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Full Length Article

Improvement of geotechnical properties of sabkha soil utilizing cement kiln dust

Abdullah A. Al-Homidy [a], Mohammed H. Dahim [a], Ahmed K. Abd El Aal [a,b,*]

[a] Department of Civil Engineering, Najran University, Najran, Saudi Arabia
[b] Geology Department, Faculty of Science, Al Azhar University, Assiut, Egypt

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ABSTRACT

Improvement of properties of weak soils in terms of strength, durability and cost is the key from engineering point of view. The weak soils could be stabilized using mechanical and/or chemical methods. Agents added during chemical stabilization could improve the engineering properties of treated soils. Stabilizers utilized have to satisfy noticeable performance, durability, low price, and can be easily implemented. Since cement kiln dust (CKD) is industrial by-product, it would be a noble task if this waste material could be utilized for stabilization of sabkha soil. This study investigates the feasibility of utilizing CKD for improving the properties of sabkha soil. Soil samples are prepared with 2% cement and 10%, 20% or 30% CKD and are tested to determine their unconfined compressive strength (UCS), soaked California bearing ratio (CBR) and durability. Mechanism of stabilization is studied utilizing advanced techniques, such as the scanning electron microscope (SEM), energy dispersive X-ray analysis (EDX), backscattered electron image (BEI) and X-ray diffraction analysis (XRD). It is noted that the sabkha soil mixed with 2% cement and 30% CKD could be used as a sub-base material in rigid pavements. The incorporation of CKD leads to technical and economic benefits.

1. Introduction

The rapidly growing population and industrialization are exerting tremendous pressure on the construction industry to build necessary infrastructure in Saudi Arabia. The newly developed infrastructure is mostly concentrated along the coastal areas, mainly on weak soils. These soils need to be stabilized utilizing chemical and/or mechanical methods. Portland cement and lime are commonly utilized materials for chemical stabilization. Some other materials, such as fly ash, are also utilized for this purpose.

Sabkha is an Arabic word meaning salt flat and is applicable to both coastal and interior salt flats. There are two types of sabkha soils, i.e. sandy sabkha soil and muddy sabkha soil. Sandy sabkha soil is very loose to medium dense soil and may sometimes be partially cemented by salts. Muddy sabkha soil is a kind of lagoon sediment mainly consisting of sandy carbonate mud. According to their locations, sabkha soils are mainly found in coastal and inland (continental) areas (Juillie and Sherwood, 1983).

Sabkha soils are commonly observed in Saudi Arabia, both in coastal and inland regions. The coastal sabkha soils extend along both the Arabian Gulf and the Red Sea shores, while the inland ones are mainly found in creeks scattered in the northeastern and eastern parts of the Arabian Peninsula, as shown in Fig. 1. Sabkha soils in the coastal plains of the Eastern Province are well documented (Johnson et al., 1978; Al-Amoudi et al., 1992), while the Red Sea coastal ones exist at Obhor, Al-Lith, Yanbu and Jazan. In the north, continental sabkha soils are reported to exist in Wadi As-Sirhan (Sabkhat Hadhoud) and in many other creeks in the region that usually run parallel to either the Red Sea or the Gulf of Aqaba. Coastal sabkha soils in Saudi Arabia are quite extensive and pose challenging issues to the construction activities along its shorelines. Fig. 1 shows the distribution of sabkha soils in the Arabian Peninsula and the generalized cross-section across coastal sabkha soils with typical surface feature.

Both coastal and inland sabkha soils are usually formed in hot, semi-arid to arid climates and are associated with shallow groundwater table. When the sabkha soil is dry, the surface of a

* Corresponding author.
E-mail addresses: Ahmed_Aka80@yahoo.com, Akahmed@nu.edu.sa (A.K. Abd El Aal).
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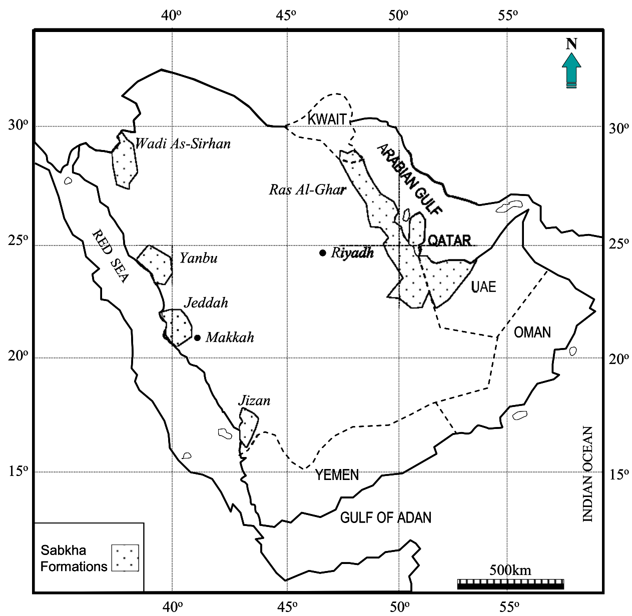

Fig. 1. Distribution of sabkha soils in the Arabian Peninsula (Al-Amoudi et al., 1992).

sabkha flat is usually hard enough to support a medium-weight vehicle, but becomes too weak when the sabkha is wet and any vehicle may sink in it (Renfro, 1994). The sabkha soil has compounded construction problems when it becomes wet, such as large concentration of salts, increasing compressibility, very low shear strength and other associated problems. Some sabkha soils have gravel mixtures within their matrices. The presence of these gravelly sediments is more common in the continental sabkha soils rather than in the coastal ones (Ghazali et al., 1985). Furthermore, the natural moisture content of sabkha deposits ranges from 8% to 65% (Abu-Taleb and Egeli, 1981).

The industrialization has also resulted in the production of significant quantities of industrial by-products. Considerable resources are utilized to dispose of the waste materials to meet the environmental restrictions. Consequently, there is a need to assess the alternative possibility of utilizing the waste materials in the stabilization of sabkha soils. Such possibilities will satisfy the economic and environmental requirements. Although some work has been conducted to evaluate the possibility of utilizing cement and lime for stabilizing weak soils over the world, researches are needed to understand the possibility of utilizing the industrial by-product for soil stabilization. Besides, there is a strong desire to reduce the consumption of cement through effective utilization of industrial waste materials in order to decrease greenhouse effect and environmental problems.

The above review shows that sabkha soils are highly variable materials with inferior "natural" strength capacity, thereby leading to several constructional problems when used. The major factor contributing to these problems is the low bearing capacity of the sabkha soils. Moreover, sabkha soils are very sensitive to moisture. Complete collapse and reduction in bearing capacity are anticipated when they are in contact with water (Al-Amoudi, 1995a; Xiao et al., 2015). Such behavior shows that the cementing materials bonding the mineral grains of sabkha soils together are relatively soluble in water, such as halite, gypsum, aragonite or calcite, thus making the sabkha soils susceptible to collapse upon exposure to moisture.

2. Characterization of materials

The selected soil and industrial by-product, cement kiln dust (CKD), are tested to determine their mineralogical and physical properties.

2.1. Sabkha soil

The concentrated nature of sabkha brine is reflected by total dissolved solids (TDS) of as much as four to six times those presented in typical seawater from the same region, as listed in Table 1.

2.1.1. Collection of soil samples

The eastern Saudi soils, namely sabkha soil samples, are collected as representative sabkha soils from Ras Al-Ghar site. Fig. 1 shows the location of sampling point. The industrial by-product (CKD) is procured from the Saudi Arabian Cement Company, Jeddah.

Firstly, the soil samples and industrial by-product (CKD) are collected. Next, the chemical composition and physical properties of the soils and CKD are experimentally determined. Besides, Atterberg limits and sieve analyses of the soils are also determined. Thirdly, the maximum dry density and optimum moisture content of the suggested mixtures are obtained. Fourthly, the unconfined compressive strength (UCS) of the proposed mixtures is tested. Fifthly, the soaked California bearing ratio (CBR) of the mixtures that satisfy the strength requirement is determined. Sixthly, the mixtures that satisfy the strength and CBR requirements are subjected to durability tests. The six tasks will be discussed in detail in the following sub-sections.

2.1.2. Mineralogical analyses

Knowledge of mineralogical composition of a material helps to predict its behavior and reaction under different environmental conditions. The mineralogical analyses of the soil and CKD are performed.

The soil samples are initially air-dried, sieved using #10 sieve and completely mixed for homogenization. They are then pulverized and sieved using #200 sieve. Thereafter, the pulverized soil samples are oven-dried at 70 °C for 72 h (Conklin, 2005; Brady and Weil, 2010). Finally, about 10 g of each soil sample is utilized for mineralogical analyses. The mineralogical composition of the soil and CKD is determined by X-ray diffraction (XRD) method. The X-ray diffractometer used in this study is Rigaku Ultima IV. The generator settings are 40 kV and 40 mA at an angle between 6° and 90° (2θ).

Furthermore, samples that satisfy the strength and durability requirements are prepared and utilized for mineralogical analyses in order to determine the chemical products that might be behind the improvement developed by the stabilization using various types of industrial by-products.

Fig. 2 shows the X-ray diffractogram for sabkha soil sampled from Ras Al-Ghar. Peaks for quartz (75%), gypsum (12%) and halite (10%) are noted in addition to traces of other minerals. The high percentage of quartz is responsible for the non-plastic and fine-grained nature of this type of sabkha soil (Al-Amoudi et al., 1992).

2.1.3. Specific gravity

The specific gravity is needed for the calculation of void ratio, unit weight of soil, and soil particle size analysis. Since the sabkha soil sample is sieved through #4 sieve and the particle sizes of the proposed stabilizers are smaller than 4.75 mm, the specific gravity is determined in accordance with ASTM D854-14 (2014). The test is conducted on two representative "disturbed" dried samples from each material and the average is taken as the specific gravity value.