Evaluation of Leaching Behavior of Treated and Untreated Gypseous Soil

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Abstract. Leaching is defined as the removal of salts and soluble materials from soil by water percolation and water table fluctuation. The physicochemical and mechanical properties of the soil are changed with the removal of soluble salts and dissolved matter. The process takes place under a hydraulic gradient or by diffusion. Gypseous soils undergo several changes in their characteristics due to the continuous loss in their mass and due to the alteration in properties of the material constituents during leaching and removal of cementation between soil particles. Some experiments on natural gypseous soil and soil treated with magnesium oxide and carbonated magnesium oxide with two relative densities (35 and 75%) are carried out in this research. Oedometer permeability leaching test and modified permeability leaching test are used to investigate the effect of the behavior of soil during leaching. The results illustrate that the coefficient of permeability in oedometer permeability shows results less than the modified leaching, and the coefficient of permeability in the modified permeability test is more believable results than the oedometer permeability test. The results showed that magnesium oxide and carbonated magnesium oxide are good treatment materials that can be used to improve gypseous soil. Using 10% of 3 hours carbonated magnesium oxide reduces the coefficient of permeability compared with untreated soil more than 100% for the samples of two relative densities and for the two types of tests.

Keywords: Leaching gypseous soil; coefficient of permeability; magnesium oxide; carbonation.

1. Introduction

The leaching of soil, especially of those containing soluble salts, causes changes in the engineering properties. These changes may create adverse problems for the structures founded on such soils. The water flows into the soil may cause one or more of this type: particle movement, compression due to seepage forces, and removal of chemicals, colloids, and microorganisms [1]. Leaching is the process where water flows through the soil. Also, the process of leaching is defined as the solubility of the gypsum in the soil by water table or flow of water into soil [2]. The strain is reduced with increasing the stress on the soil during the leaching and the gypsum dissolving at leaching cased leaching strain larger than collapse strain as well as the permeability of the soil decreased with time of leaching and decreased with increasing of the applied stress [3]. Al-Hassany [4] studied the behavior of two types of gypseous soil from Al-Therhar city treated with fuel oil during leaching. It was concluded that both permeability and compressibility decreased because the void ratio decreased.

The effect of leaching on the behavior of gypseous soil was studied by [5] through adopting a special modified Soil Leaching Apparatus for testing large soil samples of (15 cm) thickness and (15 cm) diameter under different leaching stresses with two flow directions, upward flow (UWF) and downward flow (DWF) and by applying a constant hydraulic gradient of 16. It was found that the leaching strain and accumulative dissolved gypsum increase with time, while a graduate decrease can be observed in
permeability coefficient (k) with time and with the increase in leaching stress. Also, the permeability obtained by upward flow direction is less than that obtained by downward flow (DWF). Karkush et al. [6] studied the leaching effect on the coefficient of permeability and strain by using an oedometer and Rowe cell on three types of gypseous soil with gypsum content (31.43, 51.37, and 4.86). They concluded that the results from Rowe cell had reasonable than results from the oedometer. Yousif [7] studied the effect of leaching on the gypseous soil stabilized with fuel oil with different percentages by the oedometer permeability leaching test. It was concluded that the permeability oscillated decreased then increased. Al-Badran et al. [8] studied leaching behavior on gypseous soil with different OCR ratios by using the oedometer permeability leaching test. They concluded that when OCR=1, the leaching strain is more than OCR>1. Also, they concluded when OCR>1, the strain is not affected because the void ratio increased.

A leaching study to investigate the characteristics of gypseous soil from Baheer Al-Najaf in Iraq on samples taken from three sites with different gypsum contents was performed by [9]. The combination of X-ray fluorescence and scanning electron microscopy (SEM) analysis has been used to study the changes in the surface matrix, chemical composition due to reaction between minerals of soil-gypsum and micro-fabrics of soils with gypsum. The solubility of gypsum minerals was found to be directly proportional to gypsum content and leaching period. An SEM analysis has shown an increase in the total change of voids and cavities for higher gypseous. Obead et al. [10] made a database that describes the leaching-permeability behavior of collapsible gypseous soil. The data was implemented to develop ANN prediction models for predicting the saturated coefficient of permeability and percentage of solubility by weight. According to the achieved statistical analysis, the ANNs model has a reliable capability to find out the predictions with a high level of accuracy. The gypseous soils exhibited a high rate of dissolution of soluble minerals content, which caused an increase in the coefficient of permeability as the soil samples reach the state of long-term full saturation.

The study's objective is to compare two approaches used to evaluate the leaching behavior of gypseous soil and investigate the leaching-permeability behavior of collapsible gypseous soil treated by magnesium oxide carbonated magnesium oxide prepared at two relative densities.

2. Materials

2.1 Soil

The collapsible gypseous soil was brought from Tikrit city was used in this research. The grain size distribution and its properties are shown in Figure 1 and Table 1, respectively. The soil is prepared at two relative densities 35% and 75%.

![Figure 1. Grain size distribution.](image-url)
Table 1. Physical properties of soil.

| Physical properties | Value | Specification |
|---------------------|-------|---------------|
| Gypsum content (%)  | 49    | [11] and [12] |
| Specific gravity (Gs)| 2.41  | [13]          |
| Liquid limit (LL) (%)| 26    | [11]          |
| Plastic limit (PL) (%)| N.P  | [11]          |
| % Gravel            | 0     | [14]          |
| % Sand              | 96    | [14]          |
| % Fines             | 4     | [14]          |
| D₆₀ (mm)            | 0.4   | ---           |
| D₃₀ (mm)            | 0.2   | ---           |
| D₁₀ (mm)            | 0.11  | ---           |
| Uniformity coefficient (Cu) | 3.64 | ---         |
| Curvature coefficient (Cc) | 0.91 | ---         |
| Optimum moisture content (%) | 12 | [15] |
| ρ₅₅₅ max. (kN/m³) | 17.45 | [16] |
| ρ₅₅₅ min. (kN/m³) | 12.12 | [17] |
| Classification      | SP    | [18]          |

2.2 Magnesium oxide
The magnesium oxide used in this research has a lightweight and a dry unit weight of 1 kN/m³.

2.3 Carbonation
Carbon dioxide pressure is the definition of carbonation using the carbonation apparatus made from several parts, as shown in Figure 2. The carbonation is made using the carbon dioxide CO₂ pressure. The carbonation curing apparatus was used to apply a low pressure of pure carbon dioxide gas on soil samples. The major components of the set-up include compressed gas tanks, pressure vessels, thermocouple, data acquisition, vacuum, and pressure transducer [19]. The carbonation period is 3 hours.

![Carbonation apparatus](image)

Figure 2. Carbonation apparatus [19].

3. Testing program
There are several samples tested in the Soil Mechanics Laboratory in the Civil Engineering Department in the University of Technology under two types of leaching tests, conventional oedometer permeability
leaching (OPL) and modified permeability leaching (MPL) for the gypseous soil treated with magnesium oxide (0 and 10%) and carbonated at (0 and 3 hours) with two types of gypseous soil at relative densities (35 and 75%). The soil is prepared by mixing the soil with the common percentage of magnesium oxide, and then the mix is placed in the container of carbonation, then the top of the container is closed tightly. Deflation of air in the container was made by using vacuum, then the pressure of carbon dioxide is applied for 3 hours.

The oedometer permeability leaching which is used in this research is carried out using an oedometer cell with dimensions of 76 mm in diameter and 20 mm in height. The sample is loaded gradually till reaching the pressure of 200 kPa. Then, the sample is saturated for 24 hours. After that, the leaching started with a hydraulic gradient of 20 and for 7 days of leaching. After completing the leaching, the test continued as a conventional consolidation test for loading and unloading. The oedometer permeability leaching device is shown in Figure 3.

There are weaknesses in the oedometer permeability leaching test since the size of the sample is very small, and the type of saturation may not ensure the saturation of all particles. Therefore, the modified permeability leaching test (MPLT) is developed to capture the size effect as well as the type of saturation. Modified Rowe cell was used in the test with dimensions of 150 mm in diameter and 50 mm in height. An electrical motor is used for loading with a load cell and indicator to control the load. The sample is loaded as in the oedometer permeability leaching test. The sample is saturated by allowing water to flow from the bottom of the sample upward. Soil moisture content sensors (SMCS) were used to indicate the saturation of the samples as suggested by [20].

The hydraulic gradient 20 caused by hydraulic height 1400 mm is adopted. The load is applied gradually with a short term of loading every 24 hours, and the settlement is recorded with the time the
loading is calibrated every 15 minutes. Two filter papers are used in the test to prevent the gypsum salt that does not dissolve in water from entering the porous stone slots. Figure 4 illustrates all the components of the modified-permeability leaching test. A total soluble salts TDS device is used to measure the salts that are dissolving in water, as shown in Figure 5. Figure 6 represents step-by-step the preparation of the soil sample. The soil sample is tested under MPLT by loading the cell gradually till reaching 200 kPa. Then the water is added to the sample till the sample becomes fully saturated, then it is left for 24 hours. After 24 hours, the soil is tested by leaching the water through the soil for 7 days.

![Figure 4](image1.png)

**Figure 4.** Modified permeability leaching device.

![Figure 5](image2.png)

**Figure 5.** TDS device.
4. Discussion of test results

The permeability coefficient obtained from the two types of tests (OPLT and MPLT) is shown in Figures 7 and 8 for relative densities 35 and 75%, respectively. The results show that the stabilization with Magnesium oxide or carbonated Magnesium Oxide had a good improvement to reduce the collapse during leaching. The permeability leaching was reduced by using 10% Magnesium Oxide 92-94% and 98-99% for OPLT and MPLT respectively for the two relative densities, and at carbonated 10% Magnesium Oxide for 3 hours, the permeability reduced more than 100%. When added to soil, the magnesium oxide makes the soil finer than its natural state, and it is near to be impervious so that the water did not produce leachate comfortably. The treated soil becomes stronger against dissolving because the magnesium oxide particles surround the gypsum particles and prevent them from dissolving. The carbonation is used to accelerate the stabilization of magnesium oxide in gypseous soil according to Eqs. 1 and 2.

\[ \text{MgO} + \text{H}_2\text{O} \rightarrow \text{Mg(OH)}_2 \text{ (brucite).} \]  

\[ \text{Mg(OH)}_2 + \text{CO}_2 + 2\text{H}_2\text{O} \rightarrow \text{MgCO}_3 \cdot 3\text{H}_2\text{O} \text{ (nesquehonite)} \]
Figure 7. Coefficient of permeability versus time for a gypseous soil of relative density 35% during leaching.

Figure 8. Coefficient of permeability versus time for a gypseous soil of relative density 75% during leaching.

The leaching strain for OPLT and MPLT is shown in Figures 9 and 10 for 35 and 75% relative densities samples, respectively. The total dissolved salts TDS measured during the two types of tests are shown in Figures 11 and 12 for samples of 35 and 75% relative densities, respectively. The results show that both the leaching strain and TDS are increasing with time for the untreated soil, but when the gypseous soil is stabilized with Magnesium Oxide or carbonated Magnesium Oxide, the strain remains stable.
Figure 9. Leaching strain versus time for a gypseous soil of relative density 35% during leaching.

Figure 10. Leaching strain versus time for a gypseous soil of relative density 75% during leaching.

Figure 11. TDS versus time for a gypseous soil of relative density 35% during leaching.
Figure 12. TDS versus time for a gypseous soil of relative density 75% during leaching.

5. Conclusions
From the above results, the following conclusions can be drawn:
- Using 10% of Magnesium Oxide is reducing the coefficient of permeability as compared with untreated soil by about 92% and 94% for samples of relative density 35 and 75% when using oedometer permeability leaching test, and when using modified permeability leaching test, the reduction became 98% and 99% for samples of relative density 35 and 75%, respectively.
- Using 10% for 3 hours carbonated Magnesium Oxide reduces the coefficient of permeability compared with untreated soil by more than 100% for the samples of two relative densities and for the two types of tests.
- Test in modified permeability leaching test increases the permeability coefficient to about 80% for untreated soil as compared with oedometer permeability leaching test where it is increased about 40% only when the soil is stabilized with 10% Magnesium Oxide.
- Both the leaching strain and TDS are approximately not affected when the soil is stabilized with 10% Magnesium Oxide and carbonated Magnesium Oxide.
- The results of the modified permeability leaching test are more believable than the oedometer permeability leaching test.

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