Stabilisation of Sohar’s Sabkha soil using waste gypsum plasterboard

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Abstract. Sabkha soil are salt-encrusted desert flats typically found in arid regions. Construction developments on naturally occurring Sabkha soils are usually problematic. This study examines the properties of Sabkha soil obtained from Sohar city of Oman. The Sabkha soil samples were further treated with Gypsum obtained from waste plasterboards at varying percentages of 3, 6, 9 and 12 with a view to stabilising the soil. From the results, Sohar Sabkha soil is a poorly graded sand (SP) with AASHTO classification of A-2-7(0), therefore, it is unsuitable for supporting infrastructures in its natural form. The pH test confirms the reaction between Sabkha and Gypsum, while both the compaction and unconfined compression strength (UCS) tests revealed the optimum percentage of gypsum required to enhance the properties of Sabkha soil to be 6%. The California Bearing Ratio (CBR) test yielded a 33.3% increase in CBR value for Sabkha treated with 6% of Gypsum over untreated Sabkha. Overall, a better understanding of sabkha soil and the confirmation of the potential use of Gypsum for its stabilisation was achieved in this study.

1. Introduction

Arid regions are characterised by substantial paucity of precipitation compared with evaporation. This disproportionate moisture loss yields salt concentrated rock profiles in sedimentary basins. A typical example of soil formed from such basins is the Salt-encrusted desert flats, also known as “Sabkha” [1, 2]. Sabkhas are widespread in the Arabian Peninsula, both in the inland and coastal areas, and are depicted as “continental sabkha” and “coastal sabkha”, respectively [3, 4]. Prominent distinctive features of Sabkha include their large dimension, flat slope, presence of saturated groundwater, salinity and evaporative tendencies [5, 6].

Sabkhas are known for their low-bearing strength and high compressibility. They are generally loose, porous, permeable, unconsolidated, moderately dense silt/sand material often with clay/mud interbeds of varying texture, composition, size and shape [7, 8]. With such a high concentration of salts, Sabkha soil is not suitable to use for construction purposes. At dry state, sabkha appears strong, but when in contact with water, the salt dissolves and leaves behind loose particles of soil [3].

The properties of Sabkha soil are well below engineering requirements. It is not suitable to be used as a foundation base or for road construction. Construction developments on naturally occurring Sabkha soils are liable to suffer foundation settlement and failures owing to the dissolution of cementing materials, which are mostly saline in nature [9, 10]. Cracks and tilts in walls, and
dislocation of service pipes are associated problems of buildings founded on untreated Sabkha, while rutting, raveling, cracking and formation of large potholes are some of the undesirable outcomes of road construction on natural Sabkha soils [11-13].

Geotechnical engineers have devised different approaches to improving properties of weak soils and making them viable for construction purposes. Mechanical/dynamic compaction, grouting, vibroflotation, preloading, recompaction, soil nailing, deep soil mixing, use of micro piles, geotextiles, installation of stone columns, prefabricated vertical drains, wick drains etc. are examples of ground improvement methods [14, 15]. However, the most common and cost effective method is by the incorporation of additives into soils, also known as chemical stabilisation [16].

Stabilisation methods enhance numerous engineering characteristics of soil. The resultant soil possesses increased stiffness, durability and strength with a reduction of shrinkage/swelling and plasticity, yielding an improved construction material [17]. Cement and lime are the foremost materials utilized in chemical stabilisation of soils [18-21]. However, with the increasing awareness of sustainability, waste materials from industrial and/or agricultural processes such as fly ash, bottom ash, rice husk ash, palm oil fuel ash, ground granulated blast furnace slag etc. have been employed in recent researches to improve the properties of weak soils [22-26].

Globally, the generation of construction and demolition wastes has continued to skyrocket, in correspondence with upsurge in construction activities; and the management of such wastes has continued to defy conventional strategies [27, 28]. The utilization of construction and demolition wastes in construction activities is a cost effective means of achieving environmental sustainability and resolving the waste management conundrum [29, 30]. Gypsum is a versatile construction material used as pastes and mortars for rendering of walls; and plasterboards for ceiling and decorative elements. Plasterboard is a board made of gypsum lined with paper on both sides. Gypsum accounts for a significant percentage of construction wastes generated on building construction sites [31, 32].

Oman lies in the southeastern corner of the Arabian Peninsula. It has an arid climate with topography primarily of deserts [33]. Al Batina (Batina coast), Ash Sharqiyah (As Suwayh), Al Wusta (Sawqirah) and Ad Dhahirah are the four areas where Sabkha soil can be found in Oman as illustrated in Figure 1. Sohar is the main city of Oman’s second most populous province, Al-Batinah. Sohar’s strategic location; midway between Muscat and Dubai, its unique history as a seafaring hub, its fertile agricultural lands, and most importantly, its designation as an industrial city which arose from the development of a deep port and the creation of economic free zone, catalyzed construction activities in Sohar in recent decades [34]. All these also led to an upsurge in Sohar’s inhabitants; as at June 2018, the population of Sohar stands at 231,102 comprising 51% Omani and 49% Expatriates [35].

Sohar has an extensive stretch of Sabkha soil. The soils in these parts of Sohar are unsuitable for foundation base for buildings and for road construction. This hinders the developments of infrastructure in these areas. Equally, Gypsum wastes are being generated in large quantities on building construction sites in Oman. It will be highly interesting to device an efficient utilisation of Gypsum waste which will eventually lead to a reduction in its handling cost and lessen the environmental concerns. This research investigates the physical properties and some engineering properties of Sohar’s Sabkha soil. In addition, the study examines the potentials of gypsum obtained from waste plasterboards as a stabilising agent for Sabkha soil.
Figure 1. Geological map of Oman showing the four areas where Sabkha soil are found.

2. Methodology

2.1 Materials
Sabkha soil samples were collected from Sohar coast near Silver Jubilee Public Park. More than 400 kg of sabkha soil was collected and conveyed to the Soil Mechanics Laboratory of Military Technological College (MTC) where it was air dried before usage. The waste Gypsum plasterboards were obtained from the remains of model buildings of MTC students on “work-based projects” module in the previous semester. The students used the plasterboard for numerous purposes in their projects, and it became a waste after the completion of the project. Samples were crushed, screened, grinded and dried using the Oven at 105°C for one hour. The amount of waste gypsum plasterboard used is about 10 kg. Figure 2 shows samples of waste Gypsum plasterboard and the finally obtained oven-dried Gypsum.
Figure 2. Waste gypsum plasterboard and oven dried gypsum.

2.2 Experimental Tests
Sabkha soil samples were tested for physical properties tests such as moisture content, sieve analysis, specific gravity, and Atterberg limits in accordance with BS 1377-2;1990 [36]. Compaction, pH and Unconfined Compression Strength (UCS) tests were carried out on untreated Sabkha and Sabkha mixed with 3, 6, 9 and 12% of Gypsum in accordance with BS 1377-4;1990, BS 1377-3;1990 and BS 1377-7;1990, respectively [36]. UCS samples were made using 38 mm diameter mould, the corresponding Optimum Moisture Contents (OMC) and Maximum Dry Density (MDD) obtained from the compaction tests were used to quantify the materials required, the samples were thereafter tested after 1, 7 and 28 days of curing as shown in Figure 3.

Furthermore, California Bearing Ratio (CBR) test was done on both untreated Sabkha and Sabkha mixed with 6% of Gypsum for both soaked and unsoaked conditions according to BS 1377-4;1990 [36]. The CBR test was carried out on the material passing the 20 mm test sieve. The moisture content utilised for the preparation of the sample was the optimum ratio achieved in compaction tests. For untreated Sabkha, 5000g of soil was mixed with 1364g of water. The treated sample of Sabkha was prepared by mixing 4700g of soil with 300g of gypsum and 1364g of water. The unsoaked CBR test was done on the same day while soaking of samples was done for 4 days before the soaked CBR test was done (Figure 3).

Figure 3. Sample preparations for UCS and CBR tests.
3. Results and discussions

3.1 Physical properties of Sabkha soil

The natural moisture content of Sohar sabkha soil was found to be 25.64%. This is very high but the value is comparable to that of Sabkha from Egyptian-Libyan coast [7]. Figure 4 shows the particle size distribution curve of the Sabkha soil. From the curve, it can be deduced that Sabkha soil consists of 10% fines (silt and clay), 69% of sand and 21% of clay. The uniformity coefficient (Cu) and coefficient of curvature (Cc) were calculated to be 32.4 and 0.24, respectively. According to ISO 14688-2 [37], if $Cu > 15$ and $Cc < 0.5$, the soil has a gap graded particle size distribution. The specific gravity of natural Sabkha soil was determined to be 2.78 Mg/m$^3$. The values for the Atterberg limits tests are detailed in Table 1 along with the classification of the Sohar Sabkha soil based on USCS and AASHTO nomenclatures.

![Figure 4. Particle size distribution curve of Sohar Sabkha soil.](image)

| Property                | Value       |
|-------------------------|-------------|
| Natural Moisture Content| 25.64%      |
| Specific Gravity (Gs)   | 2.78        |
| Liquid Limit (LL)       | 56.36%      |
| Plastic Limit (PL)      | 29.42%      |
| Plasticity Index (PI)   | 26.70%      |
| Liquidity index(LI)     | 24.73       |
| USCS classification     | SP          |
| AASHTO soil classification| A – 2 – 7 (0)|
3.2 Acidity/Alkalinity
Sabkha soil and Sabkha mixed with 3%, 6%, 9% and 12% Gypsum were investigated for their pH. Figure 5 shows the results. Immediately after the set-up, it was observed that the PH value for untreated Sabkha soil was about 9 which indicated that the Sabkha soil was salty and alkaline. Sabkha mixed with different percentages of Gypsum have lower pH values. This implies that they have higher acidity because of the chemical reaction that took place between the salts in the soil and the Calcium contents of Gypsum. After eight hours, it was observed that the reactions were higher because the acidity increased while the pH values were lower. This confirmed that the gypsum reacted with the sabkha soil, and the measured pH values were found to be between 6 and 7, which are acceptable values in environmental regulations.

![Figure 5. Results of pH test.](image)

3.3 Compaction
Figure 6 shows the compaction curves for the untreated Sabkha and Sabkha-Gypsum mixtures. The unit weight of untreated sabkha soil increased with increasing water content until an optimum value was reached. Beyond the optimum moisture content, the unit weight decreased with increase in moisture content. Similarly, the unit weight of the treated sabkha soil was influenced by the moisture content in the same way. In addition, the unit weight of the treated sabkha was influenced by addition of waste gypsum. For each percentage, there was optimum moisture content at which the highest unit weight was achieved. In all cases, the unit weight of the treated soil was higher than the unit weight of untreated soil. The 6% gypsum addition gives the highest value of optimum moisture water and the corresponding maximum unit weight. Therefore, for optimum stabilisation of Sabkha soil, the 6% gypsum addition is the most economical and practical percentage to be adopted.
3.4 Unconfined Compression Strength (UCS) Test

Both untreated and treated Sabkha samples with 3, 6, 9 & 12% of Gypsum were tested at 1, 7, & 28 days. Figure 7 shows the values of unconfined compressive strength, \( q_u \) obtained from the tests. The compressive strength increased with the increase in waste gypsum content up to 6%. It was observed that adding more than 6% of waste gypsum resulted in the decrease of the compressive strength. In addition, increase in number of curing days also increased the compressive strength for all the different percentage of gypsum added, and the highest values were obtained at 28 days of curing. In summary, the highest \( q_u \) value of 2320 kPa was obtained for the 6% Gypsum addition at 28 days. This corresponds to 33.3% increase over that of untreated Sabkha, 1740 kPa, at the same 28 days of testing.

Figure 7. Unconfined compressive strength for different Sabkha-Gypsum mixtures.
3.5 California Bearing Ratio (CBR) test
The California Bearing Ratio (CBR) test was done on both untreated Sabkha and Sabkha mixed with 6% of Gypsum for both soaked and unsoaked conditions. From the load–penetration curve of Figure 8, it was observed that the unsoaked samples for both treated and untreated soil have more resistance to penetration than the soaked sample. It was also observed that the treated sabkha has more resistance to penetration than the untreated sabkha. The loads at 2.5 mm and 5 mm penetration were taken to calculate the CBR values, respectively. With an unsoaked CBR value of 127.2 and 50.9 respectively, the Sabkha soil treated with 6% Gypsum demonstrates a very high strength compared to the untreated Sabkha soil. Similarly, for the soaked condition, the CBR values of 101.7 of the treated sample is a significant improvement over 35.6 of the untreated sample. In both soaked and unsoaked conditions, the values of CBR for the Sabkha soil treated with 6% of Gypsum are above 100. This confirms the suitability of practical use of gypsum for the stabilisation of weak sabkha soil for use as subbase and subgrade materials in highway constructions.

Figure 8. Load-penetration and CBR values of treated and untreated Sabkha soil samples.

4. Conclusion
Sohar Sabkha soil was explored to establish its properties and to probe its response to the addition of Gypsum from waste plasterboards. It was discovered from the physical properties’ tests and the ensuing soil classification that Sohar Sabkha soil is not suitable for supporting infrastructures in its natural state. Further tests were carried out after mixing 3, 6, 9 & 12% of Gypsum to the soil and optimum results were obtained with 6% Gypsum addition. The study proved the suitability of stabilisation of the Sabkha soil with waste gypsum plasterboards.

This research is highly significant because it provides engineers with the exact soil parameters to use in the design of structures and roads on Sohar sabkha soil. This will prevent construction failures and enhance the quality of construction projects in Sohar. It will open up more virgin sabkha soil construction of buildings and roads at no risk of hazards or construction problems. The use of construction wastes for the stabilisation of sabkha soil is a novel idea that will lead to a reduction in cost of handling wastes and it is environmentally friendly. Overall, a better understanding of sabkha soil and the method of stabilisation was achieved through this study.

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