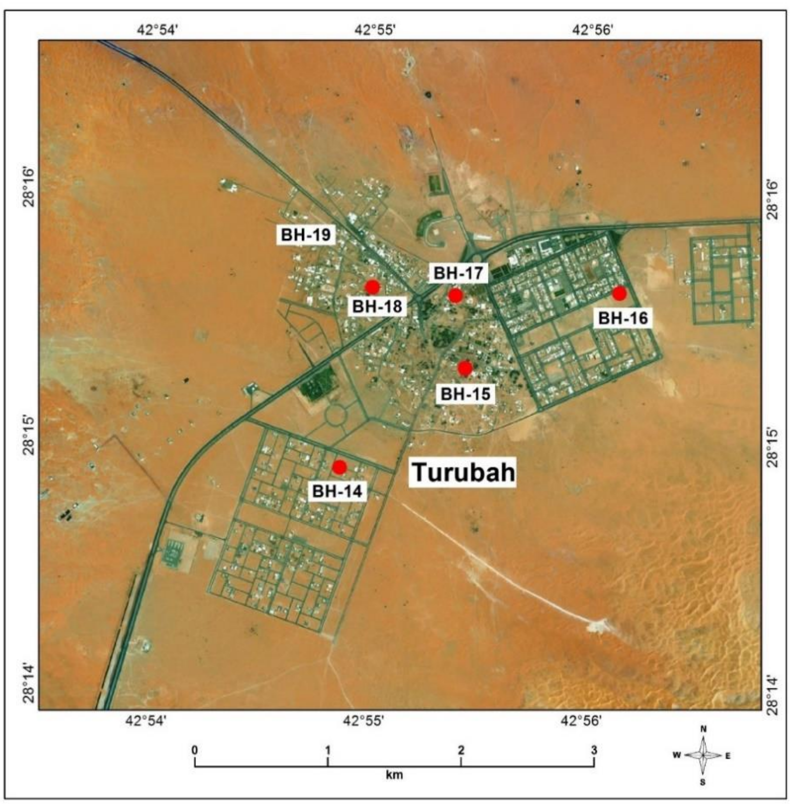


Figure 4.5 A map showing the distribution of boreholes in Turubah area.

Table 4.5 Coordinates of boreholes in Turubah area

BH.No	Depth of Drilling **(m)**	Area Borehole location	
		longitude	Latitude
BH14	15	42° 54' 52.2" E	28° 14' 53.4" N
BH15	15	42° 55' 26.4" E	28° 15' 17.9" N
BH16	15	42° 56' 8.6" E	28° 15' 36.6" N
BH17	15	42° 55' 23.4" E	28° 15' 35.4" N
BH18	15	42° 55' 0.5" E	28° 15' 37.9" N
BH19	15	42° 45' 44.7" E	28° 15' 34.7" N

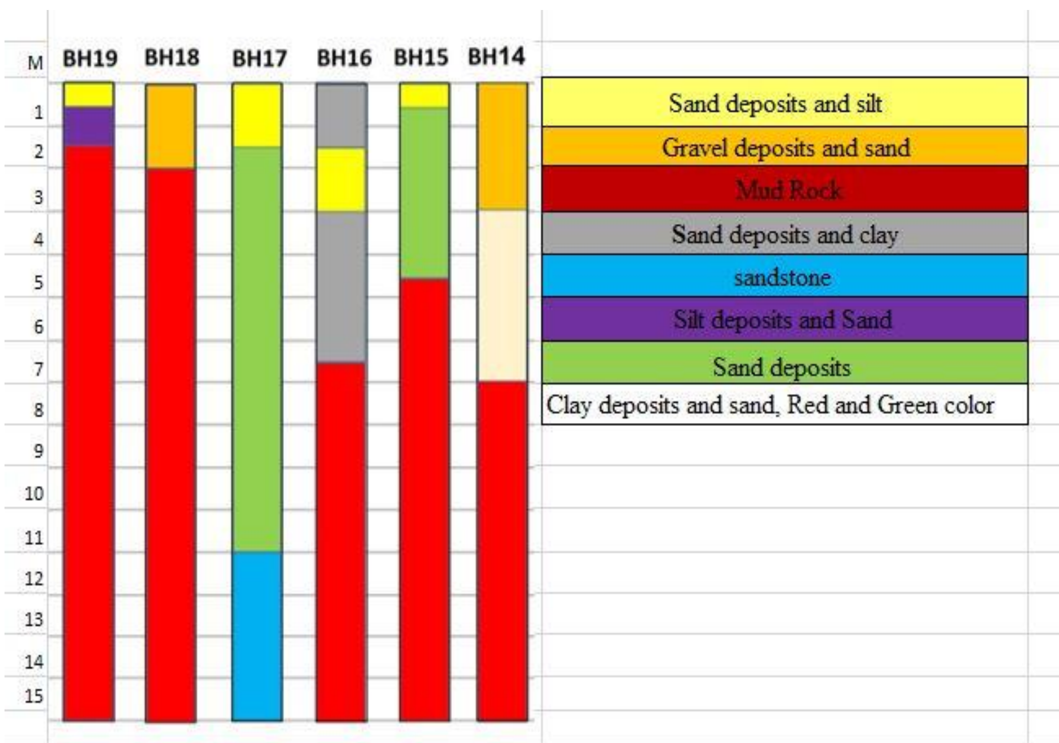


Figure 4.6 The stratigraphic of the layers in the Turubah area.

Table 4.6 Sedimentary Sequences in the boreholes and Properties of the Rock Classes in the Turubah area.

Borehole No .	Discreption	Discreption	UCS (MPa)	REC %	RQD %
BH14	0-3m Gravel deposits and sand 3-7m Clay deposits and sand, Red and Green color	7-15m brown mud rock, High cracks	4-6	70-95	0
BH15	0-0.5m Sand deposits and silt 0.5-4.5m Sand deposits	4.5-15m brown mud rock, High cracks, moderately weather.	2-6	60-90	70
BH16	0-1.5m Sand deposits and clay 1.5-3m Sand deposits and silt. 3-6.5m Sand deposits and clay	6.5-15m brown mud rock, High cracks and low weather.	4.6-4.8	100	0
BH17	0-1.5m Sand deposits and silt 1.5-11m Sand deposits.	11-15myellow sandstone, fine grain.	0	60-80	0
BH18	0-2m Gravel deposits and sand.	2-15m brown mud rock, High cracks	2.8-6.1	70-100	5
BH19	0-0.5 Sand, slit, and clay deposits. 0.5-1.5 sand deposits and silt.	1.5-15m brown mud rock, High cracks, low weather.	4.2-5	90-100	17

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

Ground cracks appeared in the study areas of Al Butayn, Mudarraj, and Turubah. The studies of cracks and geology of the region, including the investigation and analysis of the samples revealed the following:

The presence of some geological structures in the region (desiccation cracks), have a clear impact on the emergence of cracks, as in the case of the area of Al Butayn.

The evolution of clay soils has a characteristic of swelling in the Mudarraj and Turubah.

Laboratory tests have shown that the mud deposits have the ability to swell. This occurs when water leaks down from either houses or surface water and is absorbed. There are many reasons for cracks in the areas of study.

5.1.1. Causes for Cracks in the Al Butayn Area.

1- The results of geotechnical studies showed the presence of sediments and clay rocks scattered in the area, which indicates their susceptibility to swelling, especially clay rocks located beneath the surface sedimentary layers, where the values of swelling pressure reached about 2.7kg/cm2, which is found at depths close to the surface, especially since most buildings. The area is excavated approximately 2 m deep or more to make foundations, which decreases the distance between the foundation and the layers of mud.

2- Field studies showed that the central area of the Al Butayn area, with a width of about 300 m, takes the direction of northwest to southeast and is characterized by the existence of a range of cracks, an additional role in the emergence of cracks in this way in the region.

3- The mud deposits are concentrated to a depth of 10 m from the ground in the western area of the town. The eastern side is dominated by sandy soil with little clay.

4- The mud deposits are characterized by red to gray, and the percentage of mud in these sediments reached 71.7 percent.

5.1.2. Causes for Cracks in the Mudarraj Area.

1- The results of the geotechnical studies showed the presence of sediments and clay rocks, scattered in the area, which is a strong indicator of their ability to swell, especially in the clay rocks located below the sedimentary layers of the surface.

2- The values of swelling pressure are about 3.16 kg/cm2, which are found at depths close to the surface, especially since most buildings in the area excavate to a depth of 2 m or more to place the foundations increasing their proximity to the layers of the mud.

3- Mud deposits cover most of the runway town to a depth of 10 m from the ground level. Clay layers can be distinguished by their colors ranging from red to gray and green. Mud makes up 88.3% of the deposits.

5.1.3. Causes for Cracks in the Turubah Area.

1- There is no evidence of geological structures in the region. Geological data showed that there were no close fissures in the area.

2- The presence of mud deposits in the area of the member of Magma and the Jilh formation (TRJ) of the two is characterized by clay rocks that have the ability to swell.

3- The results of geotechnical studies showed the presence of sediments and clay rocks scattered in the area, some of which have the ability to swell. The results of Waterberg limits the susceptibility of the soil containing clay sediments to the addition.

4- The value ranged from 0.023 to 0.82 kg/cm2 and is believed to be the main cause of cracks.

5.2. RECOMMENDATIONS

There are many global options and proposals for treating soils and reducing their adverse effects on their structures (Das, 1999 - Dhowian et. Al., 1990 - Humaid et al., 1416), but vary in efficiency depending on site conditions. These methods include the following:

1. Replace swelling soil with a graded sandy soil (an appropriate graded sandy soil mixed with gravel and containing some soft soil) and no clay. This method can be practical if the soil is spreadable close to the ground. They must have a small thickness so that they can be replaced with better soil. The sandy soil is well compacted.

2. Changing the geological characteristics of the clay soil layer.

- Pre-hydration by submerging the soil with water and allowing it to swell before the beginning of construction. The humidification process can take a long time because the clay has a low permeability. When the area is dry, there may be a dry process immediately after the period of humidification, causing similar problems, especially at the edges of buildings. Therefore, this method is not recommended in the study area.

- Preventing the leakage of water into the soil on which houses are built by means of good insulation such as metal panels or barriers. This method cannot be applied in the region in its current state because there is no sewage network.

- Chemical treatment of swell able soil that change its natural and engineering properties. This is done by mixing clay soil with hydrated lime or cement and can be done to depths of 7 to 10 m. This proposal may be applicable to the study area but requires studying soil properties after mixing is completed at different intervals.

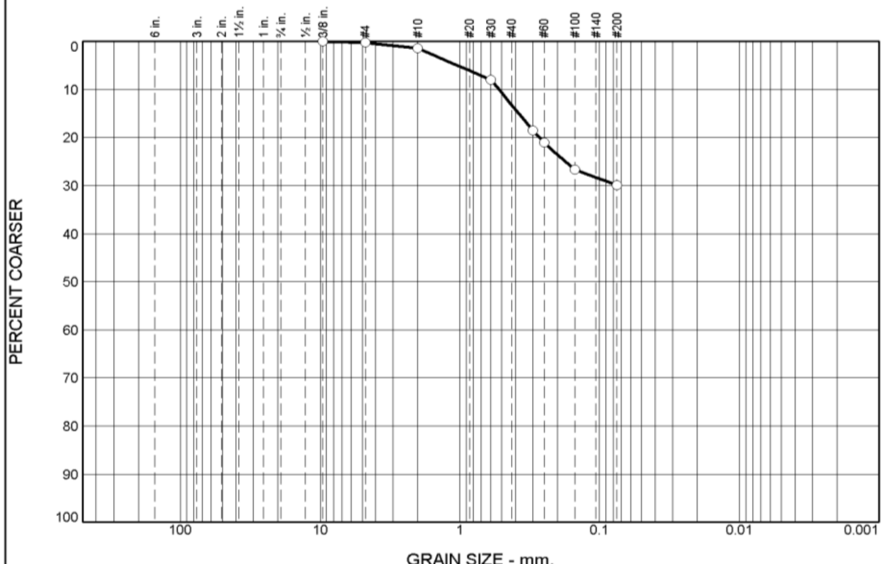
3- The design of the structures should be in accordance with the values of the expansion pressure where the highest value of the swelling pressure in the mud was observed. It is recommended that the foundation effort be greater than the value of the swelling pressure in each town. This is necessary in large buildings in the region such as schools and government departments.

4- It shall be necessary examine each establishment constructed in the area up to a depth of 10 m in order to know whether or not there are mud deposits and at depth they occur. If clay deposits are present, samples should be taken to determine their geotechnical properties and the amount of clay pressure they possess.

APPENDIX

PARTICLE SIZE DISTRIBUTION REPORT

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.3	1.1	11.8	16.7	11.2	58.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.7		
#10	98.6		
#30	91.9		
#50	81.5		
#60	78.9		
#100	73.3		
#200	70.1		

* (no specification provided)

Material Description

sandy lean clay

Atterberg Limits (ASTM D 4318)

PL= 25 LL= 38 PI= 13

Classification

USCS= CL AASHTO= A-6(8)

Coefficients

D_{85}= 0.3784 D_{60}= 0.0066 D_{50}= 0.0010
D_{30}= D_{15}= D_{10}=
C_u= C_c=

Date Tested: 1/7/2008 **Tested By:** M.BOKHARI

Remarks

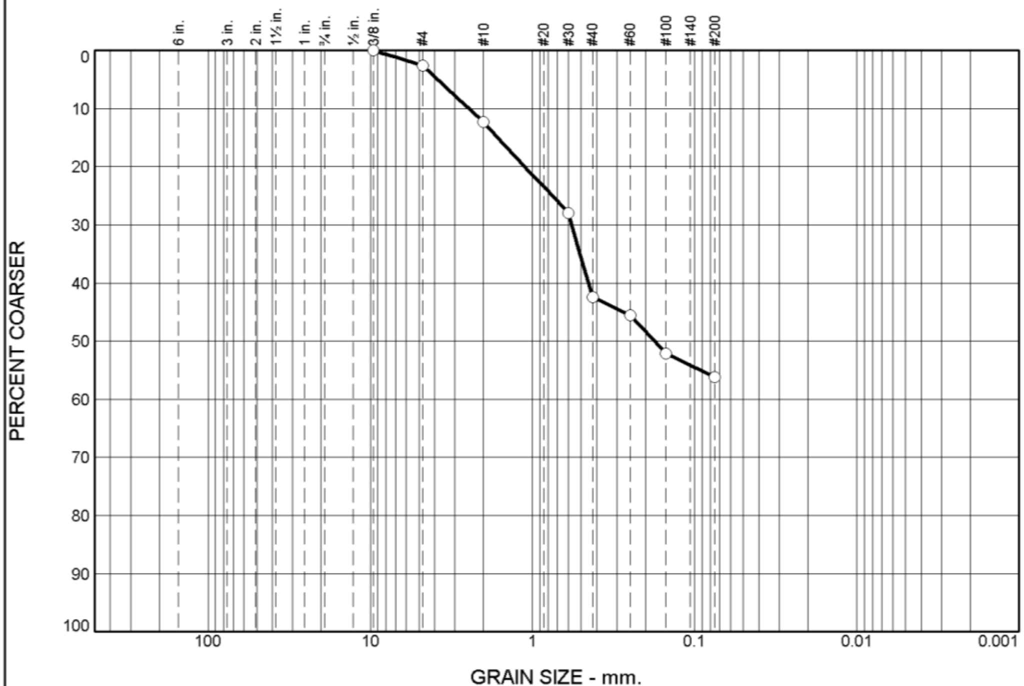
F.M.=0.59

Sample No.: BB1 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 6 m
Checked By: K.ALAHMADI **Title:**

Saudi Geological Survey / Kingdom of Saudi Arabia	Client: saudi geological survey Project: evalution of engineering properties of unstable soil at mudarraj and al butain Project No: 22020 Figure

AL Butayn , BB1 (0 - 6m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.6	9.8	30.0	13.8	7.9	35.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	97.4		
#10	87.6		
#30	72.0		
#40	57.6		
#60	54.5		
#100	47.9		
#200	43.8		

* (no specification provided)

Material Description

clayey sand

Atterberg Limits (ASTM D 4318)

PL= 19 LL= 28 PI= 9

Classification

USCS= SC AASHTO= A-4(1)

Coefficients

D_{85}= 1.6338 D_{60}= 0.4505 D_{50}= 0.1767
D_{30}= 0.0023 D_{15}= 0.0009 D_{10}= 0.0007
C_u= 609.13 C_c= 0.02

Date Tested: 1/7/2008 **Tested By:** M.BOKHARI

Remarks

F.M.=1.57

Sample No.: BB2 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 6 m
Checked By: K.ALAHMADI **Title:**

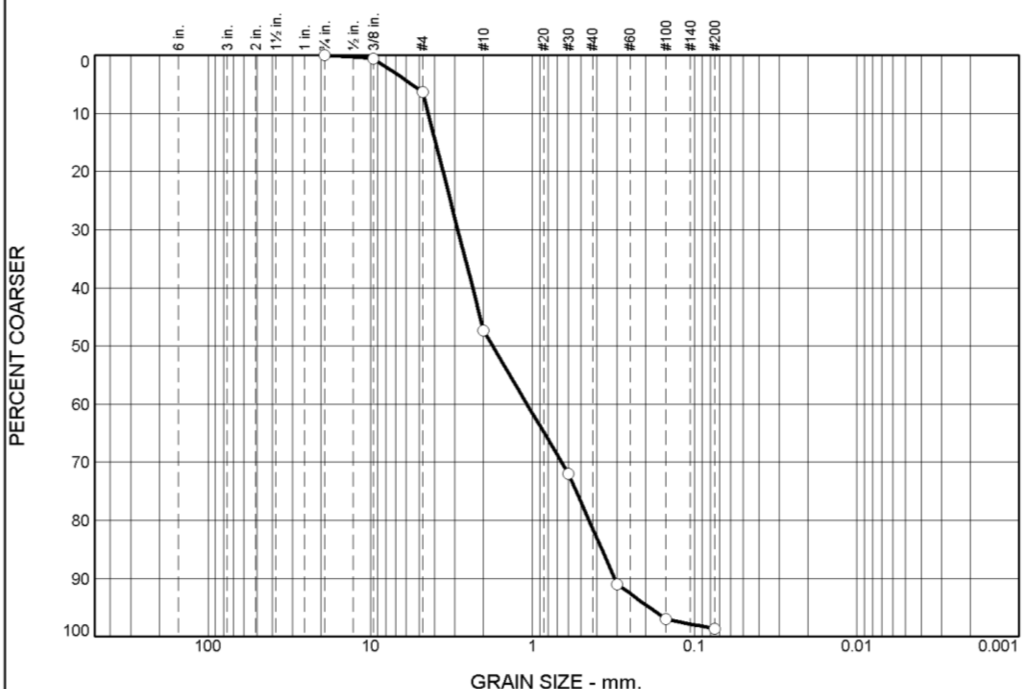
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

AL Butayn BB2 (0 - 6m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	6.3	41.0	34.1	17.2	1.4	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.375	99.5		
#4	93.7		
#10	52.7		
#30	28.0		
#50	9.0		
#100	3.0		
#200	1.4		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS= SP AASHTO= A-1-b

Coefficients

D_{85}= 3.9547 D_{60}= 2.3340 D_{50}= 1.7549
D_{30}= 0.6614 D_{15}= 0.3731 D_{10}= 0.3108
C_u= 7.51 C_c= 0.60

Date Tested: 1/7/2008 **Tested By:** M,BOKHARI

Remarks

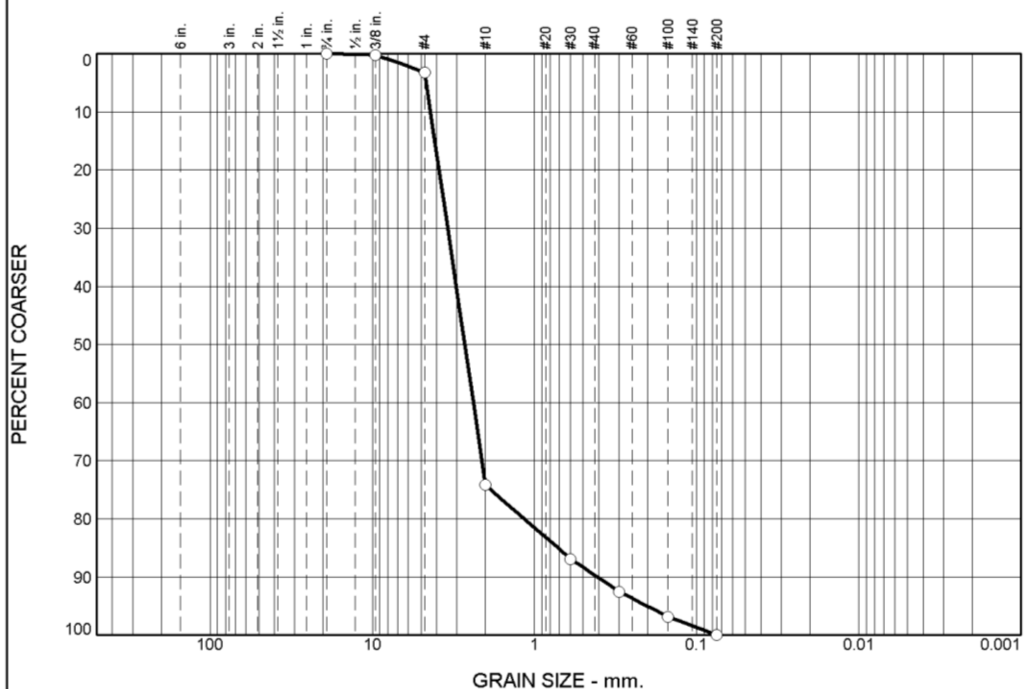
F.M.=3.64

Sample No.: BB3 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 3 m
Checked By: K.ALAHMADI **Title:**

Saudi Geological Survey Kingdom of Saudi Arabia	**Client:** saudi geological survey **Project:** evalution of engineering properties of unstable soil at mudarraj and al butain **Project No:** 22020 **Figure**

AL Butayn , BB3 (0 - 3m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	3.2	71.0	15.5	10.3	0.0	0.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.375	99.8		
#4	96.8		
#10	25.8		
#30	13.1		
#50	7.5		
#100	3.2		
#200	0.0		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS= SP AASHTO= A-1-a

Coefficients

D_{85}= 4.1126 D_{60}= 3.0330 D_{50}= 2.6852
D_{30}= 2.1046 D_{15}= 0.7174 D_{10}= 0.4089
C_u= 7.42 C_c= 3.57

Date Tested: 1/7/2008 **Tested By:** M.BOKHARI

Remarks

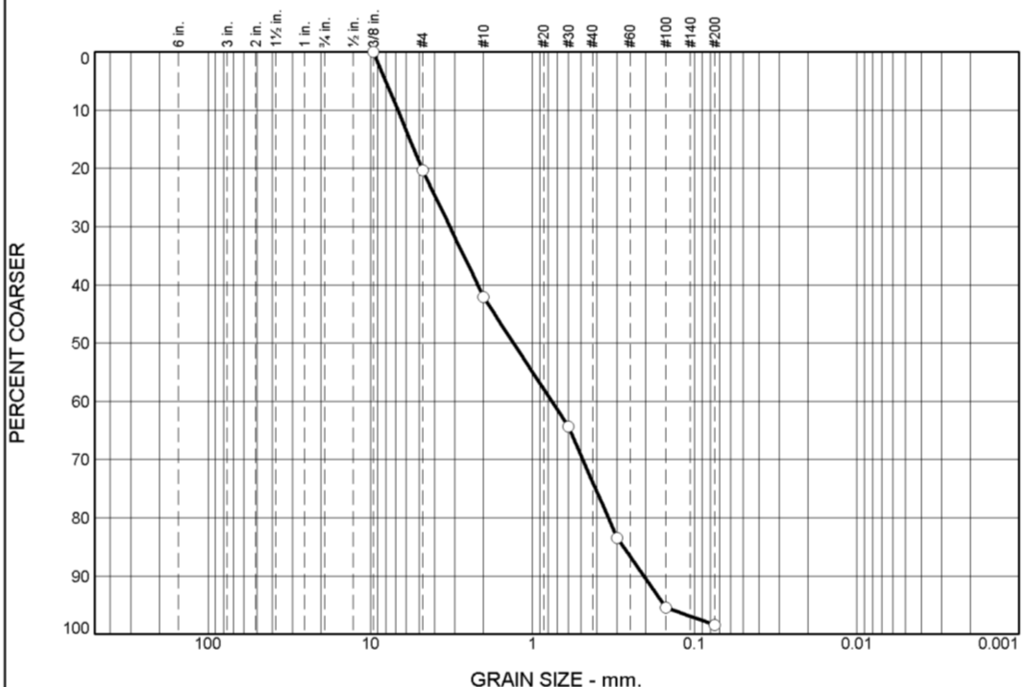
F.M.=4.20

Sample No.: BB3 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 3 - 6 m
Checked By: K.ALAHMADI **Title:**

Saudi Geological Survey	**Client:** saudi geological survey
	Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Kingdom of Saudi Arabia	**Project No:** 22020 **Figure**

AL Butayn , BB3 (3 - 6m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	20.3	21.8	31.8	24.5	1.6	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	79.7		
#10	57.9		
#30	35.6		
#50	16.5		
#100	4.6		
#200	1.6		

* (no specification provided)

Material Description

poorly graded sand with gravel

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS= SP AASHTO= A-1-b

Coefficients

D_{85}= 5.6939 D_{60}= 2.1721 D_{50}= 1.3038
D_{30}= 0.4893 D_{15}= 0.2753 D_{10}= 0.2058
C_u= 10.56 C_c= 0.54

Date Tested: 1/7/2008 **Tested By:** M.BOKHARI

Remarks

F.M.=3.53

Sample No.: BB4 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 3 m
Checked By: K.ALAHMADI **Title:**

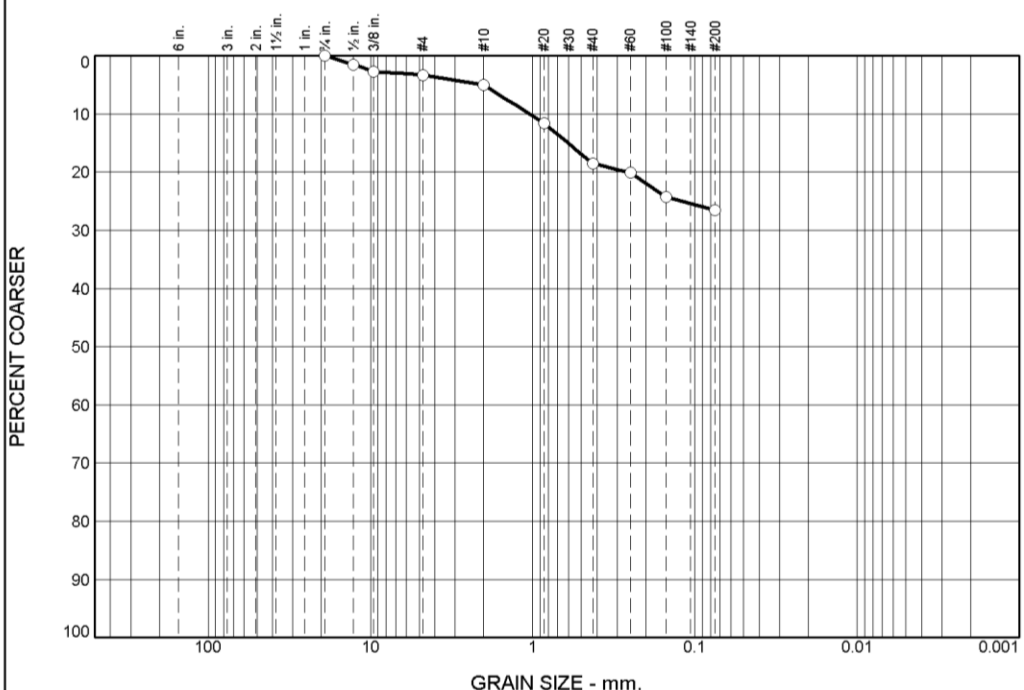
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

AL Butayn , BB4 (0 - 3m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	3.3	1.7	13.6	8.0	1.7	71.7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	98.5		
.375	97.3		
#4	96.7		
#10	95.0		
#20	88.4		
#40	81.4		
#60	79.9		
#100	75.7		
#200	73.4		

* (no specification provided)

Material Description

fat clay with sand

Atterberg Limits (ASTM D 4318)

PL= 29 LL= 55 PI= 26

Classification

USCS= CH AASHTO= A-7-6(20)

Coefficients

D_{85}= 0.6060 D_{60}= 0.0024 D_{50}= 0.0008
D_{30}= D_{15}= D_{10}=
C_u= C_c=

Date Tested: 1/7/2008 **Tested By:** M.BOKHARI

Remarks

F.M.=0.79

Sample No.: BB5 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 6 m
Checked By: K.ALAHMADI **Title:**

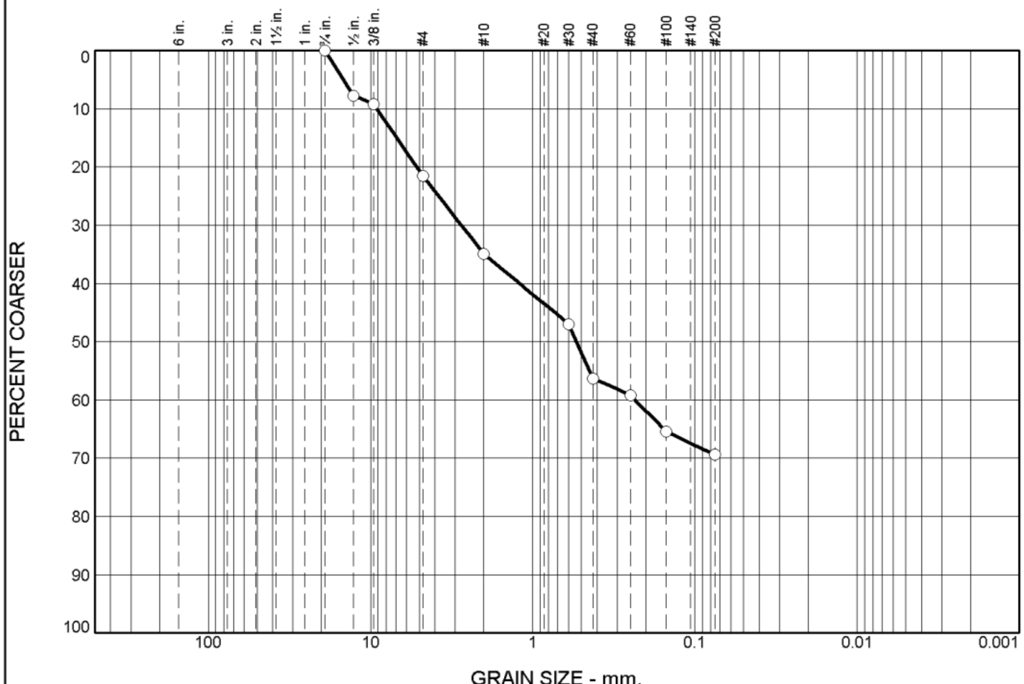
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

AL Butayn BB5 (0 - 6m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	21.6	13.3	21.4	13.1	17.3	13.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	92.2		
.375	90.7		
#4	78.4		
#10	65.1		
#30	53.1		
#40	43.7		
#60	40.9		
#100	34.5		
#200	30.6		

* (no specification provided)

Material Description

silty sand with gravel

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS= SM AASHTO= A-2-4(0)

Coefficients

D_{85}= 6.8847 D_{60}= 1.2012 D_{50}= 0.5361
D_{30}= 0.0323 D_{15}= 0.0057 D_{10}= 0.0035
C_u= 341.11 C_c= 0.25

Date Tested: 1/7/2008 **Tested By:** M.BOKHARI

Remarks

F.M.=2.74

Sample No.: BB6 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 3 - 6 m
Checked By: K. ALAHMADI **Title:**

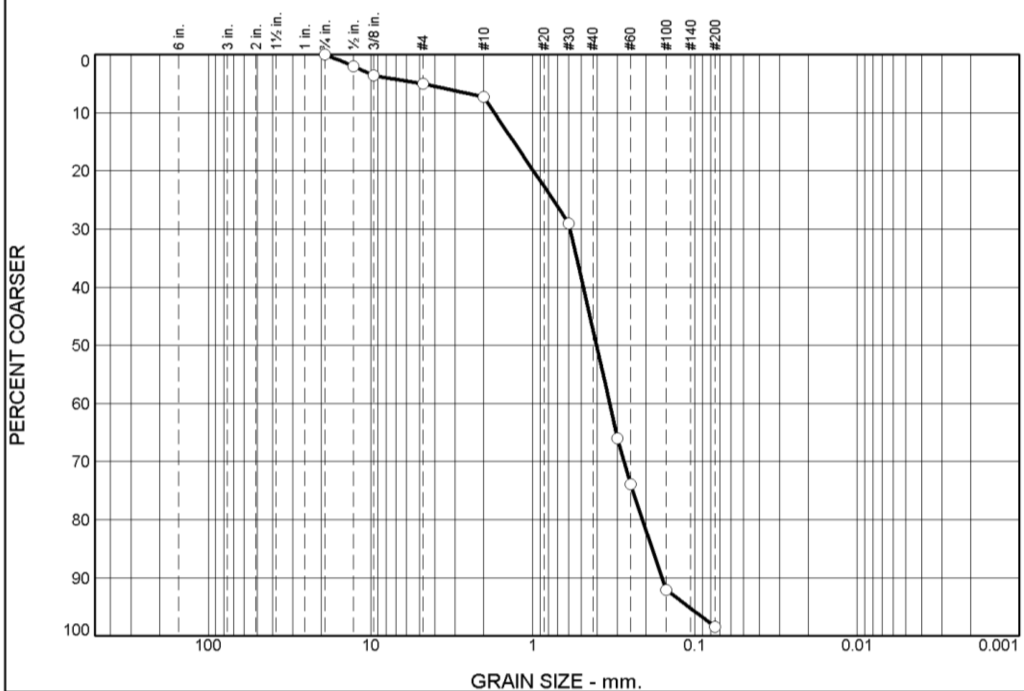
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

AL Butayn BB6 (3 - 6m),

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	5.0	2.3	40.1	51.0	1.6	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4	100.0		
1/2	98.0		
3/8	96.4		
#4	95.0		
#10	92.7		
#30	71.0		
#50	34.0		
#60	26.1		
#100	7.9		
#200	1.6		

* (no specification provided)

Material Description

red poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= No plastic **LL=** Non **PI=** Non

Classification

USCS= SP **AASHTO=** A-3

Coefficients

D_{85}= 1.3067 D_{60}= 0.4883 D_{50}= 0.4048
D_{30}= 0.2736 D_{15}= 0.1832 D_{10}= 0.1592
C_u= 3.07 C_c= 0.96

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=2.19

Sample No.: BM1 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 1.5 m
Checked By: Ahmadi K **Title:**

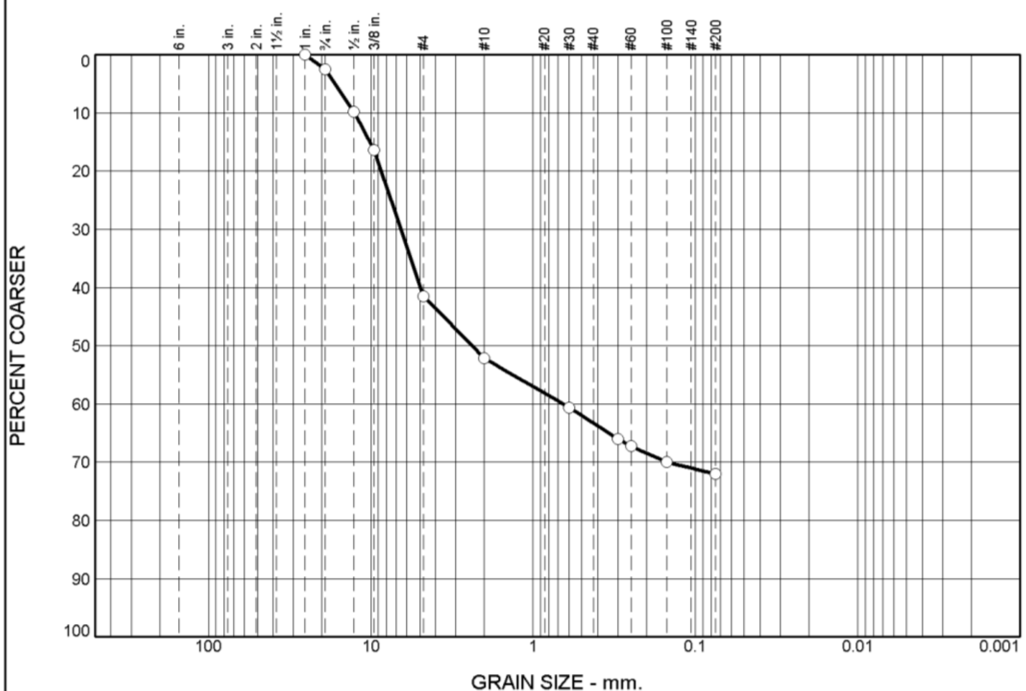
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM1 (0 - 1.5) m

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	2.6	38.8	10.7	11.2	8.7	28.0	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
3/4	97.4		
1/2	90.2		
3/8	83.6		
#4	58.6		
#10	47.9		
#30	39.4		
#50	34.0		
#60	32.8		
#100	30.0		
#200	28.0		

* (no specification provided)

Material Description

yelloesh silty gravel with sand

Atterberg Limits (ASTM D 4318)

PL= No plastic LL= Non PI= Non

Classification

USCS= GM AASHTO= A-2-4(0)

Coefficients

D_{85}= 10.1159 D_{60}= 4.9446 D_{50}= 2.3717
D_{30}= 0.1493 D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

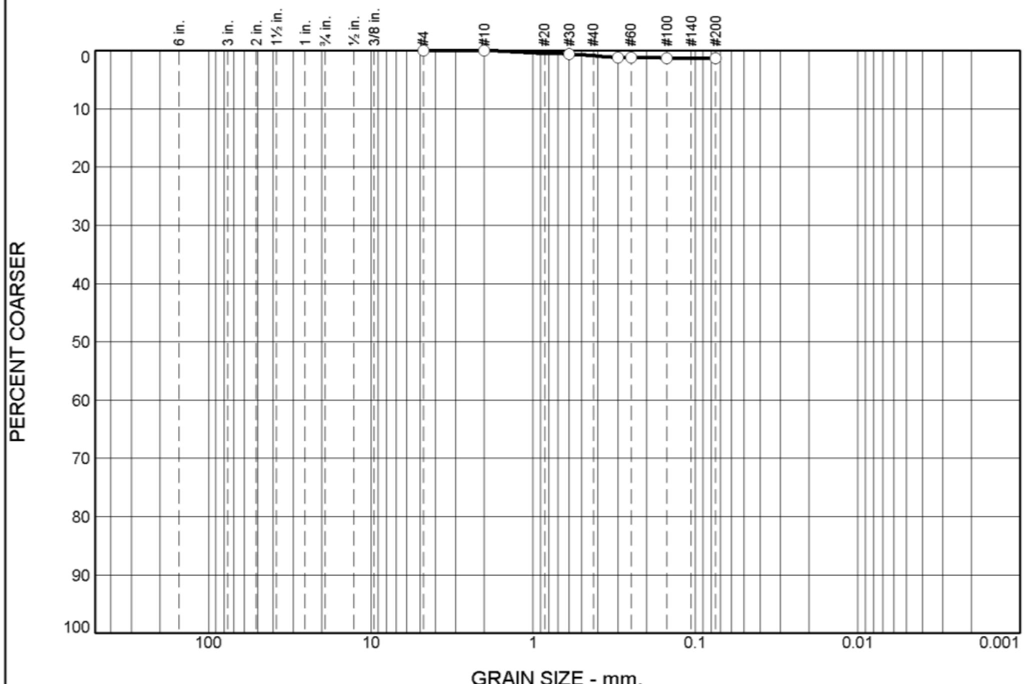
F.M.=3.63

Sample No.: BM1 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 1.5 - 5 m
Checked By: ahmadi K **Title:**

Saudi Geological Survey Kingdom of Saudi Arabia	**Client:** saudi geological survey **Project:** evalution of engineering properties of unstable soil at mudarraj and al butain **Project No:** 22020 **Figure**

Mudarraj BM1 (1.5 - 5 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.9	0.4	24.7	74.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#30	99.4		
#50	98.8		
#60	98.8		
#100	98.7		
#200	98.7		

* (no specification provided)

Material Description

fat clay

Atterberg Limits (ASTM D 4318)

PL= 26 LL= 57 PI= 31

Classification

USCS= CH AASHTO= A-7-6(36)

Coefficients

D_{85}= 0.0081 D_{60}= 0.0017 D_{50}= 0.0010
D_{30}= 0.0007 D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.03

Sample No.: BM1 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 8 - 10 m
Checked By: ahmadi K **Title:**

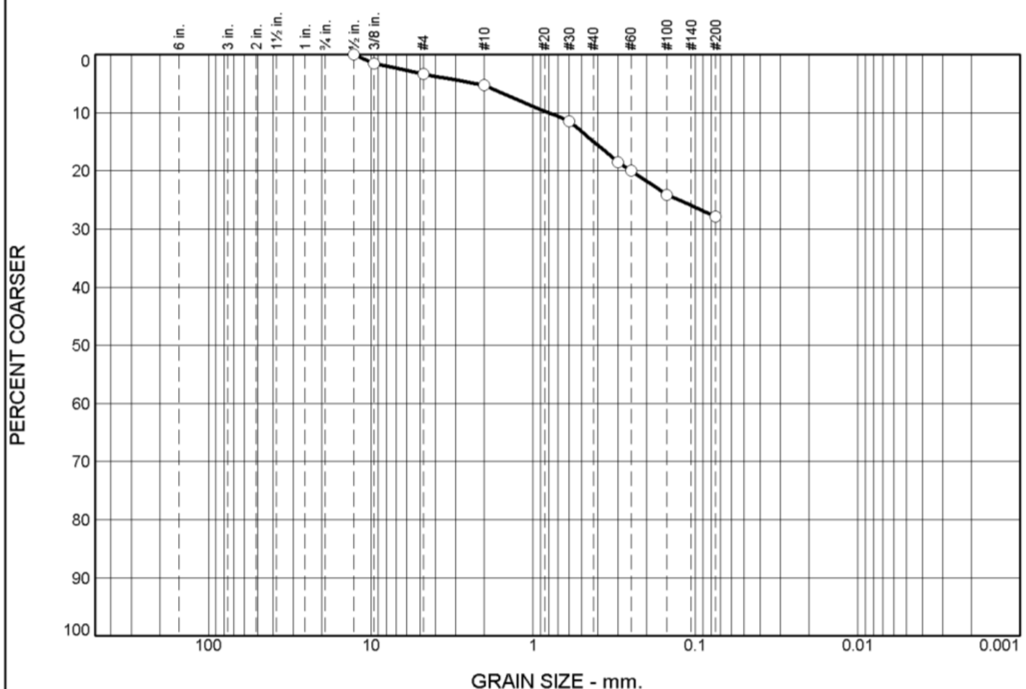
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM1 (8 - 10 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	3.3	2.0	9.7	12.8	14.8	57.4

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1/2	100.0		
3/8	98.5		
#4	96.7		
#10	94.7		
#30	88.5		
#50	81.5		
#60	80.0		
#100	75.9		
#200	72.2		

* (no specification provided)

Material Description

fat clay with sand

Atterberg Limits (ASTM D 4318)

PL= 27 LL= 53 PI= 26

Classification

USCS= CH AASHTO= A-7-6(19)

Coefficients

D_{85}= 0.4248 D_{60}= 0.0068 D_{50}= 0.0026
D_{30}= 0.0010 D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.72

Sample No.: BM2 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 3 m
Checked By: ahmadi K **Title:**

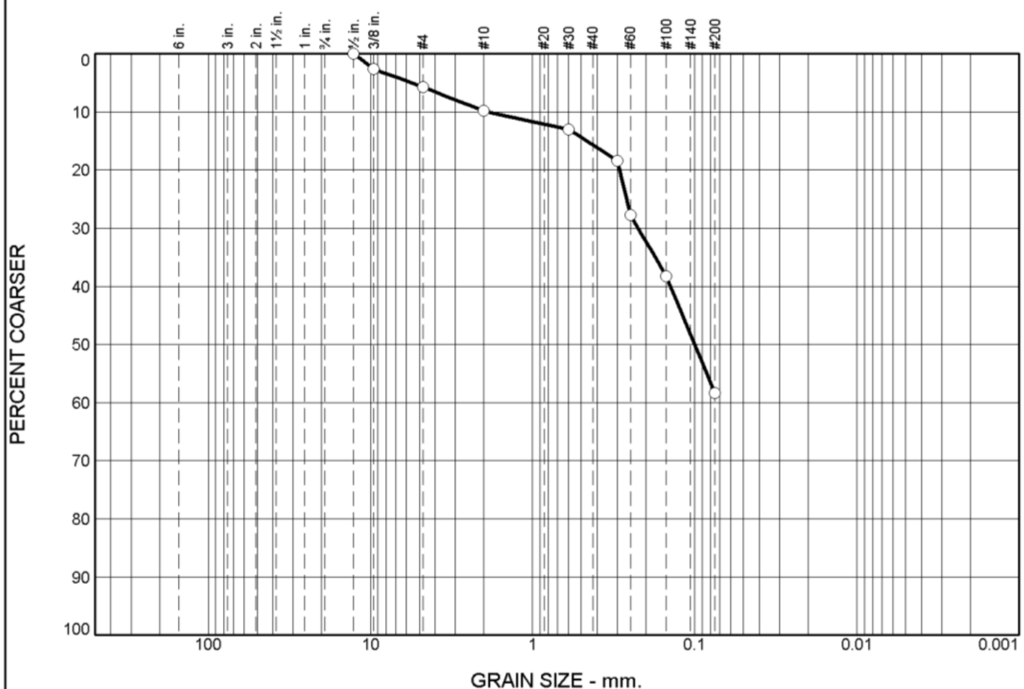
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM2 (0 - 3 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	5.7	4.2	5.8	42.7	10.3	31.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1/2	100.0		
3/8	97.4		
#4	94.3		
#10	90.1		
#30	87.0		
#50	81.6		
#60	72.2		
#100	61.8		
#200	41.6		

* (no specification provided)

Material Description

clayey sand

Atterberg Limits (ASTM D 4318)

PL= 25 LL= 51 PI= 26

Classification

USCS= SC AASHTO= A-7-6(6)

Coefficients

D_{85}= 0.4637 D_{60}= 0.1411 D_{50}= 0.1000
D_{30}= 0.0042 D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.98

Sample No.: BM2 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 3 - 5 m
Checked By: khiayiat A **Title:**

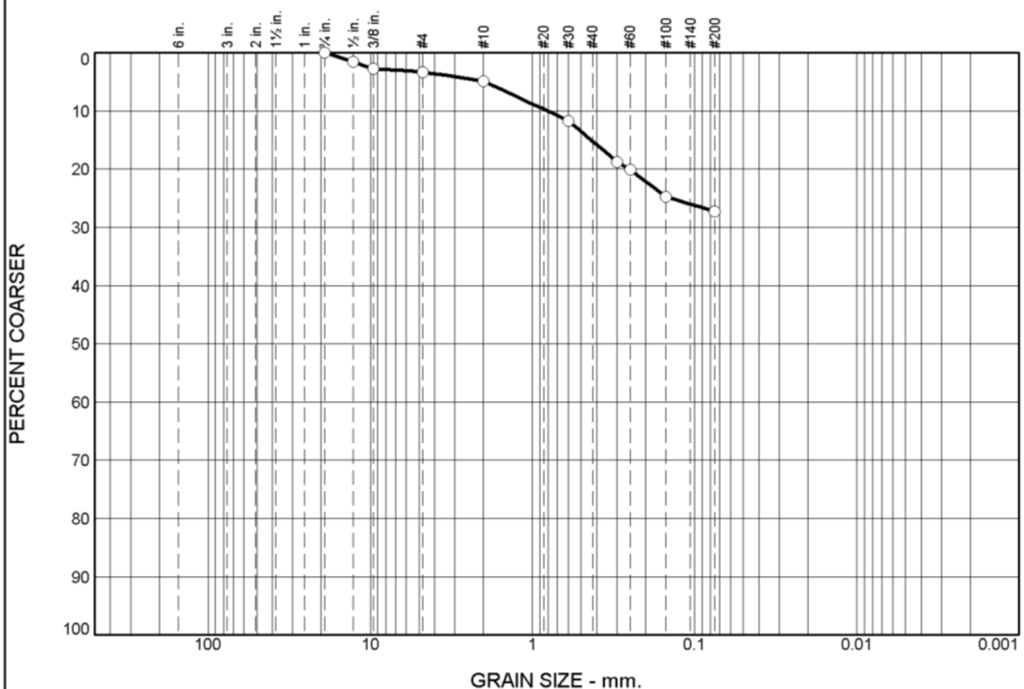
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM2 (3 - 5 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	3.3	1.5	10.4	12.1	16.5	56.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4	100.0		
1/2	98.5		
3/8	97.2		
#4	96.7		
#10	95.2		
#30	88.3		
#50	81.2		
#60	79.9		
#100	75.3		
#200	72.7		

* (no specification provided)

Material Description

fat clay with sand

Atterberg Limits (ASTM D 4318)

PL= 29 LL= 55 PI= 26

Classification

USCS= CH AASHTO= A-7-6(20)

Coefficients

D_{85}= 0.4339 D_{60}= 0.0068 D_{50}= 0.0033
D_{30}= 0.0010 D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.74

Sample No.: BM3 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 4 m
Checked By: ahmadi K **Title:**

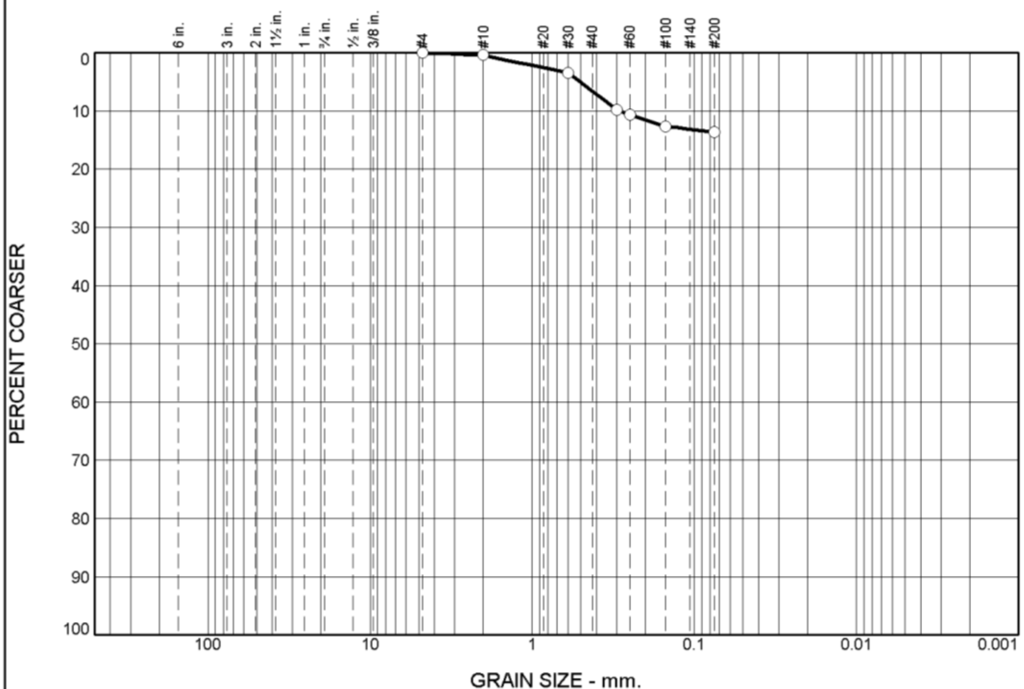
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM3 (0 - 4 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.4	6.2	7.1	13.9	72.4

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.6		
#30	96.5		
#50	90.2		
#60	89.3		
#100	87.4		
#200	86.3		

* (no specification provided)

Material Description

fat clay

Atterberg Limits (ASTM D 4318)

PL= 27 LL= 52 PI= 25

Classification

USCS= CH AASHTO= A-7-6(24)

Coefficients

D_{85}= 0.0118 D_{60}= 0.0016 D_{50}=
D_{30}= D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.28

Sample No.: BM3 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 4 - 6 m
Checked By: ahmadi K **Title:**

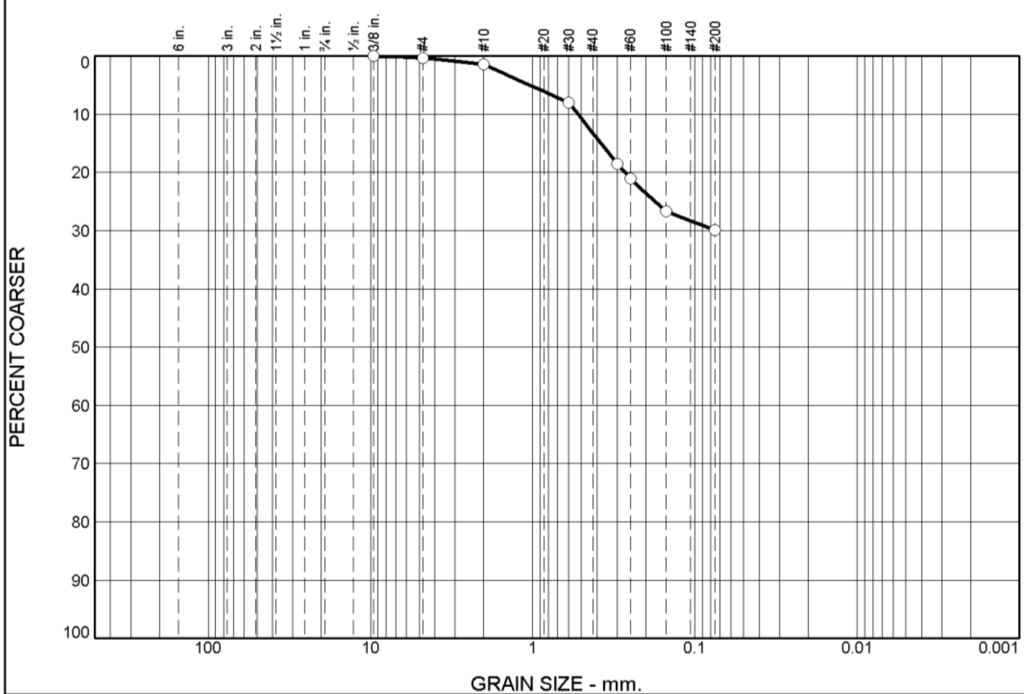
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM3 (4 - 6 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.3	1.1	11.8	16.7	14.0	56.1

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/8	100.0		
#4	99.7		
#10	98.6		
#30	92.0		
#50	81.5		
#60	78.9		
#100	73.3		
#200	70.1		

* (no specification provided)

Material Description

sandy fat clay

Atterberg Limits (ASTM D 4318)

PL= 26 LL= 51 PI= 25

Classification

USCS= CH AASHTO= A-7-6(17)

Coefficients

D_{85}= 0.3785 D_{60}= 0.0092 D_{50}= 0.0023
D_{30}= 0.0009 D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.59

Sample No.: BM4 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 4 - 6 m
Checked By: kiayait A **Title:**

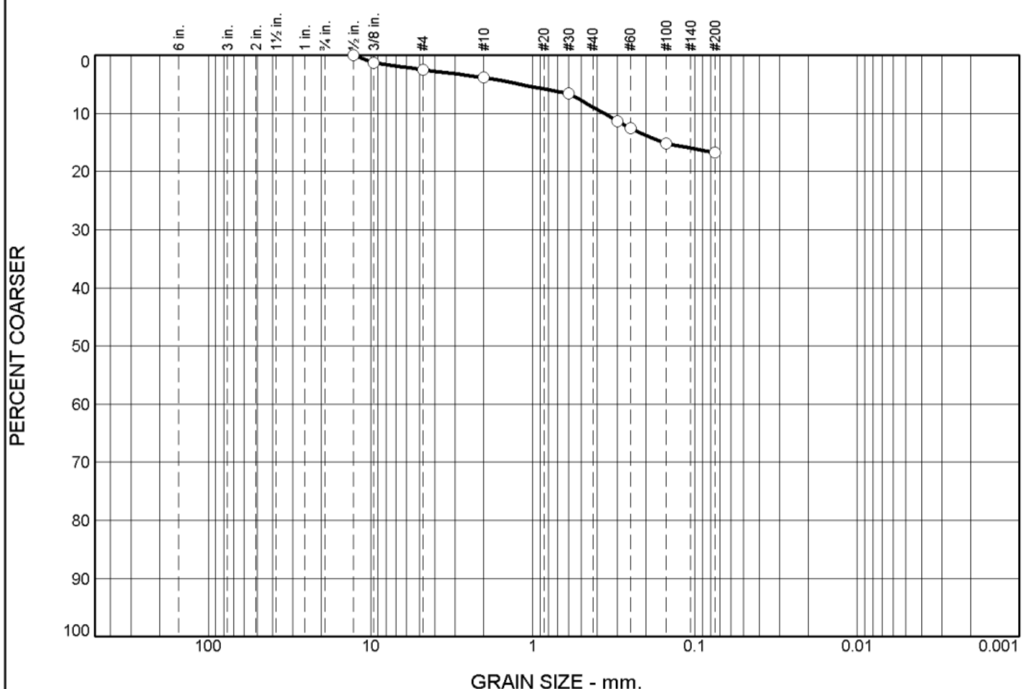
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM4 (4 - 6 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.5	1.3	5.2	7.8	33.2	50.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1/2	100.0		
3/8	98.7		
#4	97.5		
#10	96.2		
#30	93.4		
#50	88.7		
#60	87.4		
#100	84.8		
#200	83.2		

* (no specification provided)

Material Description

fat clay with sand

Atterberg Limits (ASTM D 4318)

PL= 27 LL= 54 PI= 27

Classification

USCS= CH AASHTO= A-7-6(25)

Coefficients

D_{85}= 0.1571 D_{60}= 0.0212 D_{50}= 0.0050
D_{30}= D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.46

Sample No.: BM4 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 6 - 10 m
Checked By: kiayiat A **Title:**

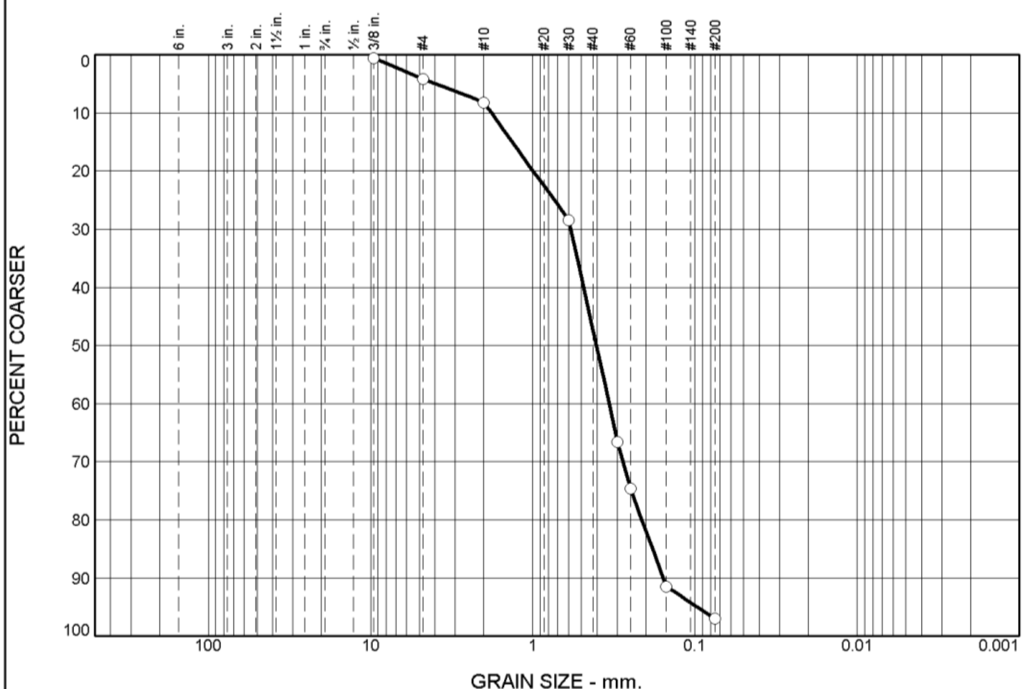
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM4 (6 - 10 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
			4.1	39.2	49.6	3.0	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/8	99.4		
#4	95.9		
#10	91.8		
#30	71.6		
#50	33.4		
#60	25.4		
#100	8.5		
#200	3.0		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= No plastic **LL=** Non **PI=** Non

Classification

USCS= SP **AASHTO=** A-3

Coefficients

D_{85}= 1.3342 D_{60}= 0.4861 D_{50}= 0.4053
D_{30}= 0.2774 D_{15}= 0.1823 D_{10}= 0.1567
C_u= 3.10 C_c= 1.01

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=2.16

Sample No.: BM5 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 2 m
Checked By: kiayait A **Title:**

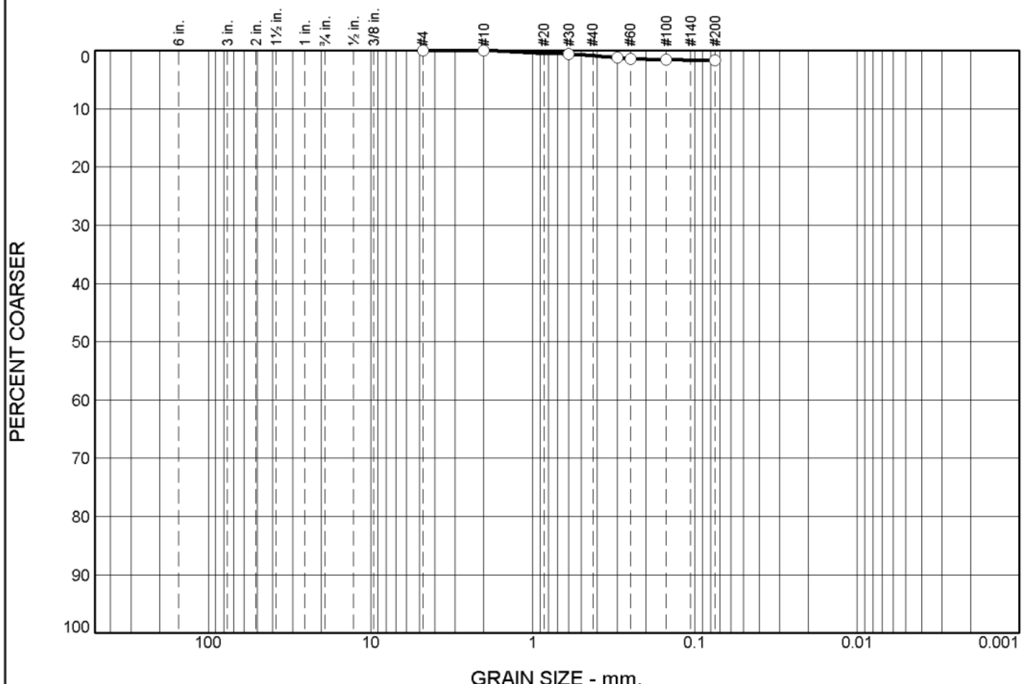
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM5 (0 - 2 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
			0.0	0.9	0.8	10.0	88.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#30	99.4		
#50	98.8		
#60	98.6		
#100	98.4		
#200	98.3		

* (no specification provided)

Material Description

fat clay

Atterberg Limits (ASTM D 4318)

PL= 29 LL= 53 PI= 24

Classification

USCS= CH AASHTO= A-7-6(28)

Coefficients

D_{85}= 0.0038 D_{60}= 0.0016 D_{50}= 0.0012
D_{30}= 0.0008 D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.04

Sample No.: BM5 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 2 - 5 m
Checked By: khiyiat A **Title:**

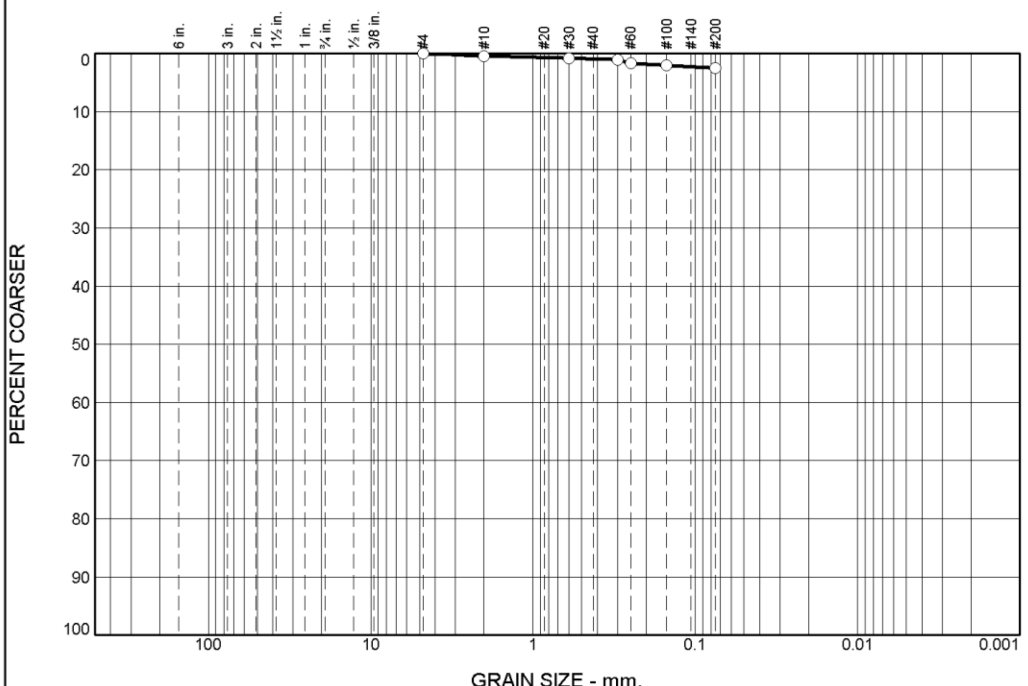
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM5 (2 - 5 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.4	0.5	1.6	16.2	81.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.6		
#30	99.2		
#50	99.0		
#60	98.3		
#100	98.0		
#200	97.5		

* (no specification provided)

Material Description

fat clay

Atterberg Limits (ASTM D 4318)

PL= 25 **LL=** 51 **PI=** 26

Classification

USCS= CH **AASHTO=** A-7-6(29)

Coefficients

D_{85}= 0.0069 D_{60}= 0.0010 D_{50}= 0.0009
D_{30}= D_{15}= D_{10}=
C_u= C_c=

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=0.05

Sample No.: BM5 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 5 - 8 m
Checked By: khayiat A **Title:**

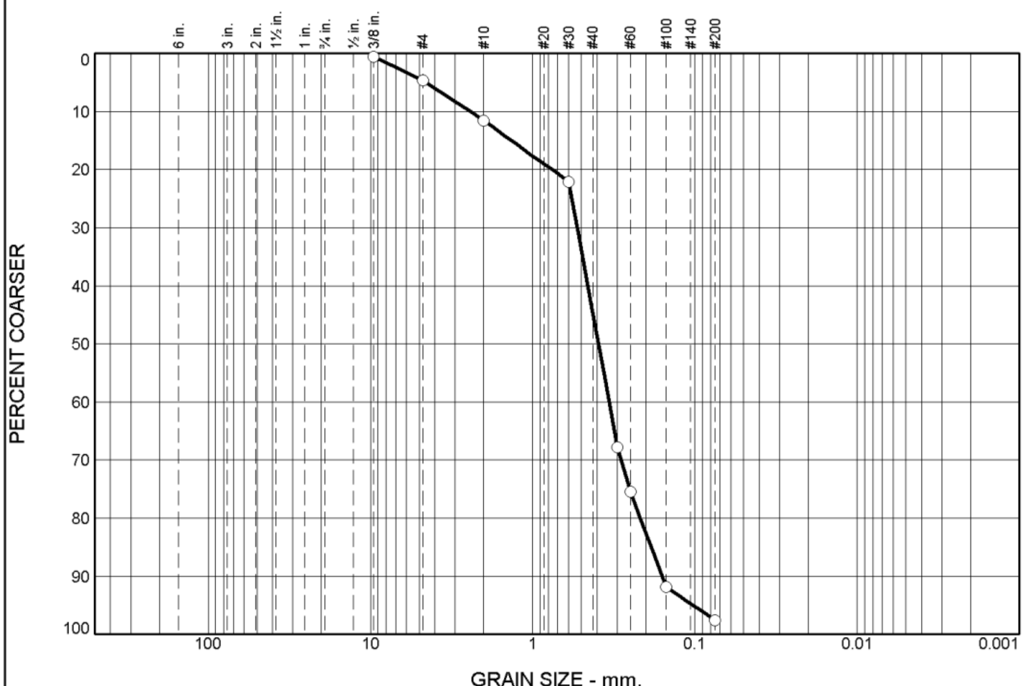
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM5 (5 - 8 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
			7.0	33.2	52.8	2.4	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/8	99.4		
#4	95.4		
#10	88.4		
#30	77.9		
#50	32.2		
#60	24.6		
#100	8.2		
#200	2.4		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= No plastic LL= Non PI= Non

Classification

USCS= SP AASHTO= A-3

Coefficients

D_{85}= 1.3493 D_{60}= 0.4573 D_{50}= 0.3931
D_{30}= 0.2848 D_{15}= 0.1855 D_{10}= 0.1588
C_u= 2.88 C_c= 1.12

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=2.13

Sample No.: BM6 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 0 - 2 m
Checked By: khiayiat A **Title:**

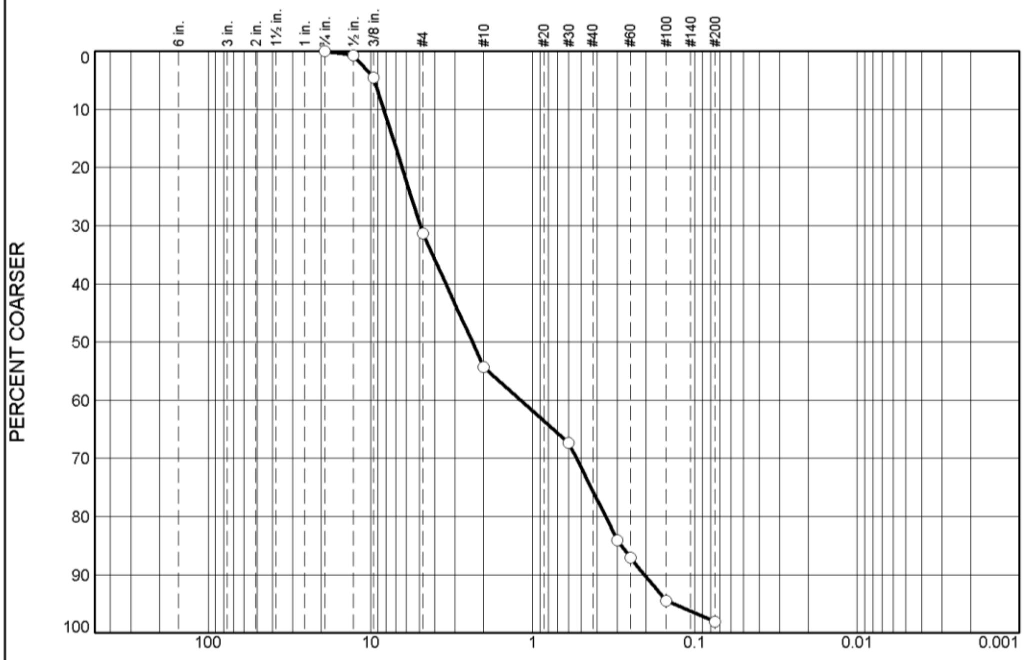
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM6 (0 - 2 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	31.3	23.0	21.3	22.5	1.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4	100.0		
1/2	99.2		
3/8	95.5		
#4	68.7		
#10	45.7		
#30	32.7		
#50	16.0		
#60	12.9		
#100	5.6		
#200	1.9		

* (no specification provided)

Material Description

poorly graded sand with gravel

Atterberg Limits (ASTM D 4318)

PL= No plastic **LL=** Non **PI=** Non

Classification

USCS= SP **AASHTO=** A-1-a

Coefficients

D_{85}= 7.2533 D_{60}= 3.4231 D_{50}= 2.3515
D_{30}= 0.5372 D_{15}= 0.2832 D_{10}= 0.2040
C_u= 16.78 C_c= 0.41

Date Tested: **Tested By:** bokhari M

Remarks

F.M.=3.92

Sample No.: BM6 **Source of Sample:** **Date Sampled:**
Location: **Elev./Depth:** 2 - 8 m
Checked By: khiaiyat A **Title:**

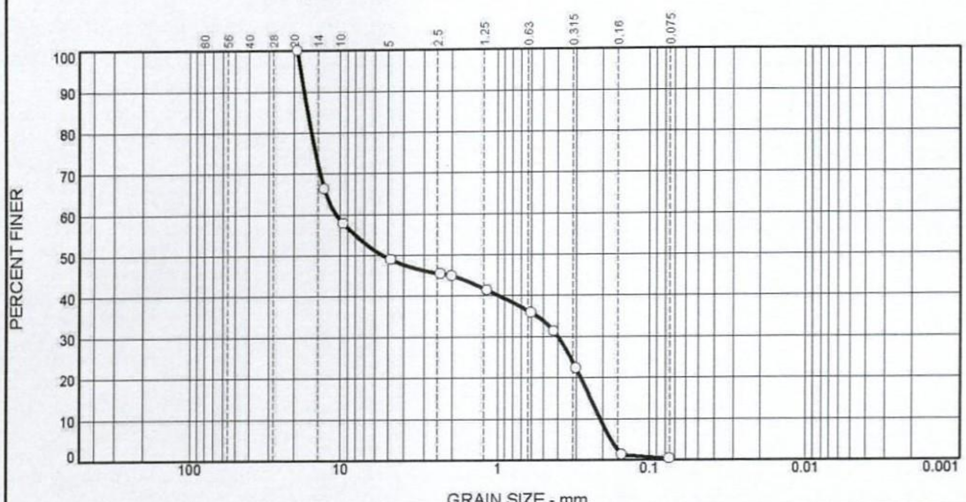
Saudi Geological Survey

Kingdom of Saudi Arabia

Client: saudi geological survey
Project: evalution of engineering properties of unstable soil at mudarraj and al butain
Project No: 22020 **Figure**

Mudarraj BM6 (2 - 8 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	51.1	4.0	13.6	31.0	0.3	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/4"	100.0		
1/2"	66.3		
3/8"	57.8		
#4	48.9		
#8	45.4		
#10	44.9		
#16	41.3		
#30	35.8		
#40	31.3		
#50	22.2		
#100	1.2		
#200	0.3		

* (no specification provided)

Material Description

poorly graded gravel with sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= GP AASHTO (M 145)= A-1-b

Coefficients

D_{90}= 17.1975 D_{85}= 16.3063 D_{60}= 10.6555
D_{50}= 5.3625 D_{30}= 0.3995 D_{15}= 0.2422
D_{10}= 0.2091 C_u= 50.97 C_c= 0.07

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

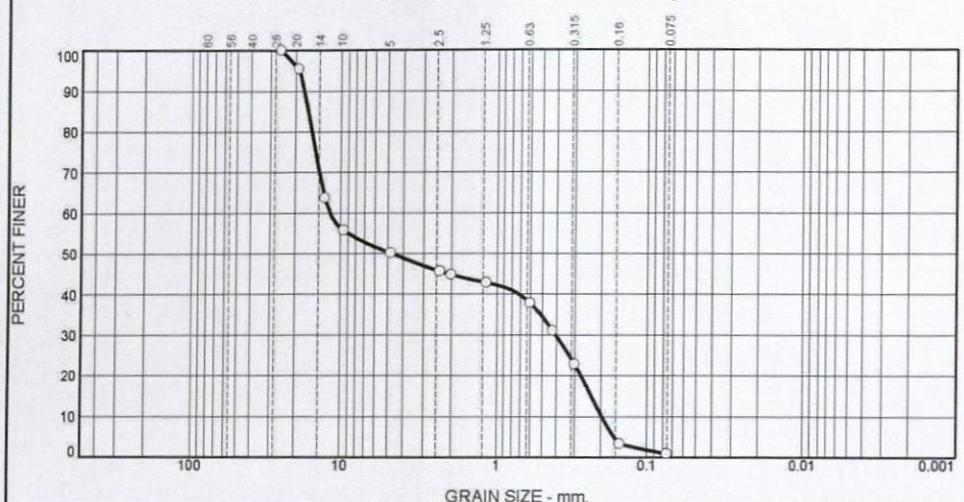
Source of Sample: BH-14 Depth: 0-1.5 Date Sampled:
Sample Number: S1

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH14 (0 -1.5m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.6	45.4	5.2	13.8	30.2	0.8	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
3/4"	95.4		
1/2"	63.7		
3/8"	55.7		
#4	50.0		
#8	45.6		
#10	44.8		
#16	42.8		
#30	37.8		
#40	31.0		
#50	22.8		
#100	3.2		
#200	0.8		

* (no specification provided)

Material Description

poorly graded gravel with sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= GP AASHTO (M 145)= A-1-b

Coefficients

D_{90}= 17.5109 D_{85}= 16.4657 D_{60}= 11.7661

D_{50}= 4.7197 D_{30}= 0.4066 D_{15}= 0.2323

D_{10}= 0.1976 C_u= 59.55 C_c= 0.07

Remarks

Date Received: Date Tested:

Tested By: ________

Checked By: ________

Title: ________

Source of Sample: BH-14 Depth: 1.5-3 Date Sampled:

Sample Number: S2

Sun of the Environment Est.

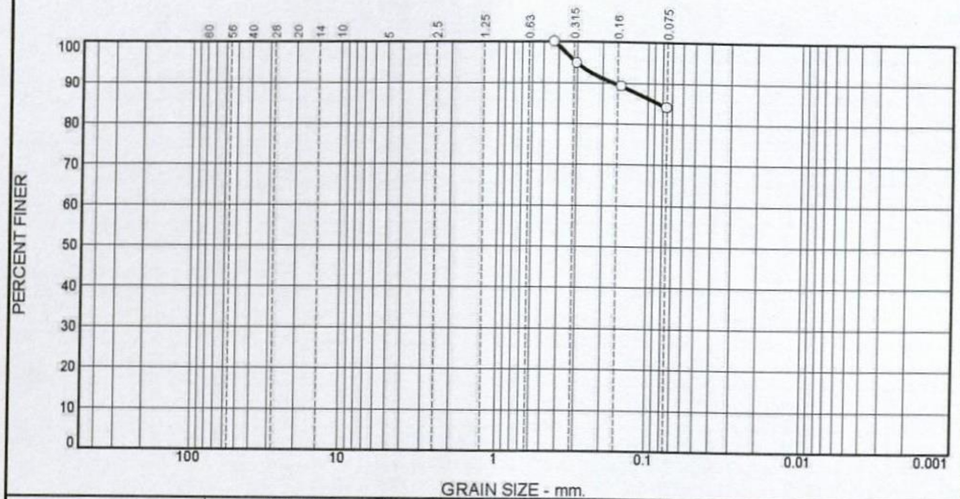
Client: SAUDI GEOLOGICAL SURVAY

Project: Earth fissured and sinkhole at Hail area

Project No: SML-001-15 Figure

Turubah BH14 (1.5- 3m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.0	15.9	84.1	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#40	100.0		
#50	94.8		
#100	89.2		
#200	84.1		

* (no specification provided)

Material Description

lean clay with sand

Atterberg Limits (ASTM D 4318)

PL= 26 LL= 46 PI= 20

Classification

USCS (D 2487)= CL AASHTO (M 145)= A-7-6(18)

Coefficients

D_{90}= 0.1708 D_{85}= 0.0847 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

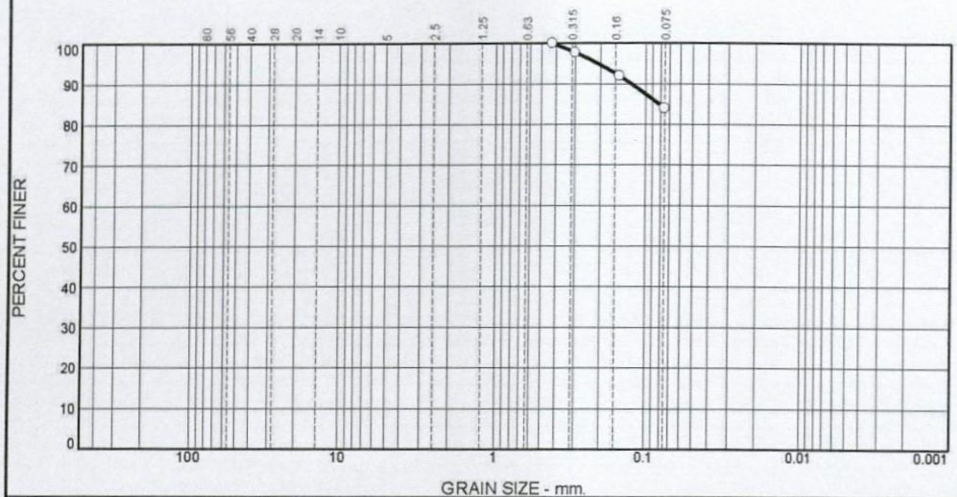
Source of Sample: BH-14 Depth: 3-4.5
Sample Number: S3
Date Sampled:

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVEY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH14 (3 -4.5m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.0	16.1	83.9	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#40	100.0		
#50	97.7		
#100	91.9		
#200	83.9		

* (no specification provided)

Material Description

lean clay with sand

Atterberg Limits (ASTM D 4318)

PL= 26 LL= 45 PI= 19

Classification

USCS (D 2487)= CL AASHTO (M 145)= A-7-6(17)

Coefficients

D_{90}= 0.1250 D_{85}= 0.0819 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

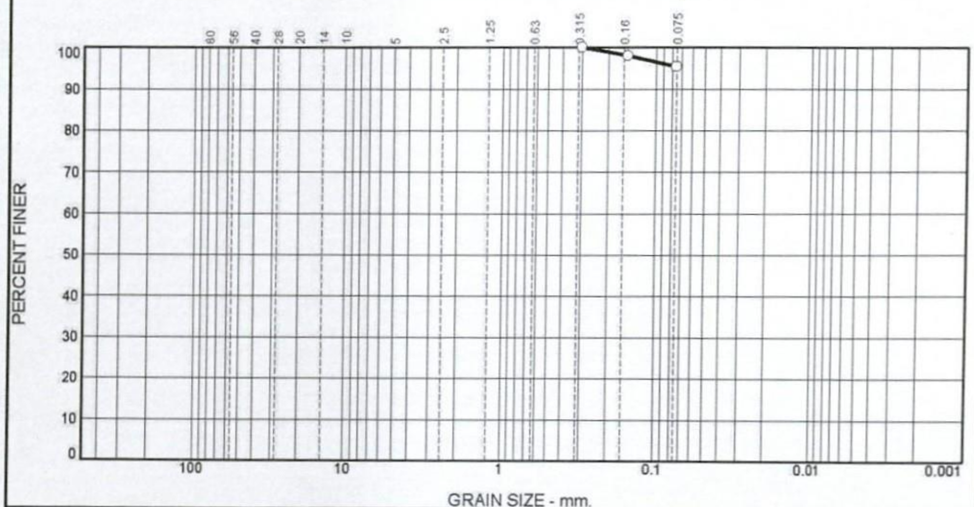
Source of Sample: BH-14 Depth: 4.5-6 Date Sampled:
Sample Number: S4

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH14 (4.5 - 6m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.0	4.7	95.3	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#50	100.0		
#100	98.0		
#200	95.3		

* (no specification provided)

Material Description

lean clay

Atterberg Limits (ASTM D 4318)

PL= 25 LL= 46 PI= 21

Classification

USCS (D 2487)= CL AASHTO (M 145)= A-7-6(23)

Coefficients

D_{90}= D_{85}= D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

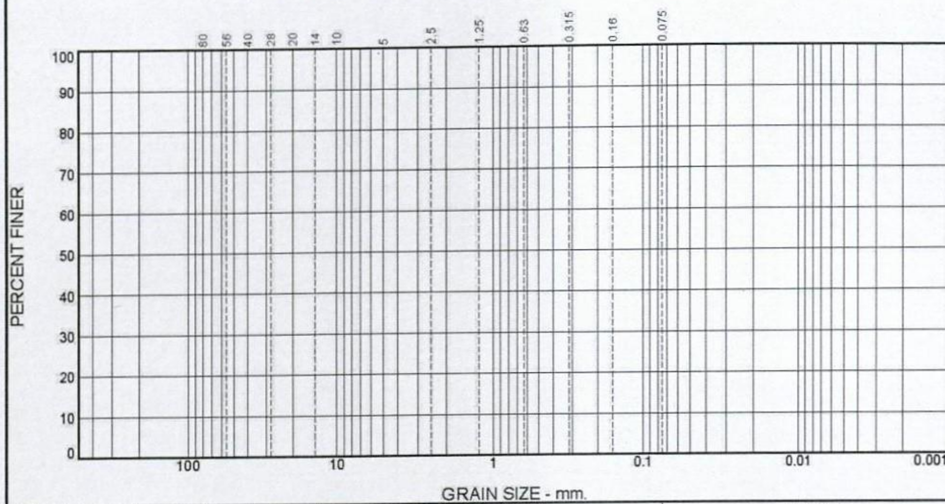
Source of Sample: BH-14 **Depth:** 6-7 **Date Sampled:**
Sample Number: S4

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 **Figure**

Turubah BH14 (6 -7m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	7.4	4.8	13.9	66.1		

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)

* (no specification provided)

Material Description

poorly graded sand with silt

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP-SM AASHTO (M 145)= A-3

Coefficients

D_{90}= 2.7051 D_{85}= 1.0757 D_{60}= 0.2882
D_{50}= 0.2445 D_{30}= 0.1817 D_{15}= 0.1344
D_{10}= 0.1079 C_u= 2.67 C_c= 1.06

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

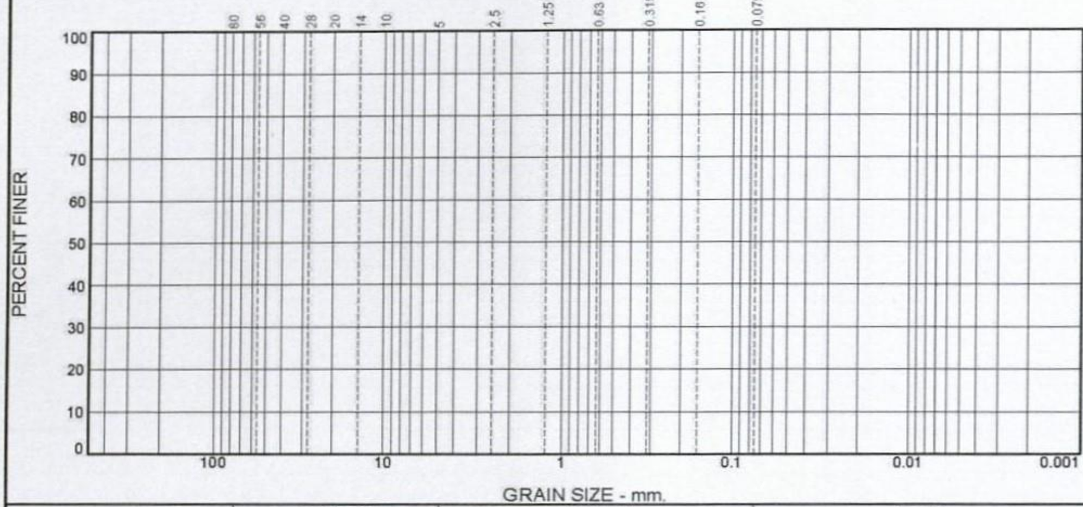
Source of Sample: BH-15 **Depth:** 0-0.6 **Date Sampled:**
Sample Number: S1

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 **Figure**

Turubah BH15 (0- 0.6 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	1.7	3.0	2.5	16.3	73.3		

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-3

Coefficients

D_{90}= 0.8310 D_{85}= 0.5783 D_{60}= 0.2973
D_{50}= 0.2594 D_{30}= 0.2044 D_{15}= 0.1683
D_{10}= 0.1552 C_u= 1.92 C_c= 0.91

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

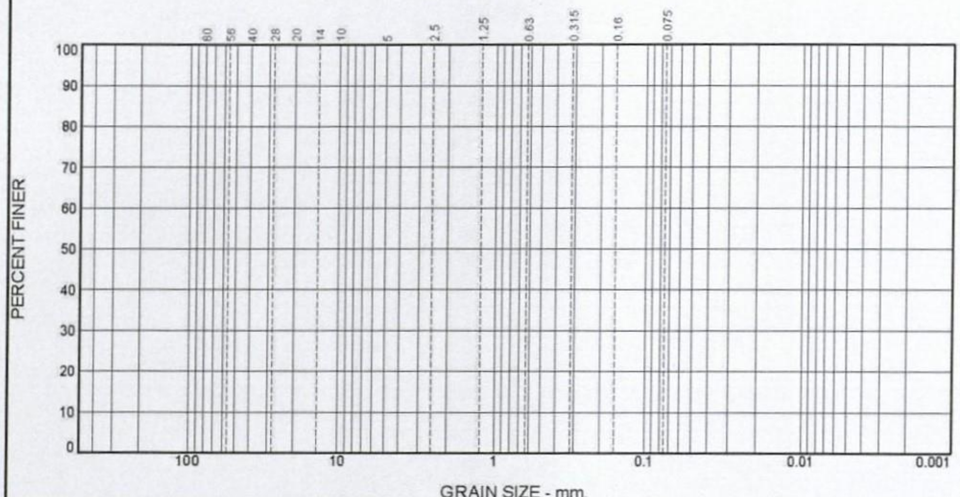
Source of Sample: BH-15 **Depth:** 0.6-1.5 **Date Sampled:**
Sample Number: S2

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 **Figure**

Turubah BH15 (0.6 -1.5m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	5.2	3.0	16.2	70.7		

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-3

Coefficients

D_{90}= 1.2908 D_{85}= 0.7230 D_{60}= 0.2775
D_{50}= 0.2401 D_{30}= 0.1852 D_{15}= 0.1385
D_{10}= 0.1023 C_u= 2.71 C_c= 1.21

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

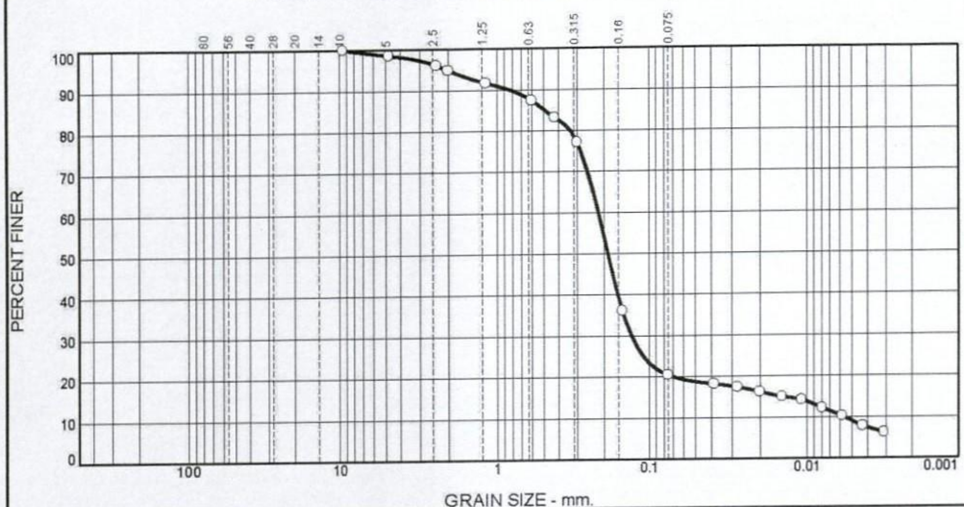
Source of Sample: BH-15 Depth: 1.5-3 Date Sampled:
Sample Number: S3

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH15 (1.5 - 3m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.5	3.7	11.6	62.8	11.4	9.0

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/8"	100.0		
#4	98.5		
#8	96.1		
#10	94.8		
#16	91.7		
#30	87.4		
#40	83.2		
#50	77.1		
#100	36.1		
#200	20.4		
0.0384 mm.	18.2		
0.0277 mm.	17.4		
0.0201 mm.	16.2		
0.0146 mm.	15.0		
0.0108 mm.	14.2		
0.0079 mm.	12.2		
0.0058 mm.	10.2		
0.0043 mm.	7.8		
0.0031 mm.	6.2		

* (no specification provided)

Material Description

clayey sand

Atterberg Limits (ASTM D 4318)

PL= 5 LL= 14 PI= 9

Classification

USCS (D 2487)= SC AASHTO (M 145)= A-2-4(0)

Coefficients

D_{90}= 0.8352 D_{85}= 0.4952 D_{60}= 0.2187
D_{50}= 0.1885 D_{30}= 0.1303 D_{15}= 0.0148
D_{10}= 0.0057 C_u= 38.47 C_c= 13.65

Remarks

Date Received: Date Tested:
Tested By: ______
Checked By: ______
Title: ______

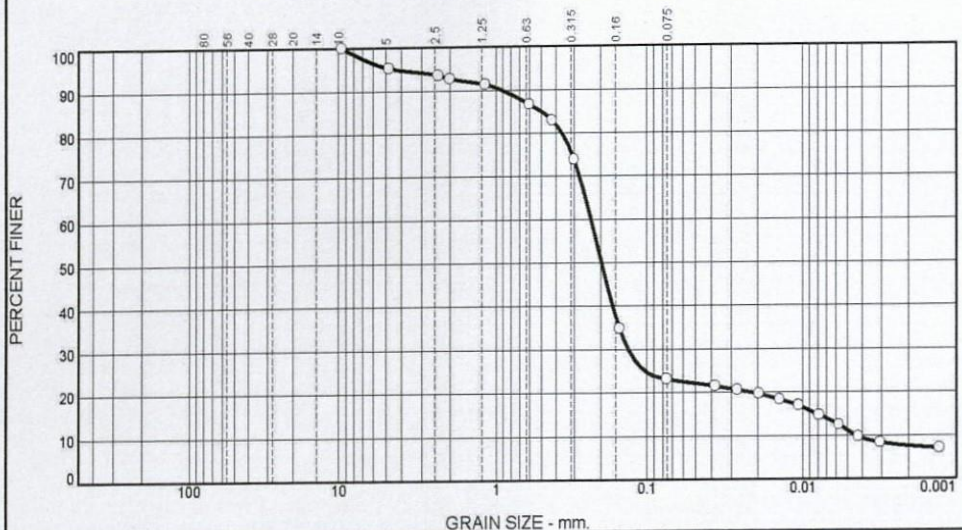
Source of Sample: BH-16 Depth: 0-1.5 Date Sampled:
Sample Number: S1

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH16 (0 -1.5m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	4.8	2.5	9.8	59.8	12.0	11.1

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/8"	100.0		
#4	95.2		
#8	93.5		
#10	92.7		
#16	91.3		
#30	86.6		
#40	82.9		
#50	73.8		
#100	34.8		
#200	23.1		
0.0377 mm.	21.4		
0.0272 mm.	20.5		
0.0196 mm.	19.6		
0.0142 mm.	18.3		
0.0106 mm.	16.9		
0.0078 mm.	14.6		
0.0057 mm.	12.4		
0.0042 mm.	9.7		
0.0030 mm.	8.3		
0.0013 mm.	7.0		

* (no specification provided)

Material Description

silty sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SM AASHTO (M 145)= A-2-4(0)

Coefficients

D_{90}= 0.9196 D_{85}= 0.5038 D_{60}= 0.2319
D_{50}= 0.1976 D_{30}= 0.1315 D_{15}= 0.0082
D_{10}= 0.0044 C_u= 52.69 C_c= 16.93

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

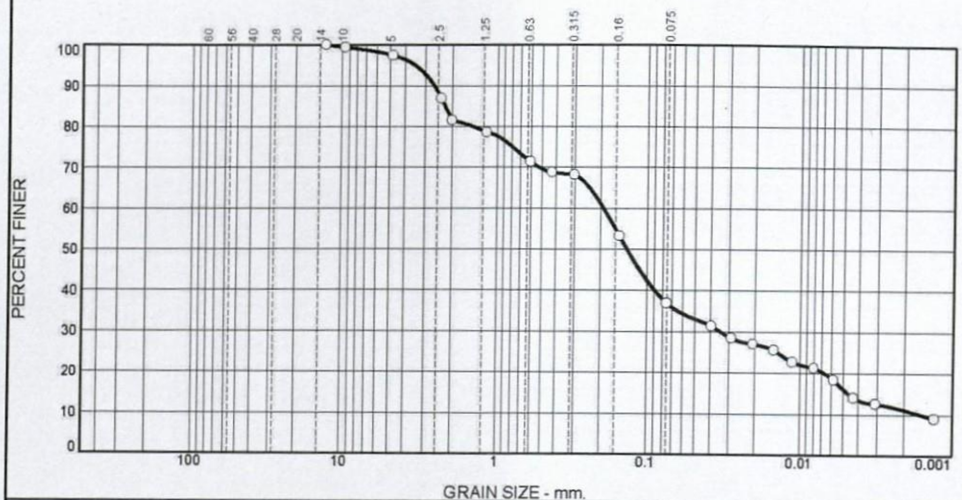
Source of Sample: BH-16 Depth: 1.5-3 Date Sampled:
Sample Number: S2

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH16 (1.5 - 3m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.6	15.9	12.8	31.8	20.8	16.1

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1/2"	100.0		
3/8"	99.4		
#4	97.4		
#8	86.9		
#10	81.5		
#16	78.5		
#30	71.3		
#40	68.7		
#50	68.1		
#100	53.2		
#200	36.9		
0.0391 mm.	31.3		
0.0286 mm.	28.4		
0.0206 mm.	27.0		
0.0148 mm.	25.5		
0.0111 mm.	22.7		
0.0080 mm.	21.2		
0.0058 mm.	18.3		
0.0043 mm.	14.0		
0.0031 mm.	12.6		
0.0013 mm.	8.9		

* (no specification provided)

Material Description

clayey sand

Atterberg Limits (ASTM D 4318)

PL= 11 LL= 19 PI= 8

Classification

USCS (D 2487)= SC AASHTO (M 145)= A-4(0)

Coefficients

D_{90}= 2.6316 D_{85}= 2.2343 D_{60}= 0.1918
D_{50}= 0.1340 D_{30}= 0.0341 D_{15}= 0.0046
D_{10}= 0.0016 C_u= 121.60 C_c= 3.85

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

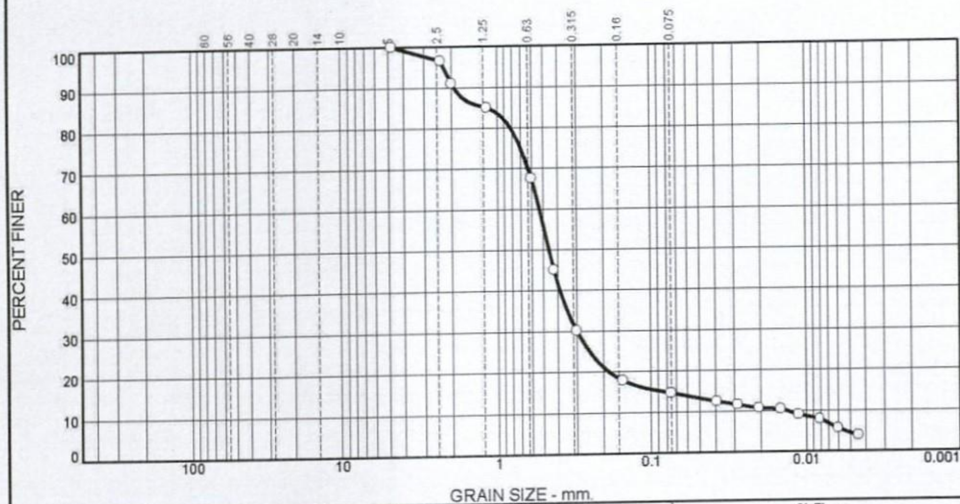
Source of Sample: BH-16 Depth: 3-4 Date Sampled:
Sample Number: S3

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH16 (3 - 4m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	9.0	45.9	30.5	10.2	4.4

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	96.6		
#10	91.0		
#16	85.0		
#30	67.6		
#40	45.1		
#50	30.1		
#100	17.8		
#200	14.6		
0.0391 mm.	12.4		
0.0284 mm.	11.6		
0.0206 mm.	10.7		
0.0147 mm.	10.4		
0.0111 mm.	9.0		
0.0081 mm.	7.8		
0.0060 mm.	5.6		
0.0044 mm.	3.8		

* (no specification provided)

Material Description

clayey sand

Atterberg Limits (ASTM D 4318)

PL= 11 LL= 23 PI= 12

Classification

USCS (D 2487)= SC AASHTO (M 145)= A-2-6(0)

Coefficients

D_{90}= 1.9322 D_{85}= 1.1895 D_{60}= 0.5322
D_{50}= 0.4594 D_{30}= 0.2991 D_{15}= 0.0846
D_{10}= 0.0134 C_u= 39.74 C_c= 12.55

Remarks

Date Received: Date Tested:

Tested By: ____________

Checked By: ____________

Title: ____________

Source of Sample: BH-16 Depth: 4-6.5 Date Sampled:
Sample Number: S4

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH16 (4 - 6.5m)

Particle Size Distribution Report

% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	4.3	22.7	39.9	19.3	10.6	3.2

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/8"	100.0		
#4	95.7		
#8	91.7		
#10	73.0		
#16	45.0		
#30	35.9		
#40	33.1		
#50	31.0		
#100	16.9		
#200	13.8		
0.0390 mm.	12.4		
0.0288 mm.	11.0		
0.0209 mm.	10.2		
0.0154 mm.	8.8		
0.0118 mm.	6.9		
0.0086 mm.	5.6		
0.0063 mm.	4.2		
0.0046 mm.	2.8		
0.0033 mm.	2.3		

* (no specification provided)

Material Description

silty sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SM AASHTO (M 145)= A-1-b

Coefficients

D_{90}= 2.3200 D_{85}= 2.2174 D_{60}= 1.7269
D_{50}= 1.4211 D_{30}= 0.2795 D_{15}= 0.1037
D_{10}= 0.0197 C_u= 87.79 C_c= 2.30

Remarks

Date Received: Date Tested:

Tested By:

Checked By:

Title:

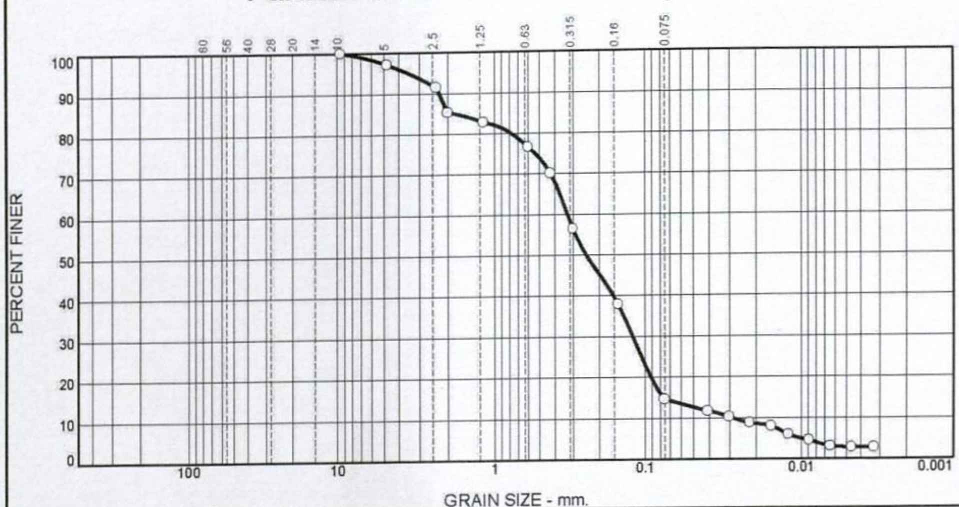
Source of Sample: BH-17 Depth: 0-0.6 Date Sampled:
Sample Number: S1

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH17 (0 - 0.6 m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.9	11.9	15.2	55.4	11.8	2.8

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/8"	100.0		
#4	97.1		
#8	91.5		
#10	85.2		
#16	82.8		
#30	76.6		
#40	70.0		
#50	56.4		
#100	37.9		
#200	14.6		
0.0408 mm.	11.6		
0.0300 mm.	10.2		
0.0220 mm.	8.8		
0.0159 mm.	7.9		
0.0122 mm.	5.9		
0.0089 mm.	4.4		
0.0065 mm.	3.0		
0.0046 mm.	2.7		
0.0033 mm.	2.7		

* (no specification provided)

Material Description

silty sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SM AASHTO (M 145)= A-2-4(0)

Coefficients

D_{90}= 2.2696 D_{85}= 1.8551 D_{60}= 0.3284
D_{50}= 0.2436 D_{30}= 0.1202 D_{15}= 0.0766
D_{10}= 0.0290 C_u= 11.33 C_c= 1.52

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

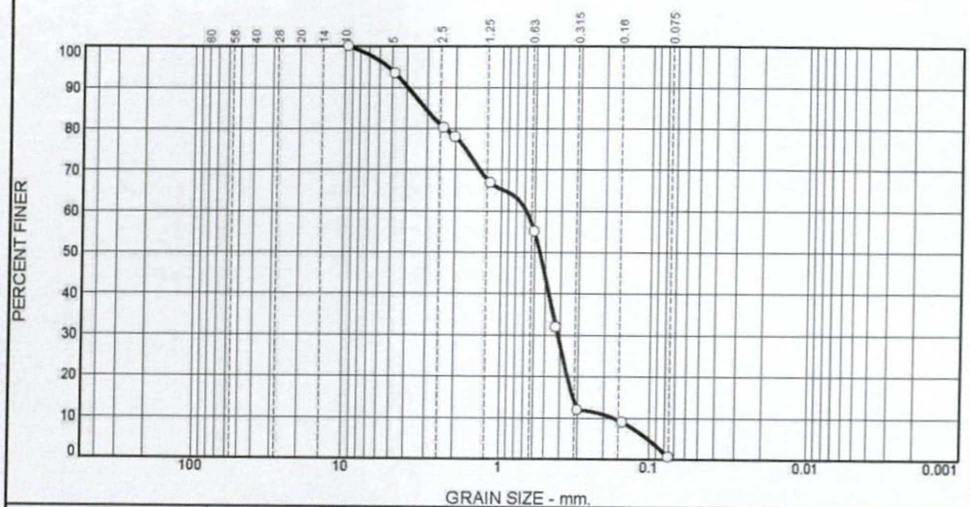
Source of Sample: BH-17 Depth: 0.6-1.5 Date Sampled:
Sample Number: S2

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH17 (0.6 - 1.5m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	6.6	15.5	46.0	31.4	0.5	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/8"	100.0		
#4	93.4		
#8	80.1		
#10	77.9		
#16	66.8		
#30	55.0		
#40	31.9		
#50	11.9		
#100	8.9		
#200	0.5		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-1-b

Coefficients

D_{90}= 3.9570 D_{85}= 3.1100 D_{60}= 0.6830
D_{50}= 0.5489 D_{30}= 0.4138 D_{15}= 0.3233
D_{10}= 0.1731 C_u= 3.95 C_c= 1.45

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

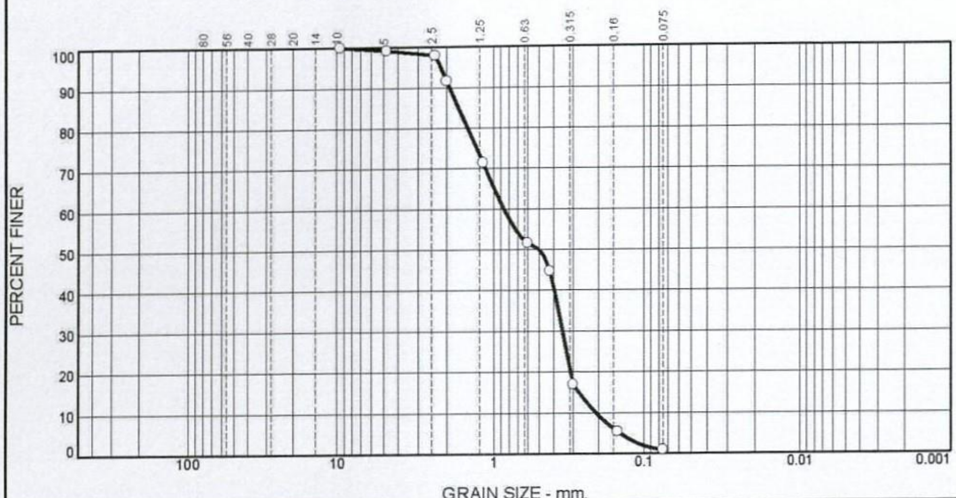
Source of Sample: BH-17 **Depth:** 1.5-3 **Date Sampled:**
Sample Number: S3

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 **Figure**

Turubah BH17 (1.5 - 3m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.8	7.6	46.9	43.8	0.9	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/8"	100.0		
#4	99.2		
#8	97.9		
#10	91.6		
#16	71.4		
#30	51.6		
#40	44.7		
#50	16.9		
#100	5.4		
#200	0.9		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-1-b

Coefficients

D_{90}= 1.9225 D_{85}= 1.6929 D_{60}= 0.8626
D_{50}= 0.5038 D_{30}= 0.3511 D_{15}= 0.2738
D_{10}= 0.2089 C_u= 4.13 C_c= 0.68

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

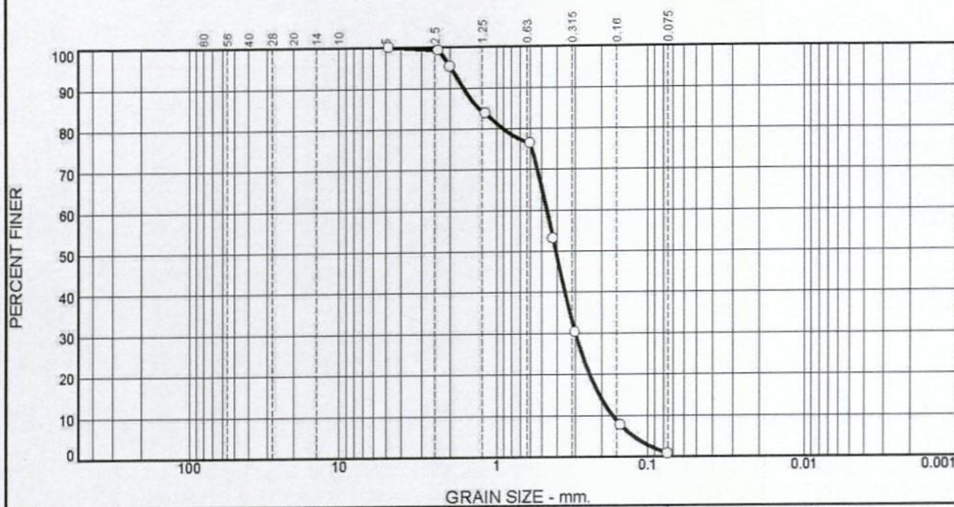
Source of Sample: BH-17 Depth: 3-4.5 Date Sampled:
Sample Number: S4

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH17 (3 - 4.5m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	4.8	42.1	52.4	0.7	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	99.3		
#10	95.2		
#16	83.8		
#30	76.4		
#40	53.1		
#50	30.2		
#100	7.7		
#200	0.7		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-3

Coefficients

D_{90}= 1.6486 D_{85}= 1.3072 D_{60}= 0.4655
D_{50}= 0.4073 D_{30}= 0.2987 D_{15}= 0.2074
D_{10}= 0.1700 C_u= 2.74 C_c= 1.13

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

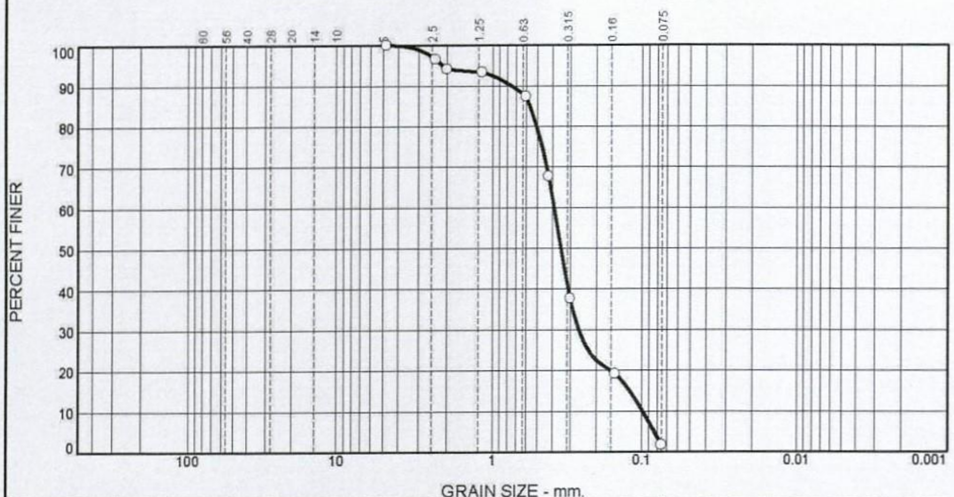
Source of Sample: BH-17 **Depth:** 4.5-6 **Date Sampled:**
Sample Number: S5

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 **Figure**

Turubah BH17 (4.5 - 6m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	5.9	26.5	65.9	1.7	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	96.5		
#10	94.1		
#16	93.4		
#30	87.4		
#40	67.6		
#50	37.6		
#100	19.1		
#200	1.7		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-3

Coefficients

D_{90}= 0.7522 D_{85}= 0.5646 D_{60}= 0.3890
D_{50}= 0.3487 D_{30}= 0.2625 D_{15}= 0.1200
D_{10}= 0.0989 C_u= 3.93 C_c= 1.79

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

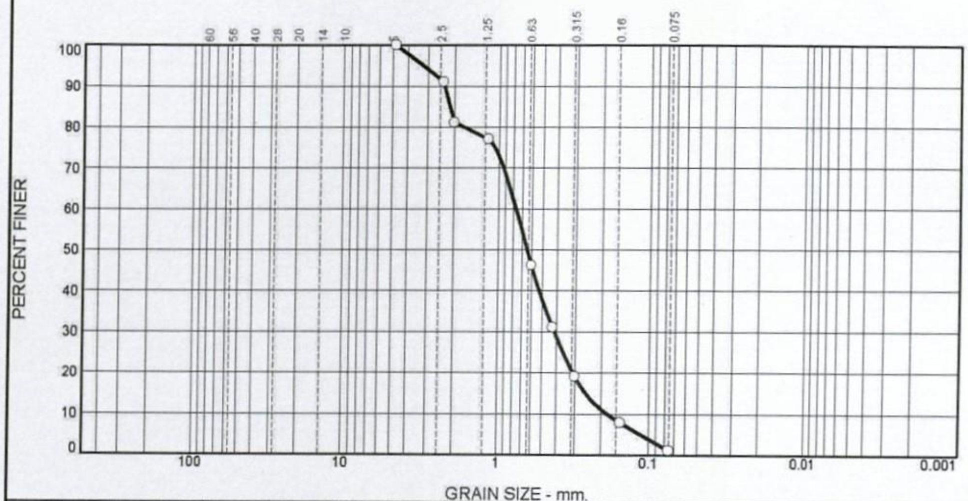
Source of Sample: BH-17 Depth: 6-7.5 Date Sampled:
Sample Number: S6

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH17 (6 - 7.5m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	18.9	50.1	29.9	1.1	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	91.0		
#10	81.1		
#16	77.0		
#30	46.1		
#40	31.0		
#50	19.1		
#100	7.9		
#200	1.1		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-1-b

Coefficients

D_{90}= 2.3198 D_{85}= 2.1440 D_{60}= 0.7685
D_{50}= 0.6446 D_{30}= 0.4137 D_{15}= 0.2534
D_{10}= 0.1834 C_u= 4.19 C_c= 1.21

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

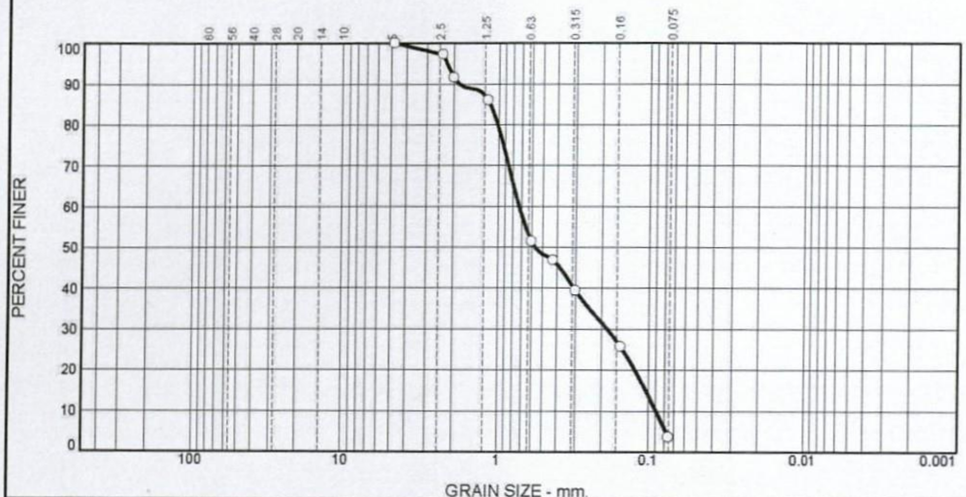
Source of Sample: BH-17 Depth: 7.5-9
Sample Number: S7
Date Sampled:

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH17 (7.5 - 9m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	8.5	44.7	43.2	3.6	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#8	97.2		
#10	91.5		
#16	86.0		
#30	51.4		
#40	46.8		
#50	39.4		
#100	25.7		
#200	3.6		

* (no specification provided)

Material Description

poorly graded sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-1-b

Coefficients

D_{90}= 1.8537 D_{85}= 1.1440 D_{60}= 0.7266
D_{50}= 0.5679 D_{30}= 0.1839 D_{15}= 0.1040
D_{10}= 0.0898 C_u= 8.09 C_c= 0.52

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

Source of Sample: BH-17 Depth: 9-11 Date Sampled:
Sample Number: S8

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH17 (9 - 11m)

Particle Size Distribution Report

% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	5.1	45.5	4.0	16.6	27.5	1.3	

TEST RESULTS			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
3/4"	94.9		
1/2"	65.4		
3/8"	56.1		
#4	49.4		
#8	45.5		
#10	45.4		
#16	40.7		
#30	31.8		
#40	28.8		
#50	25.6		
#100	8.3		
#200	1.3		

* (no specification provided)

Material Description

poorly graded gravel with sand

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= GP AASHTO (M 145)= A-1-a

Coefficients

D_{90}= 17.5334 D_{85}= 16.3968 D_{60}= 11.2718
D_{50}= 5.2178 D_{30}= 0.4946 D_{15}= 0.1950
D_{10}= 0.1616 C_u= 69.76 C_c= 0.13

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

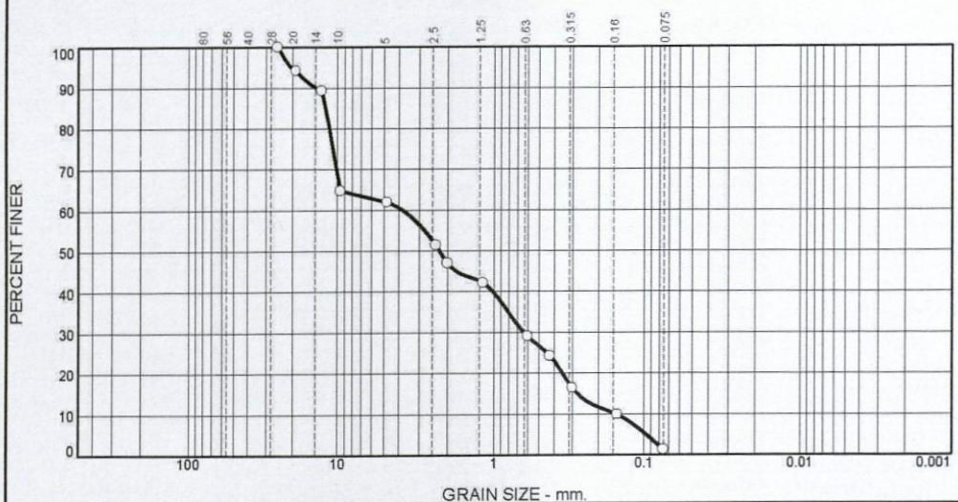
Source of Sample: BH-18 Depth: 0-1.5
Sample Number: S1
Date Sampled:

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH18 (0 - 1.5m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	5.8	32.3	15.0	22.7	23.0	1.2	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
3/4"	94.2		
1/2"	89.3		
3/8"	64.7		
#4	61.9		
#8	51.4		
#10	46.9		
#16	42.1		
#30	29.0		
#40	24.2		
#50	16.4		
#100	9.8		
#200	1.2		

* (no specification provided)

Material Description

poorly graded sand with gravel

Atterberg Limits (ASTM D 4318)

PL= NP LL= NV PI= NP

Classification

USCS (D 2487)= SP AASHTO (M 145)= A-1-a

Coefficients

D_{90}= 13.8441 D_{85}= 11.9656 D_{60}= 3.8109
D_{50}= 2.2525 D_{30}= 0.6366 D_{15}= 0.2779
D_{10}= 0.1533 C_u= 24.86 C_c= 0.69

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

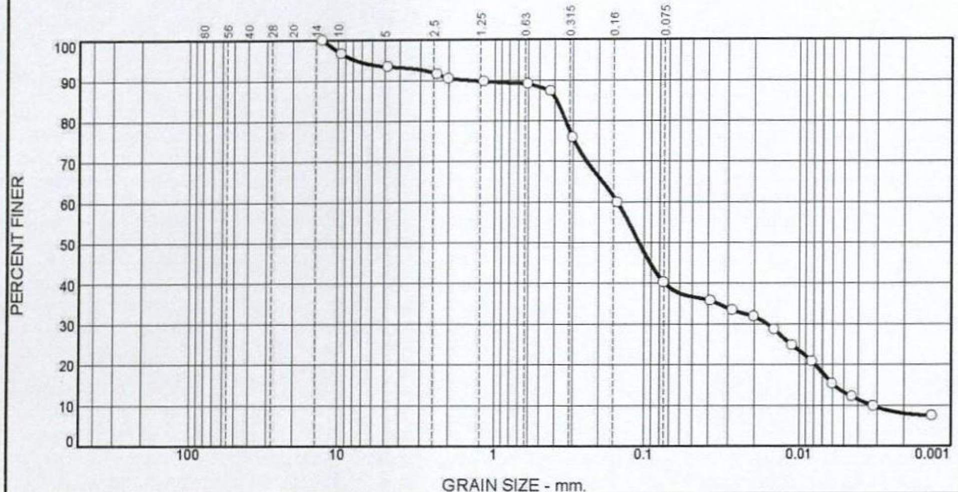
Source of Sample: BH-18 Depth: 1.5-2.2 Date Sampled:
Sample Number: S2

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH18 (1.5 -2.2m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	6.6	3.0	3.2	47.0	27.1	13.1

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1/2"	100.0		
3/8"	96.7		
#4	93.4		
#8	91.5		
#10	90.4		
#16	89.7		
#30	89.1		
#40	87.2		
#50	75.9		
#100	59.9		
#200	40.2		
0.0384 mm.	35.7		
0.0279 mm.	33.4		
0.0201 mm.	31.8		
0.0147 mm.	28.7		
0.0111 mm.	24.7		
0.0082 mm.	20.8		
0.0060 mm.	15.3		
0.0044 mm.	12.1		
0.0031 mm.	9.8		
0.0013 mm.	7.4		

* (no specification provided)

Material Description

silty, clayey sand

Atterberg Limits (ASTM D 4318)

PL= 15 LL= 22 PI= 7

Classification

USCS (D 2487)= SC-SM AASHTO (M 145)= A-4(0)

Coefficients

D_{90}= 1.4992 D_{85}= 0.3895 D_{60}= 0.1508
D_{50}= 0.1081 D_{30}= 0.0164 D_{15}= 0.0059
D_{10}= 0.0033 C_u= 46.16 C_c= 0.54

Remarks

Date Received: Date Tested:

Tested By:

Checked By:

Title:

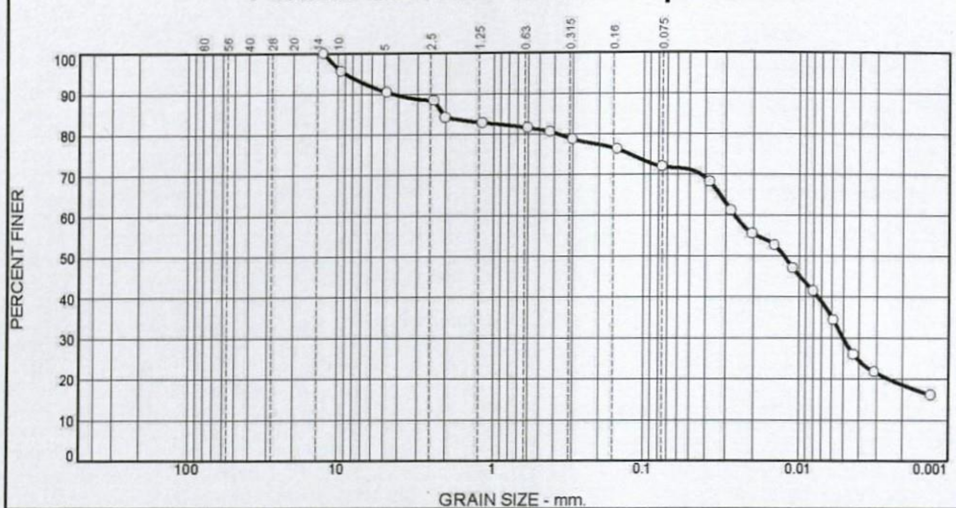
Source of Sample: BH-19 **Depth:** 0-0.6 **Date Sampled:**
Sample Number: S1

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 **Figure**

Turubah BH19 (0 – 0.6m)

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	9.6	6.3	3.5	8.7	42.1	29.8

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1/2"	100.0		
3/8"	95.6		
#4	90.4		
#8	88.3		
#10	84.1		
#16	82.8		
#30	81.5		
#40	80.6		
#50	78.7		
#100	76.2		
#200	71.9		
0.0373 mm.	68.1		
0.0277 mm.	61.1		
0.0203 mm.	55.4		
0.0146 mm.	52.6		
0.0110 mm.	47.0		
0.0080 mm.	41.4		
0.0058 mm.	34.3		
0.0043 mm.	25.9		
0.0031 mm.	21.7		
0.0013 mm.	16.1		

* (no specification provided)

Material Description

elastic silt with sand

Atterberg Limits (ASTM D 4318)

PL= 35 LL= 56 PI= 21

Classification

USCS (D 2487)= MH AASHTO (M 145)= A-7-5(17)

Coefficients

D_{90}= 4.3635 D_{85}= 2.0788 D_{60}= 0.0264
D_{50}= 0.0126 D_{30}= 0.0050 D_{15}=
D_{10}= C_u= C_c=

Remarks

Date Received: Date Tested:
Tested By:
Checked By:
Title:

Source of Sample: BH-19 Depth: 0.6-1.5
Sample Number: S2
Date Sampled:

Sun of the Environment Est.

Client: SAUDI GEOLOGICAL SURVAY
Project: Earth fissured and sinkhole at Hail area
Project No: SML-001-15 Figure

Turubah BH19 (0.6 - 1.5m)

Borehole Log

BORING NO. BBa

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 6-11-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description

Borehole Log

BORING NO. BBb

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

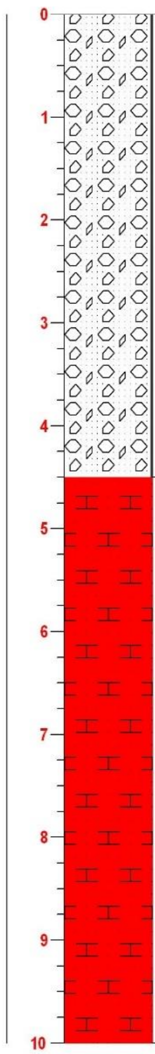
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 5-11-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description
0 – 4.5		WHITE SAND WITH GRAVEL WITH LITTLE CLAY: Loose.
4.5 – 10		RED CLAY: stiff,very dense.



Borehole Log

BORING NO. BBc

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

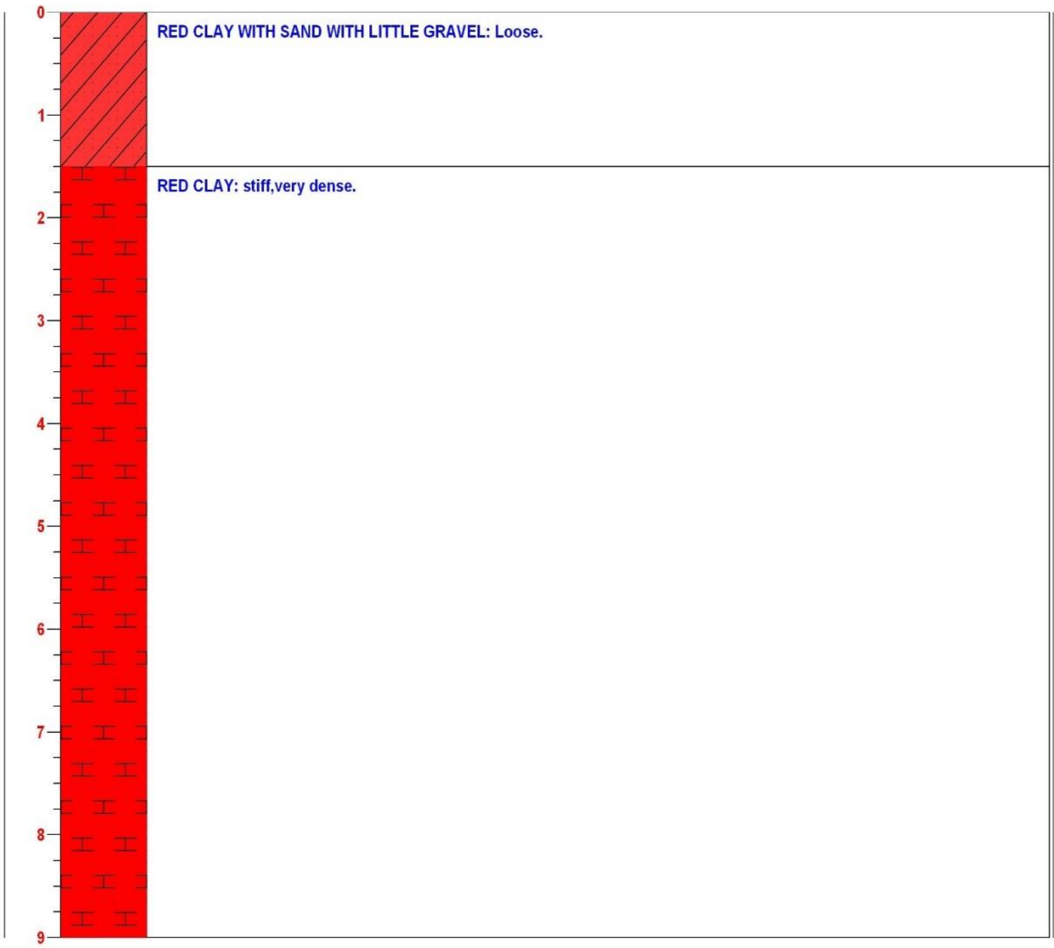
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 5-11-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description



Borehole Log

BORING NO. BBd

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 7-11-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description

Borehole Log

BORING NO. BBe

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

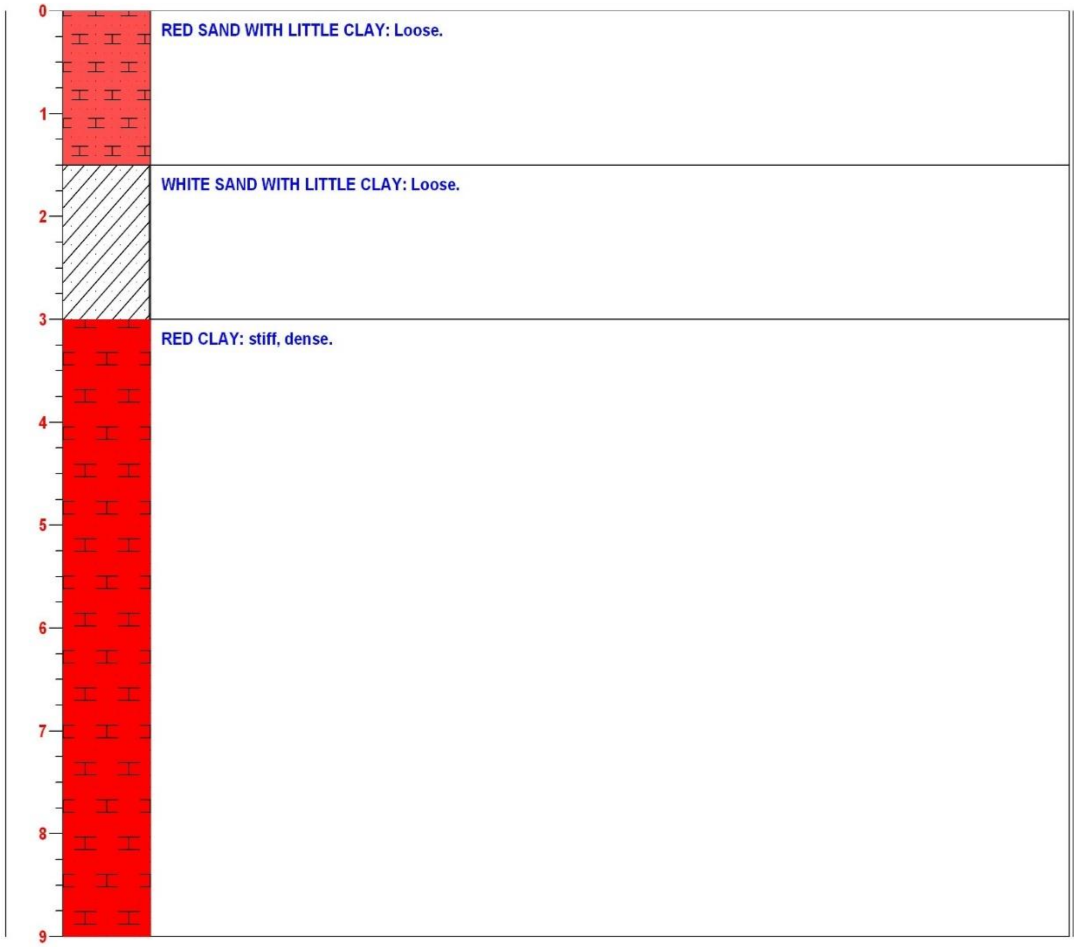
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 7-11-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description



Borehole Log

BORING NO. BBf

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

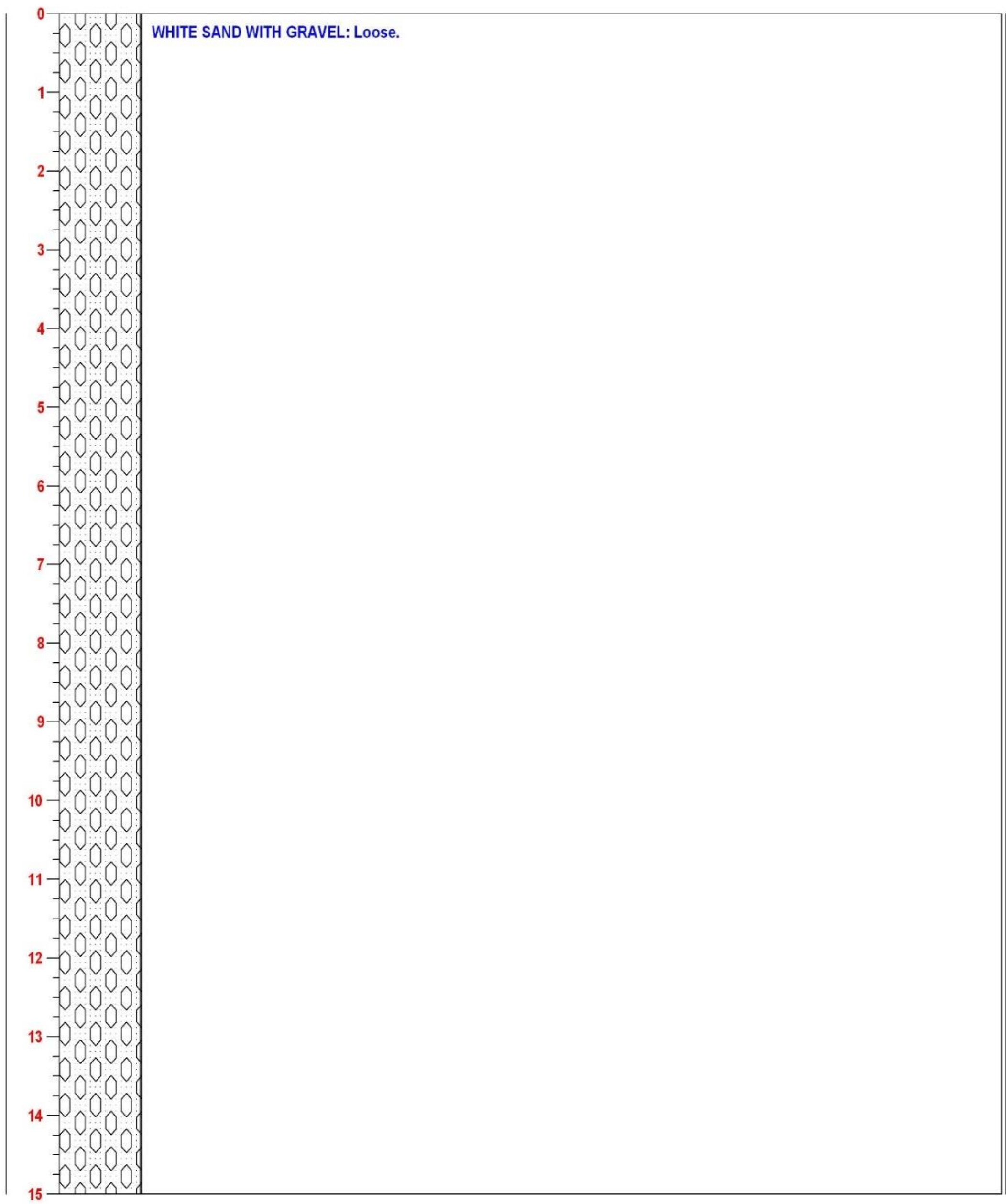
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 12-11-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description



Borehole Log

BORING NO. BBg

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

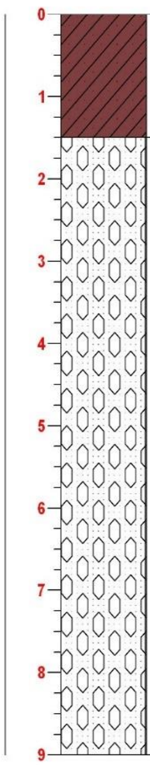
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 10-11-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description



BROWN SAND WITH RED CLAY: Loose.

WHITE SAND WITH GRAVEL: Loose, (calacitise).

Borehole Log

BORING NO. BMa

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

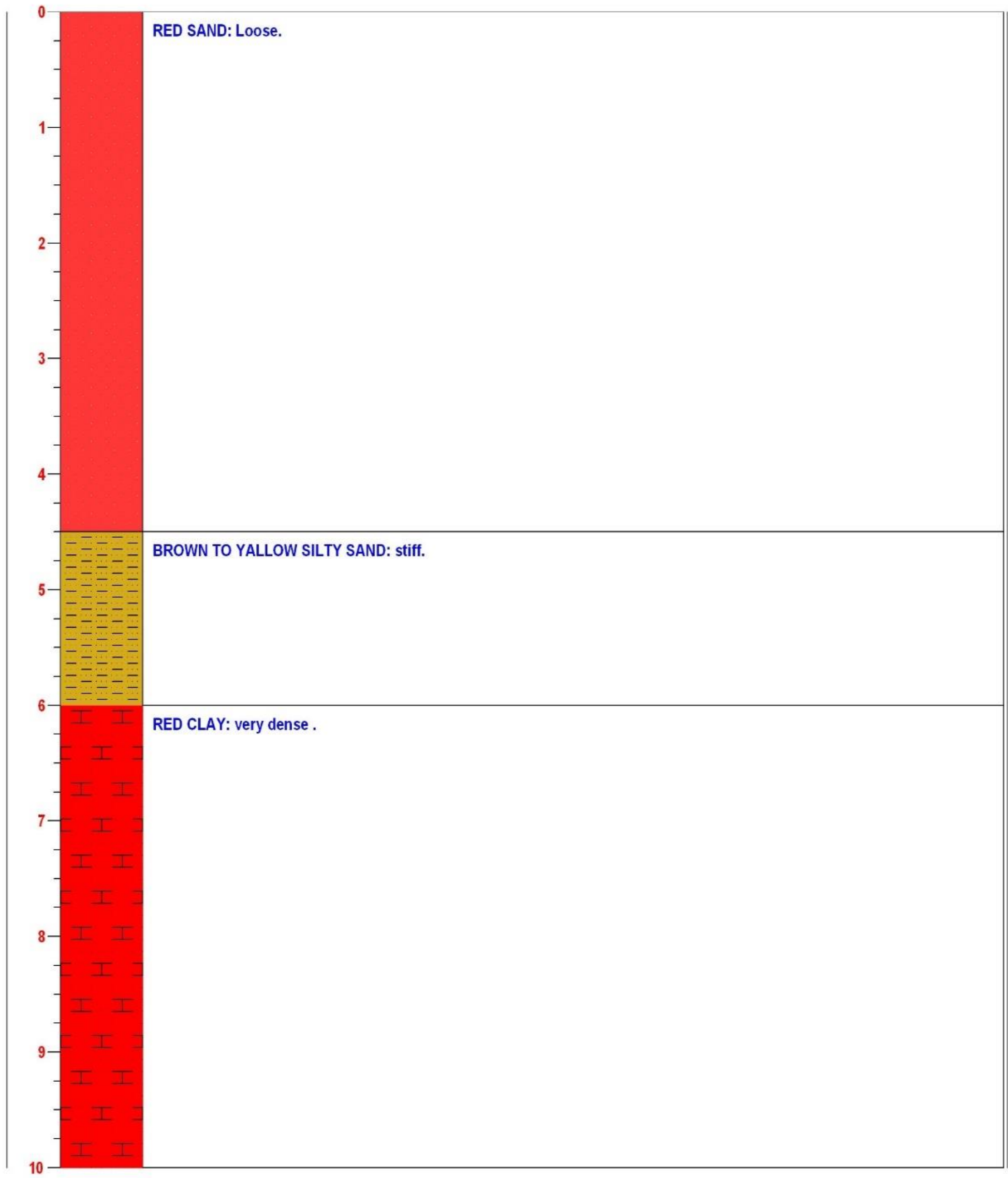
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 26-10-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description



Borehole Log

BORING NO. BMb

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

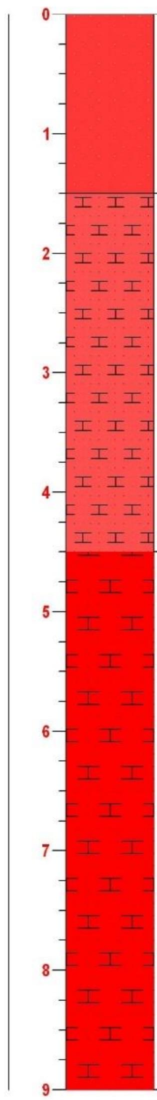
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 29-10-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description
0–1.5		RED SAND: Loose.
1.5–4.5		RED SAND WITH LITTLE CLAY: stiff.
4.5–9		RED CLAY: very dense .



Borehole Log

BORING NO. BMc

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

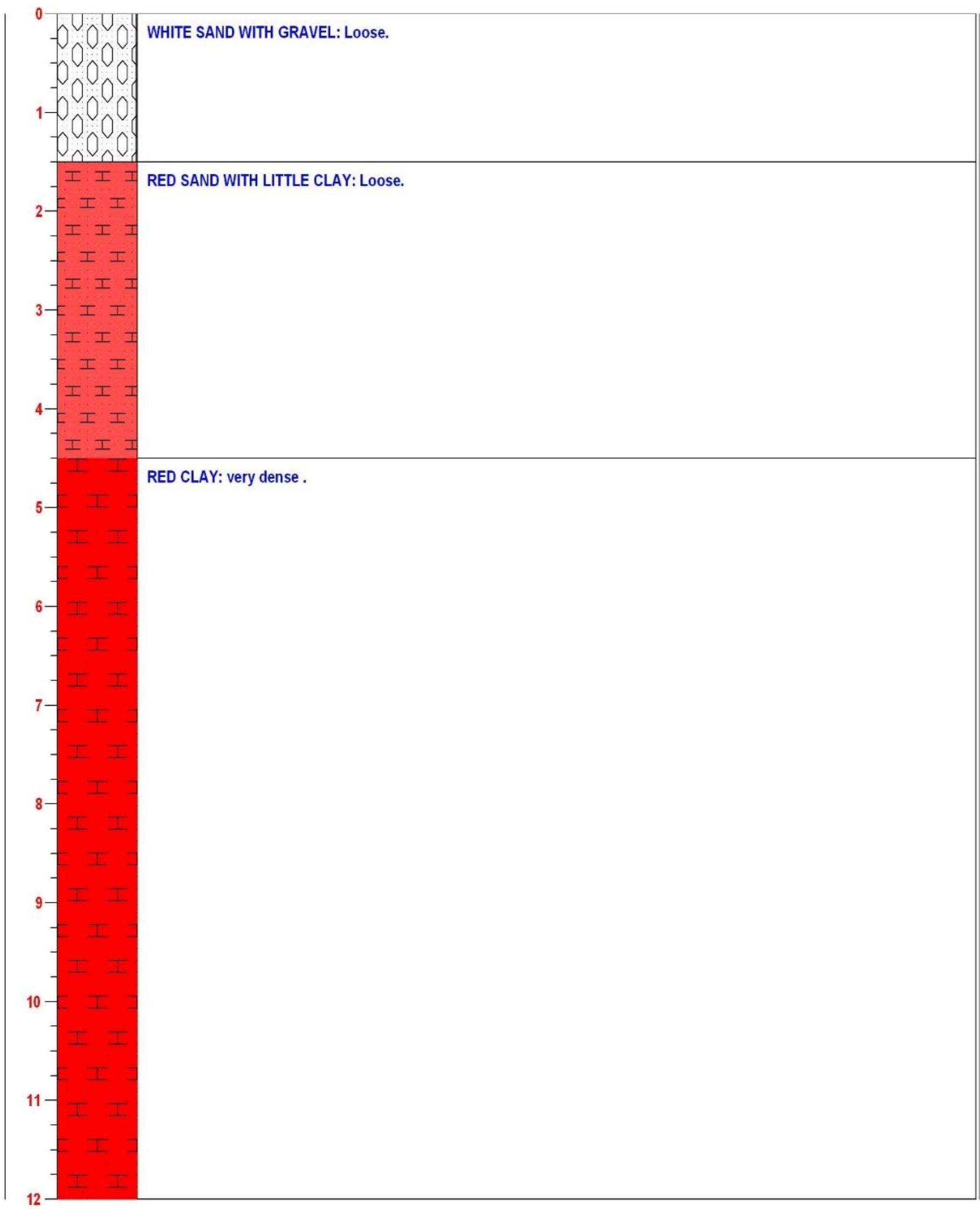
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 29-10-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description



Borehole Log

BORING NO. BMd	DRILLING ANGLE: 90
METHOD OF DRILLING: Hollow Stem Auger (SPT)	DATE: 30-10-2008
DRILLING EQUIPMENT: Risqa	
DEPTH OF GROUNDWATER	ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description
0–2		BROWN POORY GRADED SAND: Loose.
2–3		BROWN SAND WITH LITTLE GRAVEL: Loose.
3–4.5		GRAY CLAY WITH SAND: wet
4.5–9		GRAY TO GREEN CLAY : very Dense

Borehole Log

BORING NO. BMe

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

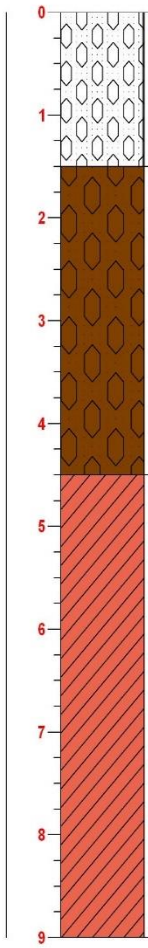
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 30-10-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description



WHITE SAND WITH GRAVEL: Loose.

BROWN SAND WITH LITTLE GRAVEL: Loose.

RED TO GRAY CLAY: stiff

Borehole Log

BORING NO. BMF

METHOD OF DRILLING: Hollow Stem Auger (SPT)

DRILLING EQUIPMENT: Risqa

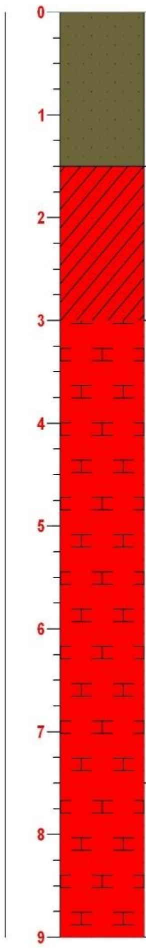
DEPTH OF GROUNDWATER

DRILLING ANGLE: 90

DATE: 2-10-2008

ENGINEERING NAME : K Alahmadi

DEPTH	Lithology	Description

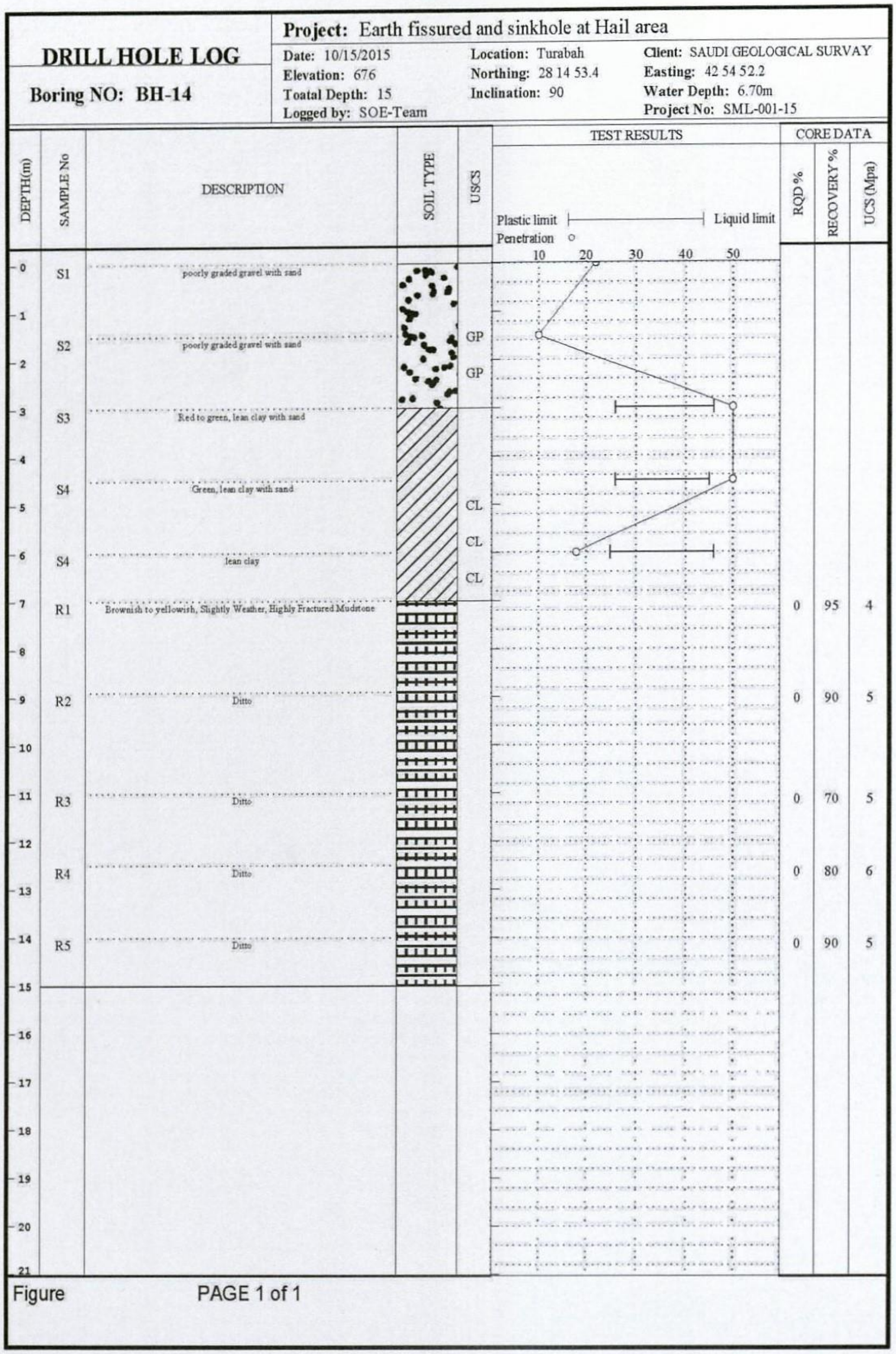


BROWN SAND: Loose.

RED CLAY WITH SAND: stiff

RED CLAY: wet, very dense

RED CLAY: very stiff


Project: Earth fissured and sinkhole at Hail area
DRILL HOLE LOG
Boring NO: BH-14
Date: 10/15/2015
Elevation: 676
Toatal Depth: 15
Logged by: SOE-Team
Location: Turabah
Northing: 28 14 53.4
Inclination: 90
Client: SAUDI GEOLOGICAL SURVAY
Easting: 42 54 52.2
Water Depth: 6.70m
Project No: SML-001-15
DEPTH(m)
SAMPLE No
DESCRIPTION
SOIL TYPE
USCS
TEST RESULTS
Plastic limit
Liquid limit
Penetration
10 20 30 40 50
CORE DATA
RQD %
RECOVERY %
UCS (Mpa)
S1 poorly graded gravel with sand
S2 poorly graded gravel with sand
GP
GP
S3 Red to green, lean clay with sand
S4 Green, lean clay with sand
CL
CL
CL
S4 lean clay
R1 Brownish to yellowish, Slightly Weather, Highly Fractured Mudstone 0 95 4
R2 Ditto 0 90 5
R3 Ditto 0 70 5
R4 Ditto 0 80 6
R5 Ditto 0 90 5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Figure
PAGE 1 of 1

Project: Earth fissured and sinkhole at Hail area

DRILL HOLE LOG

Boring NO: BH-15

Date: 10/15/2015
Elevation: 674
Toatal Depth: 15
Logged by: SOE-Team

Location: Turabah
Northing: 28 15 17.9
Inclination: 90

Client: SAUDI GEOLOGICAL SURVAY
Easting: 42 55 26.4
Water Depth: 7.80m
Project No: SML-001-15

DEPTH(m)	SAMPLE No	DESCRIPTION	USCS	RQD %	RECOVERY %	UCS (Mpa)
0	S1	poorly graded sand with silt	SP-SM			
0.5	S2	poorly graded sand	SP			
1.5	S3	poorly graded sand	SP			
3	S4	poorly graded sand with gravel	SP			
4.5	R1	Brown ,Mudstone,Slightly Weather, Highly Fractured		33	75	6
6	R2	Dark Brown ,Mudstone,Slightly Weather, Highly Fractured,with Gypsum		0	80	2
8	R3	Brownish grey , Mudstone,Slightly Weather, Moderately Fractured,with little Gypsum		60	90	3
9	R4	Dark Brown Mudstone,slightly weathered, moderatky fractured		70	90	4
11	R5	Ditto		60	90	4
12	R6	Ditto, but highly fractured		26	70	3
13.5	R7	Ditto		46	60	5

TEST RESULTS

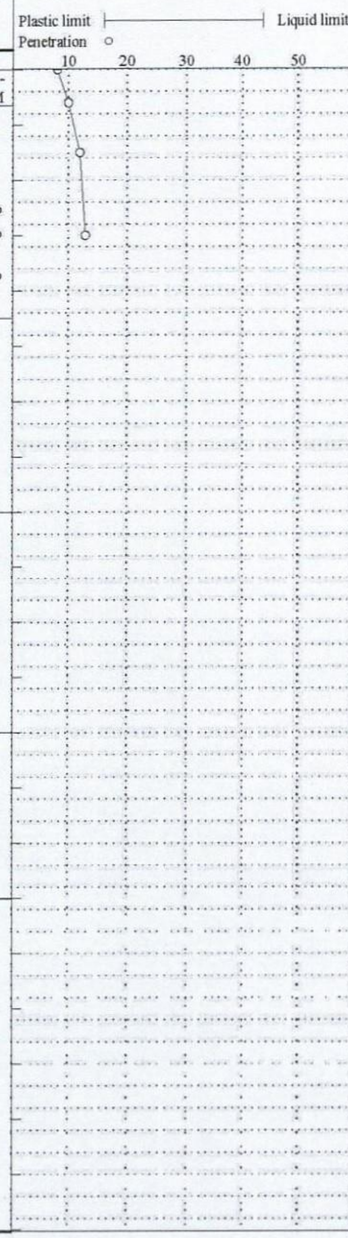


Figure PAGE 1 of 1

DRILL HOLE LOG

Boring NO: BH-16

Project: Earth fissured and sinkhole at Hail area

Date: 10/15/2015
Elevation: 690
Toatal Depth: 15
Logged by: SOE-Team

Location: Turabah
Northing: 28 15 36.6
Inclination: 90

Client: SAUDI GEOLOGICAL SURVAY
Easting: 42 56 8.5
Water Depth: 13.0m
Project No: SML-001-15

DEPTH(m)	SAMPLE No	DESCRIPTION	USCS	RQD %	RECOVERY %	UCS (Mpa)
0	S1	clayey sand	SC			
1.5	S2	silty sand	SM			
3	S3	clayey sand				
4	S4	clayey sand	SC SC			
6.5	R1	Brownish greyish, slightly weathered, highly fractured Claystone		0	100	4.65
9	R2	Ditto		0	100	4.7
12	R3	Ditto		0	100	4.8

TEST RESULTS

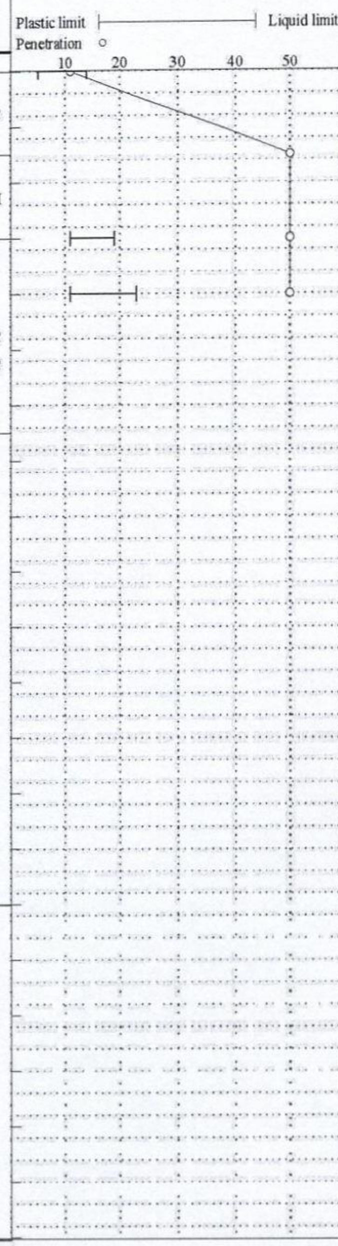


Figure PAGE 1 of 1

DRILL HOLE LOG

Boring NO: BH-17

Project: Earth fissured and sinkhole at Hail area

Date: 10/15/2015	**Location:** Turabah	**Client:** SAUDI GEOLOGICAL SURVAY
Elevation: 677	**Northing:** 28 15 35.4	**Easting:** 42 55 23.4
Toatal Depth: 15	**Inclination:** 90	**Water Depth:** 11.50m
Logged by: SOE-Team		**Project No:** SML-001-15

SAMPLE No	DESCRIPTION	USCS	RQD %	RECOVERY %	UCS (Mpa)
S1	Brown, silty sand	SM			
S2	Brown, silty sand	SM			
S3	poorly graded sand				
S4	poorly graded sand				
S5	poorly graded sand				
S6	poorly graded sand	SP			
S7	poorly graded sand	SP			
S8	poorly graded sand	SP			
R1	Yellowish, very fine grained sandstone		0	75	
R2	Ditto		0	60	
R3	Ditto		0	75	
R4	Ditto		0	80	

DEPTH(m): 0–21

TEST RESULTS

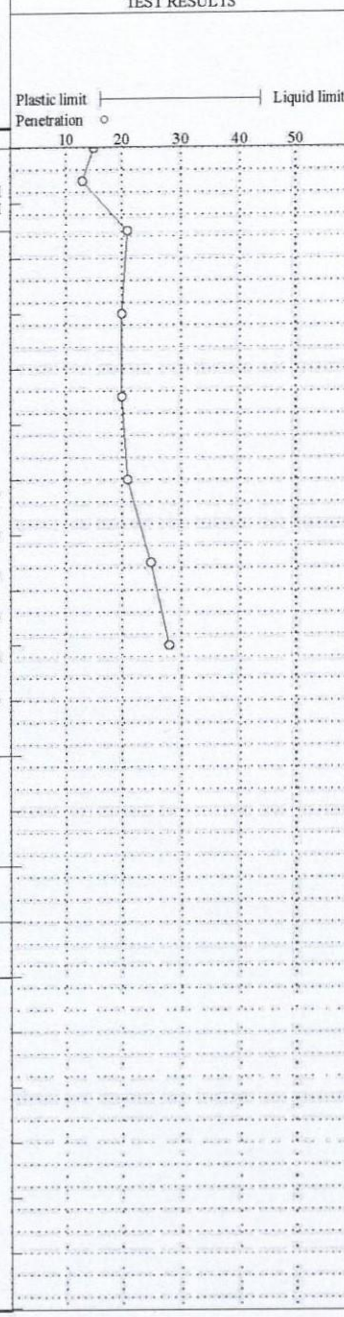


Figure PAGE 1 of 1

DRILL HOLE LOG	Project: Earth fissured and sinkhole at Hail area		
Boring NO: BH-18	Date: 10/15/2015 Elevation: 684 Toatal Depth: 15 Logged by: SOE-Team	Location: Turabah Northing: 28 15 37.9 Inclination: 90	Client: SAUDI GEOLOGICAL SURVAY Easting: 42 55 0.5 Water Depth: 9.40m Project No: SML-001-15

Test results legend: Plastic limit ├──┤ Liquid limit; Penetration ○ (scale 10, 20, 30, 40, 50)

DEPTH(m)	SAMPLE No	DESCRIPTION	SOIL TYPE	USCS	RQD %	RECOVERY %	UCS (Mpa)
0	S1	Brown, poorly graded gravel with sand		GP			
1.5	S2	Brown, poorly graded sand with gravel		SP			
2	R1	Light brown, slightly weathered, highly fractured mudstone			10	100	2.8
3	R2	Ditto, but grey in color			14	90	5
4	R3	Ditto, but dark color			25	90	4.8
6	R4	Ditto, but red and grey			35	95	6.1
8.5	R5	Ditto, but dark brown, highly to completely fravtured mudstone			0	100	5.8
10	R6	Ditto			0	70	5.2
12	R7	Ditto			0	80	4.3

Figure PAGE 1 of 1

DRILL HOLE LOG	**Project:** Earth fissured and sinkhole at Hail area		
	Date: 10/15/2015	Location: Turabah	Client: SAUDI GEOLOGICAL SURVAY
	Elevation: 690	Northing: 28 15 34.7	Easting: 42 45 44.7
Boring NO: BH-19	Toatal Depth: 15	Inclination: 90	Water Depth: 5.90m
	Logged by: SOE-Team		Project No: SML-001-15

DEPTH(m)	SAMPLE No	DESCRIPTION	SOIL TYPE	USCS	TEST RESULTS (Plastic limit ├──┤ Liquid limit; Penetration ○; 10 20 30 40 50)	RQD %	RECOVERY %	UCS (Mpa)
0	S1	silty, clayey sand		SC-SM				
	S2	elastic silt with sand		MH				
1	R1	Grey, slightly weathered, highly fractured mudstone				10	100	4.7
4	R2	Ditto, but dark brown in color				0	100	4.8
5	R3	Ditto, but grey in color				15	100	4.75
6	R4	Ditto, but brown and grey in color				12	100	5
8	R5	Ditto				13	100	4.6
10	R6	Ditto, but dark bown in color				14	90	4.2
13	R7	Ditto				17	100	5.5
15								

Depth scale: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

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BIBLIOGRAPHY

Al-Theeban, M., Yousif, and others, 2009, Study of engineering characteristics of the unstable soil in Al-Butain and Al-Modarraj villages, Al-Qasin area: Saudi Geological Survey Technical Report SGS-TR-2009-7.

Attneyer, W.T. (1955): Discussion of engineering properties of expansive clays. Proceeding, ASCE, Vol. 81, Separate No. 658, March, pp. 658-17-658-19.

Chen, F.H. (1975): Foundations on expansive soils. Elsevier Scientigic Publishing Company, Amsterdam.

Chen, F.H. (1988): Foundations on expansive soils, developments in geotechnical engineering, second Ed. Elsevier, Amsterdam.

Chen, F.H. (1988): Foundations on expansive soils, developments in geotechnical engineering, second Ed. Elsevier, Amsterdam.

Dakshanamanthy, V. and Raman, V. (1973): A simple method of identifying an expansive soil: Soils and Foundations, Vol. 13, No. 1.

Dhowian, A. W. (1981): Characteristics of AL-Ghatt collapsing and swelling soils. Proceedings, Symposium on Geotechnical Problems in Saudi Arabia, Riyadh.

Dhowian, A., Ruwiah, I. and Erol, A. (1985): The distribution and evaluation of the expansive soils in Saudi Arabia. 2nd Saudi Engineering Conference, KFUPM, Dhahran, Vol. 4.

Dhowian, A., Ruwiah, I. and Erol, A. (1985): The distribution and evaluation of the expansive soils in Saudi Arabia. 2nd Saudi Engineering Conference, KFUPM, Dhahran, Vol. 4.

Dhowian, A.W., Erol, A. O. and Youssef, A. (1990): Evaluation of expansive soils and foundation methodology in the Kingdom of Saudi Arabia. Final Report, KACST, AT-5-88.

Dhowian, A.W., Erol, A. O. and Youssef, A. (1990): Evaluation of expansive soils and foundation methodology in the Kingdom of Saudi Arabia. Final Report, KACST, AT-5-88.

EI-Sobhy, M. A. (1981): Activity of soils, Procceedings, 10th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, Stockholm, Sweden, pp. 587-591.

EI-Sobhy, M. A. and Mazen, S. O. (1983): Mineralogy and swelling of expansive clayey Soils, Geotechnical Engineering. Journal of the Southeast Asian Society of Soil Engineering, Thailand, Vol. 14, pp. 79-87.

EI-Sobhy, M. A., Rabba, S. A., and Mazen, S. O. (1985): Role of mineralogical composition in the activity of expansive soils. Transportation Research Record #1032, National Research Council, Washington D.C., pp. 28-33.

El-Sayed, S. (1981): SCII of swelling and collapsing behavior, Mobaraz Town, Eastern K.S.A. Proceedings, Symposium on Geotechnical Problems in Saudi Arabia, Riyadh.

Evaluation of engineering properties of soil in Al Butayn, Mudarraj Al Qassim and Turubah –Hail, Saudi Arabia. SGS-TR-2016-3.

Expansive Soils Problems and Practice in Foundation and Pavement Engineering John D. Nelson and Debora J. Miller, Wiley, New York, 1992, 259 pp.

Gromko, G. J. (1974): Review of expansive soils. Journal ASCE, Geotechnical Division, Vol. 100, No. GT6, pp. 667-687.

James K. Mitchell. 1930: Fundamentals of soil behavior. 2nd ed. Jon Wiley & Sons Inc. 1993.

Johnson, L. D. and Snethen, D. R. (1978): Prediction of potential heave of swelling soil. Geotechnical Testing Journal, Vol. 1, No. 3, pp. 117-124.

Mitchell, J. K. (1976): Fundamentals of soil behavior. John Wiley & Sons, Inc., New York.

Mitchell, J.K., Raad, L., 1973. Control of volume changes in expansive earth materials, in: Lamb, D.R., Hanna, S.J. (Eds.), Proceedings of the Workshop on Expansive Clay and Shales in Highway Design and Construction, vol. 2. Federal Highway Administration, Denver, CO, pp. 200–219.

Nelson, J. D., Chao, K. C., & Nelson, E. J. (2015). Foundation engineering for expansive soils

Okasha, T. M. A. (1988): Mineralogical and geotechnical studies of expansive soils in Al-Madinah and Al-Hofuf Cities, Saudi Arabia. M.S. Thesis, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.

Rogers, J. David, Olshansky, R., Dan Rogers, Robert B., 2004, Damage To Foundations from Expansive Soils.

Sabtan, A.A. (2005): Geotechnical Properties of Expansive Clay Shale In Tabuk, Saudi Arabia. Journal of Asian Earth Sciences, Vol. 25, pp. 747–757.

Seed, H. B., Mitchell, J. K. and Chan, K. C. (1961): Studies on swell and swell pressure characteristics of compacted clays. Bullettin 313, HRB, National Research Council, Washington, D.C., pp. 12-39.

Seed, H. B., Woodward, R. J. and Lundgren, R. (1962): Prediction of swelling potential for compacted clays. Journal of Soil Mechanics and Foundation Engineering Division, ASCE, Vol. 88, No. SM3, pp. 53-87.

Van Der Merwe, D. H. (1964): The prediction of heave from the plasticity index and percentage clay fraction of soils. The Civil Engineer in South Africa, Vol. 6, No. 6.

Wray, Warren K So your home is built on expansive soils: a discussion of how expansive soils affect buildings. 59 pages. American Society of Civil Engineers, New York, 1995.

VITA

Turki Essam Sehly was born in Abha, Kingdom of Saudi Arabia in April 28,1976. He entered Faculty of Earth Sciences, King Abdul Aziz University where he received his bachelor's degree in applied Geology (Engineering Geology), Jeddah; February1999.

He then became an Engineering Geologist, United States Geological Survey Mission, Ministry of Petroleum, Jeddah, Industrial Mineral department from June 2000 to February 2001. In February 2001 to April 2007: Engineering Geologist, Geohazards & Engineering Geology Department, Saudi Geological Survey, Jeddah, January 2009 to January 2012 Assistant of Head of Engineering Geology Department, and January 2012 to Present Geohazards Department team.

He was the leader and team member of many projects such as: January 2015 to December 2016 Project Leader of stability analysis of rock cuts and slopes, and mitigation Strategies along the Alkhuraytah descent road, Tabuk region. January 2015 to December 2016 member of team project of Earth Fissure hazards, at Aljuf, ALQassem, Hail regions.

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Finally, married Mashael Al Oqbi in 2001, and had two sons and two daughters. In May 2020 he received his master's degree in Geological Engineering from Missouri University of Science and Technology.