

Calcareous Sediment in Saudi Arabia: A Review of Marl Soil

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Abstract: *Calcareous sediment, named marl, is predominant type soil in eastern Saudi Arabia. The main trait of marl is Calcium carbonate (CaCO_3), organic and some clay. Thus, carbonate mineral influenced the nature and behavior of marl. Marl is usually used as subgrade layers or as a backfill in base and subbase layers of roads and highways. Unfortunately, Marl has poor strength and high water sensitivity; a drastic loss of bearing capacity occurs upon immersion. In this review, detailed discussion is presented on the current treatment of marl soil and the different type of stabilizers that was used to improve the engineering properties of marl. In addition, the proper correlations for marl properties with instrument index such as Clegg Hammer index will be discussed.*

Keywords: *Marl soil, Clegg Hammer, CBR, Unconfined compressive strength, plasticity index, Chemical treatment, permeability.*

1. Introduction

During the past three decades, there has been a construction boom in the cities in the Arabian Gulf area. Particularly, in eastern province of Saudi Arabia, enormous development programs including new industrial areas establishment, widening of petrochemical facilities, highways and airports construction, and considerable urbanization in the whole area. In all of that development programs, calcareous marl soils were utilized in the base-course of highways, service roads and foundations.

Marl is considered to be one of the four predominant types of soils found in eastern Saudi Arabia (i.e., sand, marl, clay and sabkha). Marl soils are uniquely used in the construction of almost all types of road bases, embankments and foundations. Marl soil is a synonym of calcareous sediments [1]. It has been defined by several researchers as a soil containing calcium carbonate (CaCO_3). Terzaghi and Peck [2] explained marl as a greenish calcareous marine clay varying from stiff to very stiff clay. Marl defined as a rock containing 35% to 65% of carbonate and some amount of clay [3]. Moreover, marl is known as a marine deposit of silty or clayey sand [4]. That deposit has calcite and occasionally organic colloids. Bates and Jackson [5] stated that marl is an old expression generally used for several materials. These materials are consisting, mostly, of calcium carbonate and clay. Akili [6] realized marl as a dual mixture of clay and calcium carbonate (CaCO_3). McCarthy [7] denoted soft limestone as marl. Mitchell [8] has illustrated marl as a soft calcareous material rich of clay. In addition, it is hardly consolidated and it might contain shell fragments. Moreover, marl is regularly known as argillaceous limestone [1].

1.1. Geology and Nature of Marl

Marl is accounted as a calcareous material in nature due to the presence of calcium carbonate (CaCO_3) in its composition. Over more, marl deposits are considered as a peat deposits or highly organic type of soil and contain shell fragments [9]. In addition, marl contains deferent quantities of fine soils like silt or clay. The predominant type of carbonate minerals in marl composition is calcite which has better stability than other carbonate minerals [10]. However, other carbonate minerals like dolomite, siderite and aragonite could exist in marl composition [3].

Calcareous soil is acutely water sensitive; though the strength of marl is usually high when it is dry [11,12]. Such a concern is ascribable to the fact that an almost complete strength loss may result upon inundation, particularly when the material is compacted on the wet side of optimum moisture content. The difficulty in obtaining good substitutes for the local marl for the construction of all types of earthwork has forced the researchers and practicing engineers to explore the possibility of upgrading this soil. Figure 1 is a map for marl quarries in Eastern Province in Saudi Arabia. However, marl soils have many engineering problems. For example, Marl soils are heterogeneous, have low dry density and sensitive to water. Therefore, the nature and behavior of marl have to be adjusted in order to achieve desirable engineering performance. Accordingly, the characterization of this soil should consider its inferior properties and the possible chemical stabilization to minimize or control its inferior behaviour in moist condition. The success in improving the performance of these soils will have a tremendous cost saving impact on the maintenance and life cycle of structures that are built on them [13].

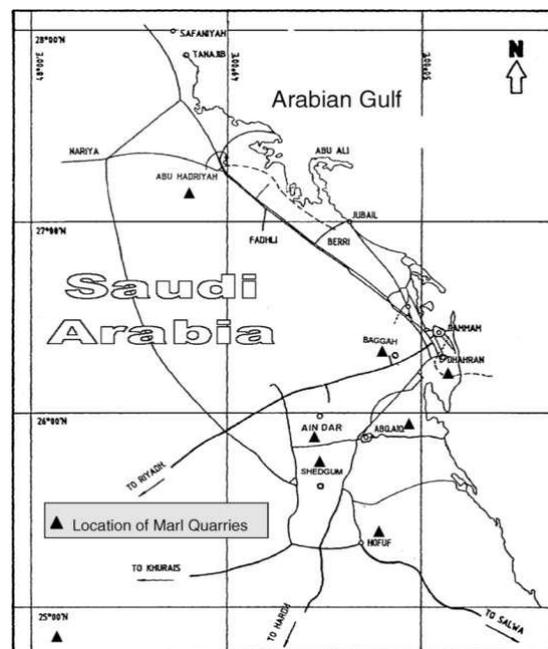


Fig. 1: Vicinity Map Showing Locations of Major Marl Quarries in Eastern Saudi Arabia [11].

2. Marl Soil Identification

There are three methods to determine marl soils [14]. All the methods are based to calculate calcium carbonate (CaCO_3) content. The methods are the following:

- Thermo-Gravimetric Analysis (TGA).
- Loss of Ignition (LOI).
- Chemical reaction based on ASTM C 25.

2.1. Thermo-Gravimetric Analysis (TGA)

Thermo-Gravimetric Analysis (TGA) method used to measure the change in weight of a certain material with increase of temperature. Based on weight vs temperature curve the material will be identified. Calcium carbonate (CaCO_3) will turn to calcium oxide (CaO) and carbon dioxide (CO_2) upon heating between 650 and 800 °C. The authors applied TGA test on 10 milligrams of soil and the rate of heating was 10 °C/min. Marl sample was heated from normal temperature of a room up to 1000 °C. Figure 2 shows the curve of weight loss and temperature of marl soil. It is clear from the graph weight loss rate is significant between 650 and 800 °C.

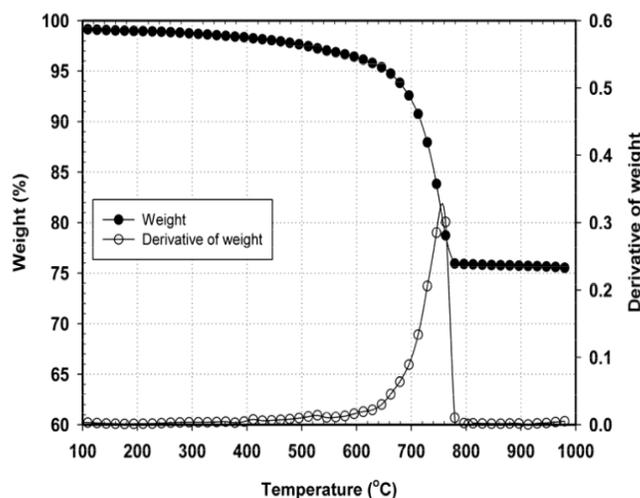


Fig. 2: Weight loss of calcareous marl sample and weight loss rate from TGA test [14].

2.2. Loss of Ignition (LOI)

Loss on Ignition (LOI) test is a standardized test to determine organic [15]. In LOI, soil sample is heated up to 455 °C which is the heat required to burn organic matters. However, Jung et al. [14] utilized LOI test to check calcium carbonate content. In their experiment marl soil was heated up to 455 °C. Then, after loss of organic matter, the weight of sample was measured. After that, the sample was heated up to 800 °C, heat of decomposing of calcium carbonate. After the end this cyclic heating, calcium carbonate was measured. The results of LOI of many samples were compared with the results of TGA, as shown in Figure 3. It is clear from the figure that LOI and TGA tests are identical in determination of calcium carbonate.

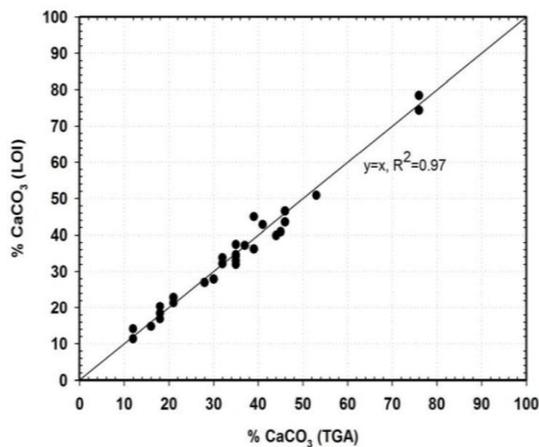


Fig. 3: Comparison between CaCO_3 percentages measured by LOI and TGA methods [14].

2.3. Chemical Reaction Based on ASTM C 25

As per ASTM C25 [16], Hydrochloric acid (HCL) is used to quantify the neutralizing capacity of any calcareous material. Based on this test, Jung et al. [14] determined calcium carbonate content for several marl samples and compared it with the outcomes of TGA, as shown in Figure 4. Similar to LOI, chemical reaction test (ASTM C25) is identical to TGA.

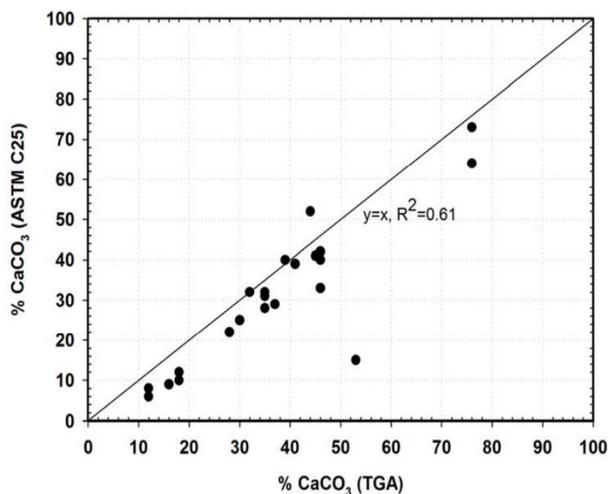


Fig. 4: Comparison between CaCO_3 percentages measured by ASTM C25 and TGA methods [14].

3. Problematic Features of Marl

Infrequent number of researches have been carried out at King Fahd University of Petroleum and Minerals (KFUPM) [11]. Based on those researches marl has the following low-grade characteristics:

- Low dry density
- Poor strength when wetted
- High water sensitivity
- A drastic loss of bearing capacity occurs upon immersion in water.

Figure 5 clarify the water sensitivity of marl. California Bearing Ratio (CBR) values of unsoaked and soaked marl samples are 134 and 90, respectively. In addition, CBR value dropped dramatically after optimum moisture content.

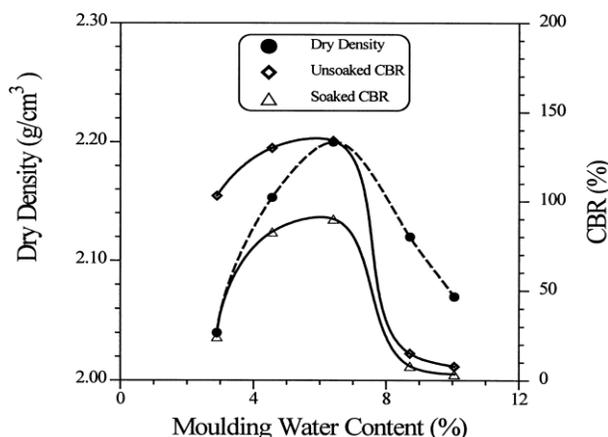


Fig. 5: Variation of CBR and dry density and with water content [11]

4. Marl Assessment

Strength properties of marl soil such as CBR, shear strength and compressive strength can be examined based on standard tests. However, an easy, non-destructive and time saving test, which is Clegg Impact Soil Test (CIST), can give fair indication about CBR for marl. The main concept of CIST is measuring the dynamic response of the soil caused by standardized impact. It consists of 4.55-kg hammer, which is similar to the modified proctor hammer, used to be dropped freely from 45 cm height. This hammer is connected with piezoelectric accelerometer to assess "Clegg Impact Value" (CIV) of the hammer when it hits the soil. Several new versions of the CIST have been used recently with different hammer weights. Fortunately, CIV-CBR model was developed, based on numerous experiments in situ and in the laboratory for marl soil, in the following exponential equation [17]:

$$CBR = 0.1691(CIV)^{1.685} \quad R^2 = 0.85 \quad (1)$$

Where CBR is California Bearing Ratio, CIV is Clegg Impact Value and R² is a coefficient of determination.

5. Marl Improvement

5.1. Dry density

Marl soil usually treated chemically with cement or lime [12]. The dry density of marl has improved up on additives treatment. Figure 6 shows the effect of additives to dry density and the results of all additives are similar.

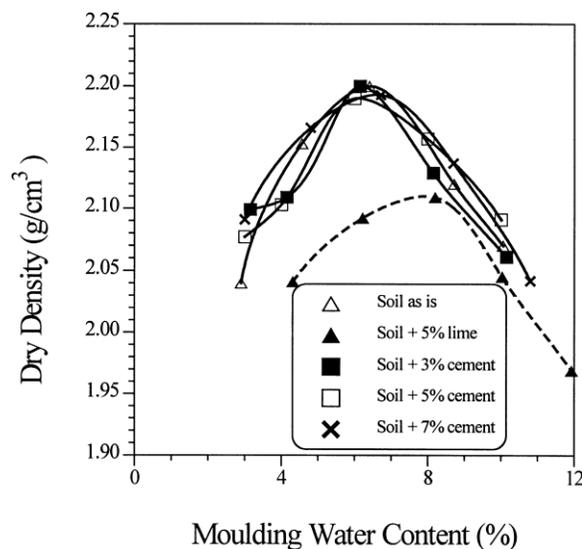


Fig. 6: Variation of dry density with moisture content for marl samples treated with different additives [12].

5.2. California Bearing Ratio (CBR)

Strength of marl soil, based on CBR test, has great improvement when treated with additives. However, lime treatment has minor effect on strength improvement of marl. Figure 7 shows CBR values variation with molded moisture content for marl samples treated with different percentages of cement and lime. Ultimately, 5% of cement has the best improvement in terms of CBR value.

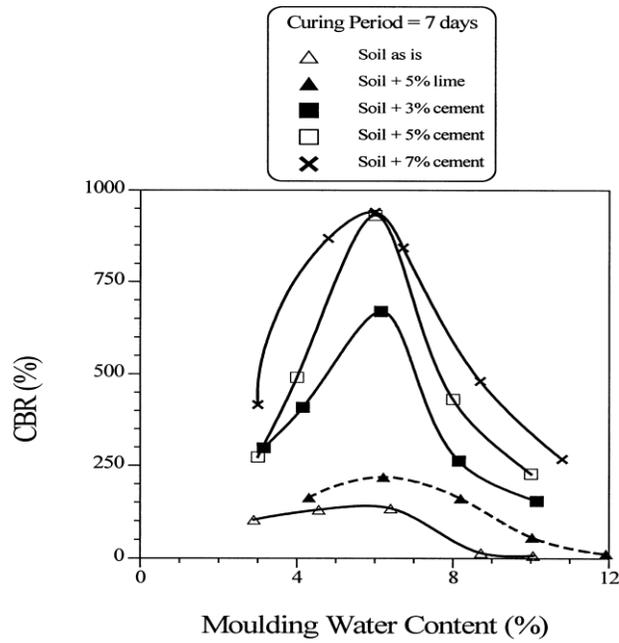


Fig. 7: CBR values variation with molded moisture content for treated marl [12].

5.3. Unconfined Compressive Strength

The unconfined compressive strength has linear increase with cement content. However, after 5% of cement content, the change was minor [12]. Additionally, the increase of curing temperature and period will approve the unconfined compressive strength and that is clear in Figure 8 and Figure 9, respectively.

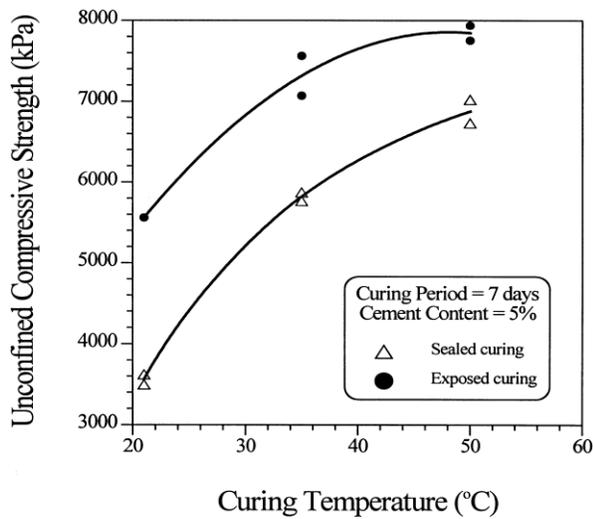


Fig. 8: Unconfined compressive strength variation with curing temperature for marl samples [12].

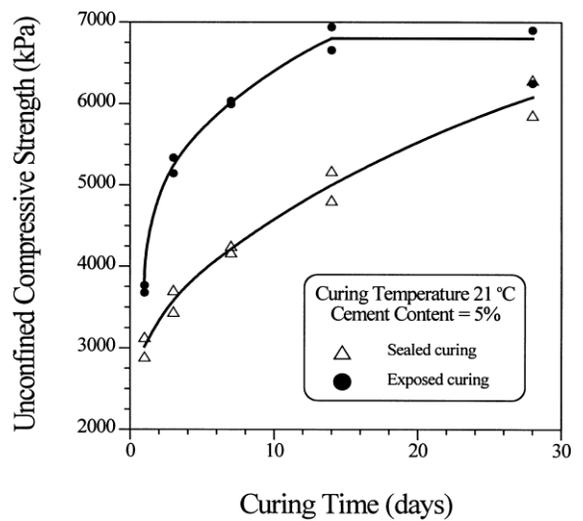


Fig. 9: Unconfined compressive strength variation with curing period for marl samples [12].

6. Conclusion

Based on the literature review for the marl soil presented in this manuscript, the following conclusions could be drawn:

- Marl soil is used as a backfill and for roads construction abundantly in Saudi Arabia and some other places in the world.
- Marl soil is highly sensitive to moisture. For example, a noticeable loss of marl strength caused due to high moulding water content or immersion in water.
- CIV has an acceptable correlation with CBR value for marl soils. As a result, lots of time and money could be saved upon using Clegg Impact Soil Test to assess marl stiffness.
- Cement stabilization of marl soil showed a great improvement for the marl properties.

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