Studies on improvement of properties of gypseous soils

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ABSTRACT

Pavements and embankments fail for different reasons; poor design, poor materials and poor construction methods are the most common. The pavement foundation (subgrade) represents one of the key elements in pavement design and its behavior shall influence the overall pavement performance. It was found necessary improving gypseous subgrade stiffness characteristics in order to prolong pavement design life. We also believe that too much emphasis in finding out untraditional methods in treating weak gypseous soils and then using them in subgrade layers taking into consideration type and values of loading effects in the employed design models. This has lead to erroneous predictions. In general, the more resistant to deformation the subgrade is the more loads it can support before reaching a critical deformation value.

Gypseous soils cover about (35%) of the total area of Iraq and therefore the study of the properties of these soils to be used as subgrade embankments becomes very important due to the problems caused by these soils during leaching which lead to what is called collapsibility. Many trials were conducted in order to study the possibility of improving the properties of gypseous soils using chemical and natural materials. Results showed that some natural and chemical materials could improve the behavior of gypseous soils, but these results are based on routine laboratory tests. In this study, two types of local gypseous soils are selected to be improved by three chemical stabilizing materials, namely, 5% hydrated lime, and 2.5% hydrated calcium chloride and 6% kaolin. The soils employed are classified as (SP-SM) and (SP) with gypsum content of (48.3%) and (35%) for Baiji and Al-Thurthar area soils, respectively. An engineering model is adopted to carry out tests on these soils and to analyze their behavior before and after improvement especially their collapsibility property. The results show that all employed chemical and natural additives can be used to reduce the collapsibility property of gypseous soils, but with different degrees. Using lime reduces the collapsibility of gypseous soils to a small degree compared with calcium chloride and kaolin.

Keywords: gypseous soil, soil model, leaching, improvement, compressibility, collapsibility

1 INTRODUCTION

Collapsible soils, which are sometimes referred to as metastable soils, are unsaturated soils that undergo a large volume change upon saturation. Many collapsible soils may be residual ones that are products of weathering of parent rocks. The weathering process produces soils with a large range of particle-size distribution. Soluble and colloidal materials are leached out by weathering, resulting in large void ratios and thus unstable structures, Das (1990).

Gypsum rich soils refer to ones which are usually classified as collapsible soils. This is due to the fact that the gypsum present in the soil provides an apparent cementation when the soil is dry, but the intrusion of water causes dissolution and softening leading generally to serious structural collapse, Razouki et.al (1994).

Gypsum, whether in massive or particular form, dissolves due to water table flocculation or water infiltration into gypseous soils producing cavities, causing deterioration of the cemented soil structure, and therefore sudden settlements of buildings erected on them, and increasing hydraulic conductivity and flow rates in hydraulic structures, Al-Abdullah (1995).

The goal of this study is to improve the subgrade pavement performance and embankments by employing experimental and analytical approaches. Furthermore, it aims in investigating, evaluating and suggesting procedures to improve the performance of gypseous soils underneath roads, highways and embankments against permanent deformation. Finally, it is sought to achieve an optimal design criterion due to the existence of gypsum by meeting all requirements. Adopting this definite criterion is for the sake of improving gypseous soil properties by adding stabilising materials like lime, calcium chloride and kaolin which can be most useful for their treatment when used in subgrade layers.
2 MATERIALS

2.1 Soil used: Two types of soils with different gypsum contents are used. The first is taken from a site in Baiji at Salah El-Deen Province with a gypsum content of 48.3% extracted from a depth of 0.75 meters below the ground surface and designated as (S1). The second sample is taken from a site at Al-Tharthar at Salah El-Deen Province with a gypsum content of 35% extracted from a depth of 0.5 meter below ground surface and designated as (S2).

2.2 Lime: Hydrated lime Ca(OH)$_2$ is used with 5% by weight to treat the gypseous soil used in this study. This percent was confirmed by Al-Janabi (1997).

2.3 Calcium Chloride: 2.5% by weight of dehydrate calcium chloride (CaCl$_2$.2H$_2$O) is used as an additive to treat the gypseous soil used in this study which was confirmed by Al-Busoda (1999).

2.4 Kaolin: Based on the conclusion of Al-Neami (2000), 6% by weight of kaolin is used as an additive to treat the gypseous soil employed in this study.

3 CLASSIFICATION TESTS

The results are summarized in Table (1)

4 COMPRESSIBILITY TESTS

4.1 Collapse test

The procedure proposed by Knight (1963). The sample loaded to a stress of 200 kPa with a load increment ratio (LIR) of (1) and load increment duration (LID) of (24) hours. Then the sample is soaked with water for (24) hours and the additional settlement is recorded. Finally, the test is completed by a further cycle of loading followed by unloading.

4.2 Double Oedometer Test

Jennings and Knight (1957) proposed the double oedometer test. Two similar samples are selected to be tested in different oedometer devices following the same procedure. The first sample is tested dry until the end of the test, while the other sample is soaked at the beginning of test. The difference between the two curves represents soil collapse at any given pressure.

5 ENGINEERING MODEL TEST.

5.1 The Model Box

The model box used in this study is made out of steel plates of 3mm thickness; dimension of the box is shown in Fig. 1. The front side of the box consists of a glass plate of 10mm thickness used to observe the rise of water through the soil placed inside the box. The soil is placed inside the box at its natural moisture content in three layers. Each layer is compacted by tamping to duplicate field density through a soil height of 18 cm.

The box is placed on a steel base put on another that should be maintained balanced to prevent any inclination of the system, see Fig. 3.

5.2 The Model Footing

The footing of dimensions 4cm width, 27cm length and 3.5cm height is made out of rigid oak wood. The upper face of the footing is covered with two thin steel plates, as shown in Fig. 2. The upper plates have a suitable hole of 3mm diameter at the center of the footing used to convert the load to the footing by the use of the loading ram.

5.3 General Description of Apparatus

Figure 3 shows the details of the loading apparatus. The model box is set on a steel base that should be maintained balanced to prevent any inclination of the system. This balanced steel base is set on another and this is placed, in turn, on concrete blocks.

The model footing is placed at the center of the model box. The loading is applied through a loading ram on the footing with a diameter of 3cm. This loading ram is connected to a balancing bar of 33cm length, 4cm width and 5.8cm height through a threaded hole. The datum bar has a steel plate fixed centrally at its top used for setting the loads and contains two small holes. Two vertical steel rods enter through these holes to support the datum bar and maintain its balance throughout the loading phase. The two rods are joined with the steel base by a frame placed on concrete blocks.

Static loads are placed at the center of the steel plate. The settlement of the soil under the footing is read by a dial gauge placed on the footing and supported to the vertical steel rod by a magnetic holder, as shown in Fig.3.
5.4 Testing Procedure

The soil is placed inside the box at its natural moisture content in three layers. Each layer is compacted by a wooden tamper with a rubber end to duplicate field density through a soil height of 18 cm. The method used for applying the load is by using an initial load of \((21.76 \text{ kg})\) equivalent to a stress of \((19.44 \text{ kN/m}^2)\) and the load is increased afterwards by \((40 \text{ kg})\) until arriving to a load of \((221.76 \text{ kg})\) which is equivalent to a stress \((201.85 \text{ kN/m}^2)\) (about \(200 \text{ kN/m}^2\)).

Every load is maintained until no change in the dial gauge reading is observed. After applying \((221.76 \text{ kg})\) load, the load is maintained for 24 hours. Then the soil is saturated for 24 hours by allowing water rise from the base of the box to the surface of the soil by using pipes connected to a small cylindrical tank with a proper head (50cm), see Plate 1. The dial gauge reading at the end of the collapse is recorded. The test is completed after that by using additional load increments and the collapse potential of the soil can hence be calculated.

6 RESULTS AND DISCUSSION

6.1 Collapse Test

The values of the collapse potential of the natural soil and soil treated with 5% lime, 2.5% calcium chloride and 6% kaolin are summarized in Table 2. It could be noticed from Table 2 that there occurs some degree of improvement during using additives as treatment materials to improve gypseous soil properties which depend on collapse potential. It is found that all natural or chemical additives that contain \((\text{Ca}^{++})\) can lead to improve such a soil.

6.2 Double Oedometer Test

The values of collapse potential for natural and treated soils predicted from double oedometer tests are summarized in Table 3. It can be noticed from Tables 2 and 3 that the collapse potential obtained from the double oedometer test is more than that obtained from the collapse test. This behavior may be attributed to the long period of dissolution of gypsum in case of double oedometer test when water is added to the soil at the beginning of the test. This behavior was also observed by Al-Neami (2000).

7 ENGINEERING MODEL TESTS

To make a clear picture of gypseous soils behavior before and after stabilization, an engineering model is adopted to study their behavior before and after applying additives. This is done in order to determine the degree of improvement in them and weigh their ability to withstand loads within tolerable settlements upon leaching in case it happens.

1- Natural Soil: Figure 4 shows the results carried out on both selected natural soils by utilizing the engineering model test. It is seen that the collapse potential values are \((20\%)\) and \((14.3\%)\) for Baiji and Al-Tharthar soils, respectively. These values are greater than those of collapse potential obtained from collapse and double oedometer tests. This behavior may be attributed to the small specimen used in the oedometer device and to the confinement of the specimen in the consolidation ring. This difference can lead to decide that routine tests suggested for natural soils by many researchers may not be applicable on gypseous soils.

2- Treated Soil:

a- Lime Treatment: Results of Baiji and Al-Tharthar soils treated with 5% lime are shown in Figs. 5 and 6, respectively. It is observed that the collapse potential of both soils decreases largely and can then be classified as (Not problematic). This behavior is due to the cementing bond produced by soil-lime mixtures which includes: cation exchange, flocculation - agglomerate, and soil-lime pozzolanic reaction. This results confirm with Al-Janabi (1997).

b- Calcium Chloride Treatment: Figures 7 and 8 show test results on soils treated with 2.5% calcium chloride. It can be seen that the collapse potential of the treated soils also decreases. This can be attributed to the dissolution of the salt \((\text{CaCl}_2)\) in water, water becomes saline and its ability to dissolve gypsum decreases.

Furthermore, this behavior can be attributed to the increase in calcium cations \((\text{Ca}^{++})\) within the soil. On the other hand, \((\text{Ca}^{++})\) ion represents a common one
with gypsum. Hence, the solubility of gypsum decreases. This behavior was also introduced by Al-Busoda (1999). c- **Kaolin Treatment**: Test results for soils treated with 6% kaolin are shown in Figs. 9 and 10. The collapse potential also decreases for both soils. This behavior could be due to a decrease in solubility of gypsum because of the presence of kaolin as an additive which may coat and fill the voids that occur during dissolution of gypsum and lead to delay gypsum dissolution. This behavior was also observed by Al-Neami (2000).

The collapse potential values for natural and treated soils are summarized in Table 4. It is observed that the collapse potential of both treated soils decreases as compared with natural soils. It should be mentioned that using lime as an additive gives a reliable decrease in collapse potential more than the other two additives. To make a comparison between the results obtained from collapse test, double oedometer test and engineering model test, a collapsibility reduction factor (CRF) is adopted which can be obtained from the following formula (give reference):

\[
CRF = \left( 1 - \frac{\text{collapse potential of treated soil}}{\text{collapse potential of natural soil}} \right) \times 100
\]

(1)

The values of CRF are summarized in Table 5 for Baiji soil and Table 6 for Al-Tharthar soil.

The variations of CRF with additive percent are shown in Figs. (11) For Baiji and it could be approximately for Al-Tharthar soils, respectively. From these Figs., it is noticed that there is a clear convergence in results of all tests on soils treated with 5 % lime. On the other hand, the divergence in results of these tests on soils treated with calcium chloride and kaolin is shown clearly. This may be attributed to the cementing process that takes place in case of lime treatment regardless of the condition of the tested soil.

**8 CONCLUSIONS**

1- Results, obtained by utilizing the engineering model test give reasonable results in selecting the specified additive for treatment of gypseous soils.

2- Adding 6% kaolin to the natural material is favorable for the treatment of gypseous soils.

3- Lime can be used successfully as an additive to improve the properties of gypseous soils in a percentage of 5%.

4- Treatment by using 2.5% calcium chloride is more active in high gypseous contents of soils, because it provides the soil with calcium ion (Ca\(^{++}\)) which increases the cementing agent between the soil particles.

5- It is preferable to carry out collapse tests under 200 kPa to predict the collapse potential rather than carrying out double oedometer tests.

6. It is concluded that stress release and water infiltration lead to further increases in collapsibility due to removal of bonding between cementing particles upon wetting. In addition, rearrangement of soil particles is developed because of softening. Thus, the standard consolidation curve is not clear and there was no definite end point to primary consolidation.

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Table 1 Results of classification tests

| Properties          | Baiji site (S1) | Al-Tharthar site (S2) |
|---------------------|-----------------|-----------------------|
| Specific gravity(GS)| 2.51            | 2.48                  |
| Soil classification | SP-SM           | SP                    |
| Liquid limit (LL) % | 50              | 26.4                  |
| Plastic limit (PL) %| 37              | 19.7                  |
| Plasticity index (PI)| 13             | 6.7                   |
| Minimum unit weight (kN/m$^3$)| 10.07 | 10.31                |
| Maximum unit weight (kN/m$^3$)| 15.95 | 16.82                |
| Field unit weight(kN/m$^3$) | 13.3     | 14.11                |
| Relative density (%)| 65.88           | 69.58                 |

Table 2 Collapse potential values of natural and treated Soil (collapse test).

| Test type | Natural Soil | Treated soil |
|-----------|--------------|--------------|
| Site      |              | 5% lime      | 2.5% chloride | 6% kaolin |
| CT 0      |              | 95.8         | 74.4          | 62.7      |
| DOT 0     |              | 92.9         | 72.4          | 64.1      |
| EMT 0     |              | 93.7         | 44.6          | 39.2      |

Table 3 Collapse potential values of natural and treated soils (double oedometer test).

| Site          | Natural Soil | Treated soil |
|---------------|--------------|--------------|
|              |              | 5% lime      | 2.5% chloride | 6% kaolin |
| Baiji soil(S1)|              | 8.19         | 0.58          | 2.26      | 2.94  |
| Al-Tharthar soil(S2)| | 4.96         | 0.66          | 3.76      | 2.16  |

Table 4 Collapse potential values of natural and treated soil (engineering model test).

| Site          | Natural soil | Treated soil |
|---------------|--------------|--------------|
|              |              | 5% lime      | 2.5% chloride | 6% kaolin |
| Baiji soil(S1)|              | 7.51         | 0.31          | 1.92      | 2.8   |
| Al-Tharthar soil(S2)| | 4.5         | 0.49          | 3.52      | 2.04  |

Table 5 Values of collapsibility reduction factor (Baiji soil).

| Test type | Natural Soil | Treated soil |
|-----------|--------------|--------------|
| Site      |              | 5% lime      | 2.5% chloride | 6% kaolin |
| CT 0      |              | 89.2         | 22.1          | 54.9      |
| DOT 0     |              | 86.7         | 24.2          | 56.5      |
| EMT 0     |              | 88.6         | 14.8          | 23.6      |

Table 6 Values of collapsibility reduction factor (Al-Tharthar soil).
Fig. 4. Results of engineering model tests on natural soils.

Fig. 5. Results of engineering model test on soil treated with 5% lime (Baiji soil).

Fig. 6. Results of engineering model test on soil treated with 5% lime (Al-Thurthar soil).

Fig. 7. Results of engineering model test on soil treated with 2.5% calcium chloride (Baiji soil).

Fig. 8. Results of engineering model test on soil treated with 2.5% calcium chloride (Al-Thurthar soil).

Fig. 9. Results of engineering model test on soil treated with 6% kaolin (Baiji soil).

Fig. 10. Results of engineering model test on soil treated with 6% kaolin (Al-Thurthar soil).

Fig. 11. Variation of collapsibility reduction factor with additive (%) (Baiji soil).