Application of Date Palm Ash to Improve Strength Characteristics of Sabkha Soil

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Abstract. Surface layer of earth’s crust in Kingdom of Saudi Arabia is composed of loose sand with soluble salts, which is generally termed as Sabkha. Poor strength and durability characteristics of the Sabkha soil adversely challenge the safety and serviceability of infrastructure built on it. Therefore, improvement of its physical properties demands urgent attention of the engineering society. In this study, date palm ash (DPA), a local industrial waste, is utilized as an additive to improve strength characteristics of problematic Sabkha soil. A remarkable improvement in compaction characteristics and compressive strength is achieved. By investigating the effect of different proportions, the optimum quantity of additive is determined with respect to compressive strength.

1. Introduction

Since the prominent oil boom of the 1970s and demographic growth, the Kingdom of Saudi Arabia is rapidly developing infrastructure facilities which are mainly concentrated along the coastline. The soil in shallower depth of the region is mainly composed of loose sand with soluble salts, which is generally termed as Sabkha [1]. These salts occur as crusts on the surface or in the dissolved form in soil moisture [2]. Previous studies [3 -6] revealed that magnesium, calcium, sulphates, sodium, chlorides, and carbonates of calcium dominate the salt precipitation in the Middle Eastern desert region. Presence of crystalized salt makes the cementation bond very weak. The presence of high salt content, extreme environmental conditions, and fluctuation of ground water table lead to large changes in density, consistency, strength, and swelling and shrinkage characteristics of the soil [7 - 9]. All these changes make the soil highly variable and complex in nature and can drastically damage the foundations as well as other infrastructure above them, especially to lightweight structures [8, 10]. Expansive behavior of the salt bearing soil along with salt crystallization leads to differential settlements and cracking of the pavement structures [11].

The strength and durability characteristics of the problematic Sabkha soil need to be improved to the civil engineering requirements by mechanical and/or chemical stabilization methods, which will reduce permeability and compressibility of the soil mass and increase its shear strength. In chemical stabilization, cement, bituminous materials, lime, blast furnace slag, and fly ash are most commonly used binders [12, 13]. Due to its high strength, workability, durability and availability, Ordinary Portland Cement (OPC) has been most excessively used for ground improvement. Nevertheless, production and processing of cement consumes huge amount of energy and has a significant
contribution in global greenhouse gas emissions which is threatening for the environment [14]. The increasing use of cement also affects surface runoff of water, vegetation growth, and quality of ground water. Furthermore, the irreversible hydration reaction of cement makes it almost impossible to retain the original untreated state of soil [15]. Furthermore, cement is also considered relatively expensive for its mass scale application of ground improvement. To address the shortcomings of OPC, different ash-based cementitious binders evolved in the field of geotechnical engineering. Some typical examples of these binder include oil palm shell (OPS), palm oil fuel ash (POFA), and biomass ash (BA). The ash based cementitious materials are deemed environment-friendly and they have comparable or even better characteristics than OPC [16, 17].

Date palm is one of the major agricultural products in arid and semi-arid regions. The Kingdom of Saudi Arabia has more than 23 million date palm trees which produce enormous mass of agricultural waste in the form of midribs, stems, leaves, fronds, and coir. It has been revealed in some studies that Saudi Arabia annually produces more than 200000 tons of date palm biomass. Usually, date palm wastes are disposed in landfills or burned in the farms which cause environmental pollution. Despite producing excessive amount of date palm ash (DPA), no significant attention has been paid to make its use in construction and ground improvement.

This article presents an improvement in strength and durability properties of the salt bearing desert sand (Sabkha) by the addition of date palm ash (DPA), a locally produced industrial waste. It has a dual benefit of improving ground condition and reducing the environmental waste. Since all other Gulf countries have similar trend with respect to soil compositions, behavior, and production of date palm ash, outcomes of this study could be equally applicable to the whole Gulf region.

2. Study Area and Methodology

Study Area. The soil employed in this study was sampled from King Fahad Suburb, a new residential city developed in the west of Dammam, Saudi Arabia (Fig. 1). The surface layer of the soil in the study area is loose sand with different types of salts in dissolved or crystalline form. Analyzing the soil investigation reports provided by the municipality, it has been observed that the ground water table is very shallow in the whole study area. The residential, commercial and community service structures built on the problematic soil of the study area experienced severe cracking and damages due to excessive total and differential settlement of the foundations. Currently, there is increasing pressure from the inhabitants for the municipality to provide lasting solution to protect their lives and properties. The date palm ash used in this study is obtained from a local palm recycling plant.

![Study Area](image)

**Figure 1.** The Study Area (King Fahad Suburb, Eastern Province, Saudi Arabia)

Methodology. The DPA is mixed in different proportions of 2.5%, 5%, 7.5% and 10% by wight to the oven dried soil. The required amount of DPA is thoroughly mixed in the dry soil passing sieve number 4.
For Unconfined Compression Test (UCT), cubical specimens (5cm x 5cm x 5cm) were prepared for all the proportions of DPA. The specimens were properly cured for seven days before testing. The standard ELE equipment is used to perform sieve analysis, standard proctor compaction, and unconfined compression tests in order to determine grading, compaction, and strength attributes of the collected soil samples. ASTM standard procedures were followed in performing all the experiments.

3. Results and Discussion

Gradation. The sieve analysis tests were performed on the collected samples in accordance with ASTM D6913 to obtain soil gradation. It is very clear from the gradation curve (Fig. 2) that the surface layer of the soil in the study area is poorly graded, dominated by the percentage of sand. The percentage of gravels, sand and fines is found to be 6.5%, 90.5%, and 3.0%, respectively. The soil is classified as “A-3(0)” according to American Association of State Highway Transportation Officials (AASHTO), while “SP (poorly graded sand)” according to Unified Soil Classification System (USCS).

![Figure 2. Grain size distribution curve of a representative soil sample from the study area](image)

Compaction Characteristics. Following ASTM D558, the compaction characteristics of the collected soil samples were determined in their natural condition as well as with different proportions of DPA. The tests were performed initially by adding 7% of water to the oven dried soil samples, followed by an addition of 4% each time until we get at least two (02) points to ensure decline of compaction curve.

Figure 3 represents compaction curves along with variation of optimum moisture content (OMC) and maximum dry density for different proportions of DPA. It is evident from both the figures that the maximum dry density is continuously increasing with the increased proportion of DPA. The fine DPA grains are filling the voids between the sand particles, giving a higher maximum dry density. The optimum moisture content is also increasing with the increased proportion of DPA. It is well in line with the literature studies that a soil with more fine particles will have higher OMC. This is due to the fact that more water is required to make a lubricating film around increased number of particles.
Figure 3. Compaction curves for the soil samples with different proportions of DPA (left), and variation of maximum dry density and OMC with different proportions of DPA (right)

Unconfined Compressive Strength. To investigate the cementitious properties of DPA, the soil samples with all the adopted proportions of the additive were tested in Unconfined Compression testing machine in accordance with ASTM D2166. Figure 4 represents compressive strength of all the tested samples. The results showed a remarkable increase in compressive strength up to 7.5% of DPA and a decline after that. The decline of compressive strength could be attributed to the domination of fine content in the sample over cementitious properties of DPA.

Figure 4. Effect of different proportions of DPA on Unconfined Compressive Strength of Sabkha soil

4. Conclusions

Surface layer of earth’s crust in Kingdom of Saudi Arabia is composed of loose sand with soluble salts, which is generally termed as Sabkha. This Sabkha soil has poor strength and durability characteristics which adversely effect the infrastructure built on it. Therefore, it needs to be improved to the civil engineering requirements by mechanical and/or chemical stabilization methods.

In this study, a remarkable improvement in compaction characteristics and compressive strength of the Sabkha soil has been achieved by adding different proportions of date palm ash (DPA), a locally available industrial waste. Investigation has proved 7.5 % of the date palm ash as the optimum proportion of additive giving maximum compressive strength.
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