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A Lab Study on the Factors Effecting Settlement and Electrical Resistivity of Gypsum Sands

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Abstract. A large number of engineering hazards on constructions based on gypsum soils have been documented all over the world. Gypsum sands are especially found in the dry parts of the world. The problem of dissolution and settlement is one of the most widespread among gypsum soils. Gypsum sands are complex materials and the effect of the geotechnical parameters on settlement behavior of gypsum soils have been studied by several researchers over the years, but the results were found to be varying. Also, there have not been many geophysical investigation techniques that were used to study gypsum soils. In this study, the effect of several factors like gypsum content, water content, leaching and dissolution of gypsum and time on the settlement of reconstituted gypsum sands were investigated. Settlement due to initial moisture and leaching was studied by subjecting the soil specimens to a rapid drained loading of 200 kPa. The long term settlement of the soil samples was studied using the consolidation test setup. Further, electrical resistivity tests were conducted on the soil samples using a four-electrode soil resistivity box. The effect of moisture content, gypsum content and density on electrical resistivity was investigated. The studies showed that settlement of the gypsum sands increased with gypsum content, initial moisture, leaching and time. The soil box resistivity tests showed that, moisture content had a major influence on resistivity, while gypsum content and density had less influence on the resistivity. Based on the results, it was concluded that electrical resistivity testing could be a moderately successful method for estimating the settlement of gypsum sands.

Keywords: gypsum, sand, settlement, electrical resistivity

1 Introduction

Soils containing gypsum, often termed as gypsiferous or gypseous soils are generally found in the drier parts of the world. Places like Iraq, some middle-eastern states, southern Spain, and south western United States have sizeable proportions of gypsiferous soils [1]. These soils generally make stable building material under dry condition but undergo considerable settlement in the presence of water. Gypsum is a moderately soluble calcium-sulfate mineral, belonging to a group of minerals called evaporites. Gypsum soils are often classified as collapsible soils. There has been a lot of damage all over the world because of the settlement of structures constructed on gypsum soils. The hazards associated with these soils and factors causing the collapse settlement have been studied by numerous researchers in the past. Seleam (2006) [2], Al-Marsoumi et al. (2008) [3] and Fattah et al. (2008) [4], were some researchers who had studied the geotechnical and collapsibility properties of gypsum soils from samples obtained from different parts of Iraq. For this research, a laboratory study was conducted on reconstituted specimens poorly graded sand mixed with different percentages of gypsum and the impact of various factors like gypsum content, initial water content, leaching and time of soaking on the settlement of the soil were studied. For quick and preliminary soil exploration over a large area, electrical resistivity testing is a promising new method that is finding a lot of application these days. Kalinski et al. (1993) [5] used this method to estimate the water content of clayey soils. Pandey et al. (2015) [6] studied the electrical resistivity of sandy soil using the four electrode soil box method. In this investigation, the feasibility of electrical resistivity in investigating gypsum soil horizons was studied in a lab scale by using a four-electrode soil box method. The electrical resistivity of the soil samples were measured under varying conditions of moisture content, gypsum content and dry density. The results of these studies have been discussed in the following sections.

2 Test Setup

Poorly graded Sand was mixed with different percentages of commercial gypsum and samples were prepared for testing (Fig 1). For studying the factors effecting settlement of gypsum, cylindrical samples of 6.4 cm diameter and 2.8 cm depth were prepared in a shear box. The void ratio of the all samples was maintained close to 0.7. The samples for long-term loading test were prepared in a consolidation load cell of 6.4 cm diameter and 1.8 cm depth.

The electrical resistivity behavior of gypsum-sand mixtures was studied with respect to change in variables like moisture content, gypsum content and dry density of soil samples. The tests were carried out using a lab scale four-electrode soil resistivity box. In this arrangement the resistivity of the soil is measured by placing the soil sample in a rectangular soil box, and measuring the potential drop between the two inner electrodes of the box caused by passing an electric current through the soil box. Resistivity (Ohm-m) is calculated as the ratio of voltage and current, multiplied by a box geometry constant (k). A schematic of the test setup is shown in figure 2. The details of the testing methodology can be found in Bhamidipati and Kalinski (2020) [7].

Fig. 1. Sample of sand mixed with gypsum

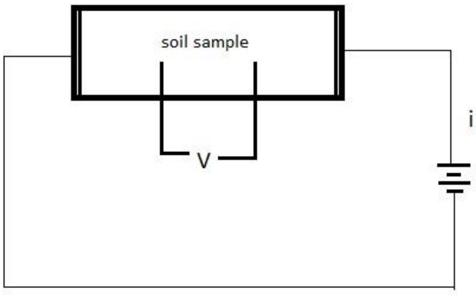

Fig.2. Arrangement for a four-electrode soil box resistivity test

3 Factors Influencing the Settlement of Gypsum Sands

The settlement of different gypsum and sand mixtures was studied by conducting several tests as described in this section. Initially, the effect of initial moisture content on the soil samples was observed. The samples were placed in the shear-trac II loading apparatus and a normal load of 200 kPa was applied on the samples. The axial strain of the samples was recorded for a sufficiently long time until no further strain could be observed. Soil samples were prepared at different initial moisture contents ranging from 0% to 15%. The initial void ratio of all the samples was approximately 0.7. At moisture contents close to 20%, the samples were almost saturated and rapid loading led to the building up of excess pore pressures. This was leading to an incorrect measurement of vertical strain. Hence those, values were not considered for the test. From Fig 3, it can be seen that the vertical strain increased with increase in initial moisture content of the samples. Also the samples with higher gypsum content (50% and 70%) show a greater vertical strain than the sample with 20% gypsum content.

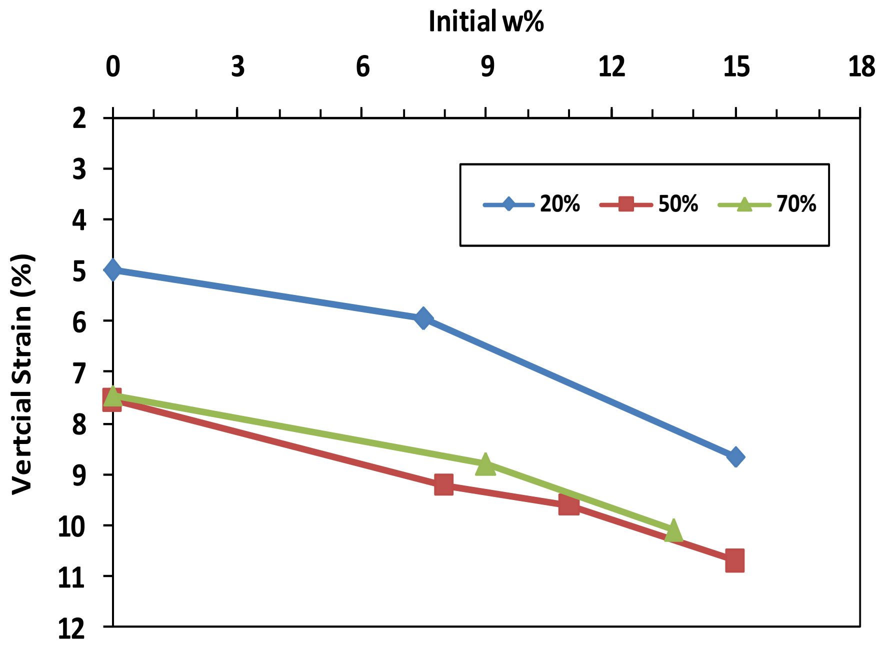

Fig. 3. Vertical strain versus initial water content for samples subjected to a load of 200 kPa

Leaching of gypsum from soils was studied using a similar setup. In this case, two saturated samples with 30% and 50% gypsum were prepared and a small amount of water (around 2 drops per minute) was continuously percolated through the samples for different time intervals of 10 minutes, 1100 minutes (18 hours) and 2880 minutes (48 hours). The water coming out from the bottom of the sample was collected in a trough. The settlement of these samples was measured by placing them in the shear-trac II apparatus and applying a normal load of 200 kPa on them. The results from this test are shown in Fig 4. It was seen that the longer the samples were subjected to leaching, the more vertical settlement they were undergoing. Also the sample with 50% gypsum showed greater settlement than the sample with 30% gypsum.

The concentration of gypsum in the effluent water (collected in the trough) was measured at different times using an Extech pocket conductivity meter. For both the 30% gypsum and 50% gypsum sample, the conductivity of the effluent was roughly unchanged with time, indicating a constant rate of dissolution (Fig 5). The dissolution of 30 % gypsum was found to be very slightly higher at the 18 hour (1080 minutes) and 48 hour (2880 minute) marks. The conductivity of the effluent varied between 3200 µS to 4000 µS (micro-Siemens). Tap water at 21 ºC was used for the testing. The conductivity of the tap water during the testing was found to be in the range of 670 µS to 730 µS.

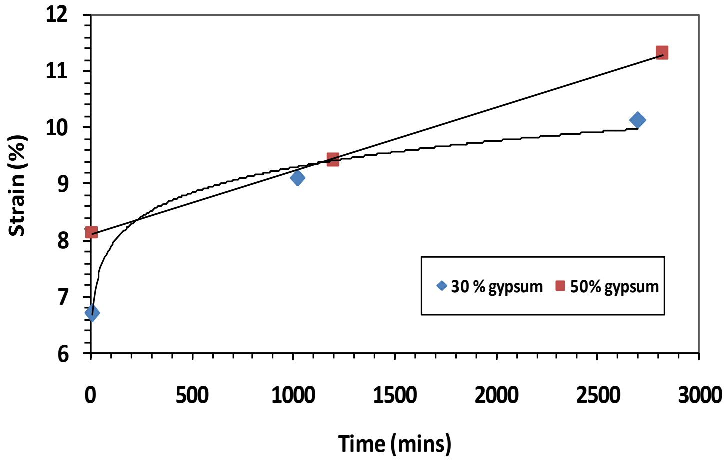

Fig. 4. Vertical strain at 200 kPa versus time period of leaching for two samples

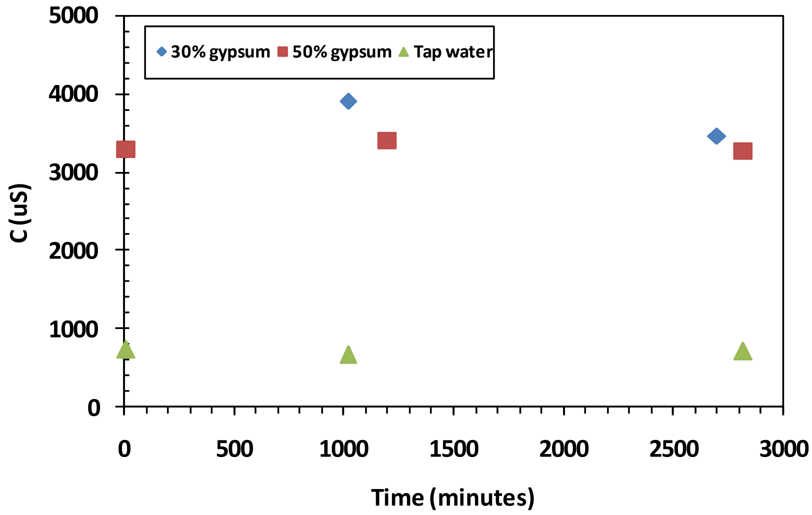

Fig. 5. Conductivity of effluent water leaching from soils at different times

The long term settlement of gypsum sand mixtures was studied using three samples with 10%, 30% and 60% gypsum respectively. The samples were placed in a consolidation load cell, previously inundated under 200 kPa. After completion of settlement, the load was increased to 300 kPa. The decrease in height of the samples was recorded over three days (ranging from 1 hour to 72 hours) (Fig 6). Greater long-term settlement was observed in samples containing a higher gypsum percentage. Over a 72 hour period, the settlement varied from around 0.1 mm for the 10% gypsum sample to 0.6 mm for the 60% gypsum sample.

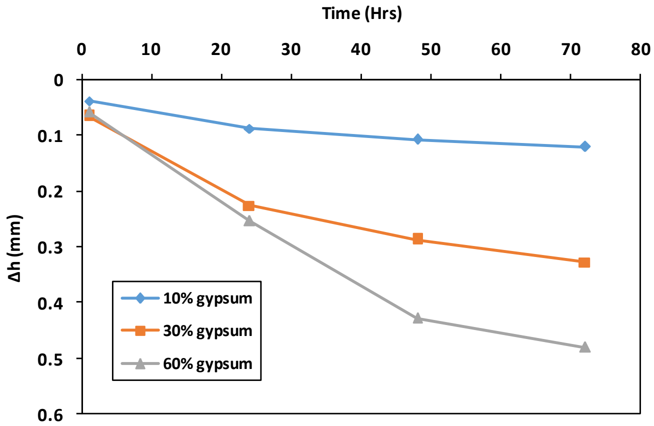

Fig. 6. Settlement of inundated gypsum sand samples over 72 hours under 300 kPa

4 Factors Influencing the Electrical Resistivity of Gypsum Sands

The electrical resistivity behavior of gypsum sands was studied using the four-electrode soil box. First, the variation in resistivity with respect to volumetric water content was investigated. Moist sand samples with different proportions of gypsum were prepared and placed in the box at a void ratio of approximately 0.6. The resistivity measurements were taken at different moisture contents as the sample was allowed to air dry naturally. The results of the test are shown in Fig 7. It was found that resistivity varied over a wide range with change in moisture content. The resistivity of all samples was typically less than 100 Ω-m for volumetric water content more than 0.15. However, resistivity increased very steeply below water content of 0.1 for all the samples, measuring into several hundreds of Ω-m. The same trend was found for samples with different gypsum contents.

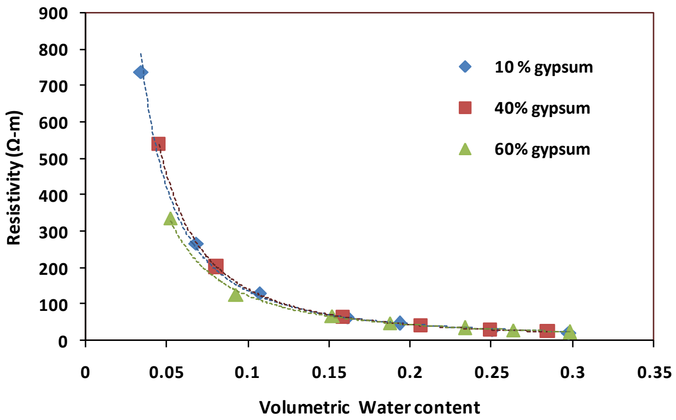

Fig. 7. Electrical resisitivity plotted against water content

Gypsum is a sparingly soluble salt (Adiku et al. 1992)[8] and gets dissociated into Ca^{2+} and SO_4^{2-} ions upon dissolution in water (Bolan et al.,1991) [9]. Electrical resistivity tests were carried out to see if the gypsum content and the presence of ions had any effect on the resistivity of gypsum sands. A detailed investigation for the effect of gypsum content on resistivity of gypsum sands was conducted by studying the resistivity of several saturated gypsum sand mixtures. Saturated mixtures were prepared and placed in the soil box and their resistivity was measured (Fig 8). Soil samples with gypsum content varying from 0% to 90% were used. The results showed that sand with no gypsum had a resistivity of 27 Ω-m. Resistivity decreased with the addition of gypsum into the soil. Between 10% to 30% gypsum, the resistivity was around 16-17 Ω-m and increased slightly up to 20 Ω-m, with further addition of gypsum. No appreciable change in resistivity was found beyond 50% gypsum.

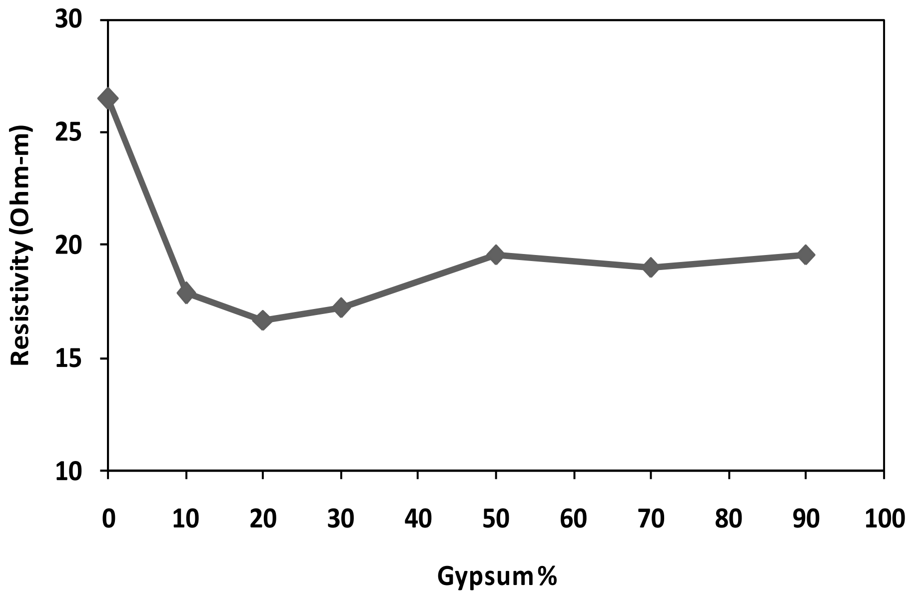

Fig. 8. Electrical resisitivity plotted against gypsum content

Further, the influence of dry density of the gypsum sand on the electrical resistivity of the soil was tested. Saturated sand samples of 20% and 50% gypsum were prepared and compacted (by tamping) to different dry densities. The samples showed a slight increase in resistivity with increase in dry density (Fig 9). For the sample with 20% gypsum, resistivity varied between 15-25 Ω-m between dry density of 1.5 to 1.86 g/cc. The 50% gypsum sample displayed a resistivity range of 20-30 Ohm-m, for dry density values between 1.55 to 1.85 g/cc. The overall change in resistivity was relatively small, with respect to change in dry density of the soil.

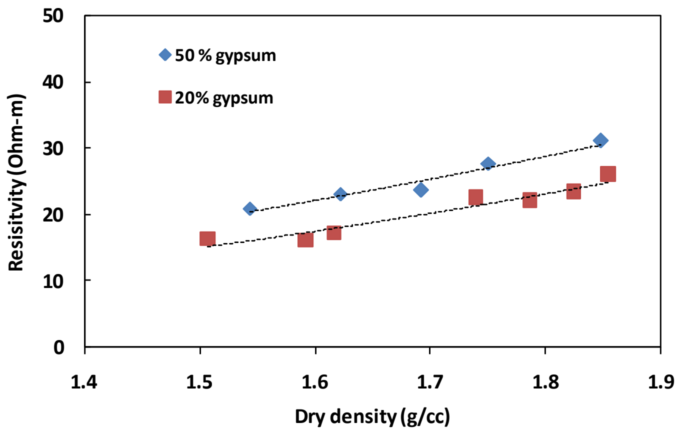

Fig. 9. Electrical resisitivity plotted against dry density

5 Results and Discussion

Both initial moisture content as well as gypsum content effect the settlement of gypsum sands. The addition of water causes an increase in dissolution of gypsum and also causes weakening of any cementing bonds between the sand and gypsum. The long-term settlement of the gypsum soil samples increased with time. It was also found to be dependent on the gypsum content of the soil, with greater settlement taking place with increasing gypsum concentration.This observation was consistent with the findings of Fattah et al. (2008) and Mahmood et al. (2020) [10]. Percolating water through samples of gypsum sand causes leaching of gypsum. The settlement of soil also increases with leaching. From the tests, it was seen that leaching and settlement was greater when gypsum content was higher. The amount of gypsum dissolved at any given time was roughly constant.

The effect of moisture content, gypsum content and density of the soil sample on the electrical resistivity behaviour of gypsum sands were studied and their results were noted. Moisture content had the greatest effect on the resistivity of the soil samples, showing a variation across hundreds of Ohm-m. These results were in agreement with the study conducted by Pandey et al. (2015). Resistivity increased very steeply at low moisture contents. In the absence of clay minerals, water is the only main conductor of electricty in otherwise inert sands. Hence the lower the water content, the greater the resistivity. The presence of gypsum salt in the sand showed only a small change in resistivity values. In general, the resisitivty of saturated gypsiferous sands was slightly lower than that of sand without any gypsum. This lowering in resisitivity is likely due to the presence of Ca^{2+} and SO_4^{2-} ions. However, the increasing concentration of gypsum shows minimal effect on the resisitivity poiniting towards the low solubility of gypsum. Lastly, the resisitivity of the saturated gypsum soils showed an increase with increasing dry density. The reduction of voids with increasing density causes lower amount of water to be present in the soil matrix. Hence the lower the water, the greater the resistivity. The results could however vary when partially saturated soil is tested. The range of resisitivity variation was about 10 Ω-m.

6 Conclusions

The study shows that the settlement of gypsum sands is influenced by factors like initial moisture content and gypsum content. Long term settlement (creep) increases with the amount of gypsum in soil. Leaching of gypsum by percolation of water through the soil is also a major factor effecting soil settlement. Thus, these factors shoud be investigated and considered during the geotechnical investigation stage for any site containing gypsum.

Electrical resisitivity testing can also be used a tool to assess soils containing gypsum. Resistivity may not show much variation with density and gypsum content of the sand, but it varies significantly with the moisture content. The results from the testing can be used to make any judgements about the properties of the gypsum soil and any risk of settlement associated with the soil.

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