Geotechnical properties of gypseous soil contaminated with crude oil

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Abstract. Gypseous soils are extensively distributed and especially in Iraq where area of hot climate is extant. These soils may be contaminated by crude oil due to the multiple oil wells, the oil exploitation, damaged storage tanks and pipelines, natural seepage and the crude oil spills during the war. Therefore, this study presents the geotechnical properties of gypseous soils contaminated with crude oil and the possibility of using the crude oil as an improvement material. The soil used in this study has been brought from Haditha city at Al-Anbar Governorate in Iraq with (34%) average gypsum content and classified as silty sand (SM) according to unified soil classification system (USCS).
A series of laboratory tests included physical, chemical, shear strength, collapsibility test conducted on both clean and contaminated soil samples with crude oil. Compacted soil samples are prepared and three percentages of crude oil (3%, 6%, and 9%) are added to the gypseous soil samples and then tested. The results showed that the crude oil increases the liquid limit of the gypseous soils and changes the soil from non-plastic to plastic material, the crude oil also increased the maximum dry density (MDD) and decreases the optimum moisture content (OMC).
The results also showed that using crude oil denotes good solution and appropriate alternate to improve the properties of gypseous soils by elimination the melting of gypsum when it comes in touch with water in addition to increase in stability and strength properties of gypseous soil by decreasing the collapse potential and increasing CBR values.

Keywords
Crude oil, Gypseous soil, mechanical properties, collapsibility, shear strength.

1. Introduction
The term "Gypseous soil" is used to identify "soils that contain gypsum". Gypseous soils are very hard when they dry due to the cementation and strengthening of soil particles with gypsum, but large losses in strength and sudden increase in compressibility occur when the soils are exposed to moisture or leaching because of the melting of gypsum between soil particles (Nashat, 1990). Most types of gypseous soils are found in arid and semi-arid areas, and are considered as "problematic soils", and they exhibit unexpected behavior that can cause significant problems with civil works (Petrukhin & Boldyrev, 1978). When collapsible soil under loading are saturated, sudden settlement and rapid failure will be held which leads to damages in the structures built on these soil. Gypseous soils are extensively distributed specially in Iraq when gypsum covers about 12% of its total area (FAO 1990, Ismail 1994) indicated that gypseous soils covers 31.7 of the whole area of Iraq. The estimated amount of gypsum can reach (80%) in the northern and mid parts of the Tigris and Euphrates beds, while the...
content of gypsum in Al-Jazeera area ranges from (3%–10%) in the upper parts and may exceed (50%) in the lower parts. 

(Al-Deffaaee, 2002). Some physical properties such as "dry unit weight" and "liquid limit" are useful to estimate collapse potential of gypseous soils (Nafie, 1989). Several studies indicated that engineering properties of gypseous soils are changing as a result of water movement and leaching out of gypsum from it (Rezaei et al., 2012).

There are many problems that occur as a result of damages to roads and structures built on gypseous soils, such as tilting, cavities, cracks and overturning of structures, and these problems can be very serious. Therefore, the improvement of the gypseous soils are very important. 

(Khattab1986) showed that sulphate-resistance cement improves the unconfined compressive strength of granular gypseous soil, but a significant reduction in strength and stiffness when immersed in water. (Seleam, 1988) investigated the effect of some petroleum products on the properties of sandy gypseous soil. It was concluded that both kerosene and the gasoil affect soil behavior in the similar way and cause swelling of the gypseous soil with low gypsum content when contaminated. (Al-Obaidy 1992 and Al-Zory 1993) mixed lime by (5 –7) % with soil of 43 % gypsum content. Their results showed an increase in strength and high leaching resistance and the soil became virtually impervious to water after 28 days curing. (Al- Aqaby 2001) noticed a decrease in cohesion of soil containing gypsum between 30 –67 % when immersed in kerosene or water and a decrease of 6 degrees of internal friction when soaked in kerosene. (Al-Hassany 2001) implemented consolidation tests for two samples of gypseous soils in which the gypsum content 26 % and 51% treated with fuel oil. The results showed that the oil filled the pores of the soil and prevented leakage of water and thus reduced the permeability of the soil. (Fattah M. Y. et. al., 2014) grouted the gypseous soil by acrylate liquid and showed a decrease in compressibility by more than 60–70% and collapsibility by more than 50–60%. The acrylate liquid decreases the angle of friction and increases the cohesion. Al-Adili et. al. (2017) studied the effect of crude oil on gypseous soil and concluded that the water content required to achieve max. dry density had decreased when the crude oil content was increased as well as the liquid limit and specific gravity.

Since different parts of Iraqi gypseous soils are contaminated by crude oil due to multiple oil wells, oil explorations, damage storage tanks and pipe lines, natural seepage and spills during the war, therefore, this paper is presented to study the effect of crude oil contamination of geotechnical properties of gypseous soil and to determine the possibility of using it as an improvement material.

2. The Materials used

2.1 The Soil

A gypseous soil was brought up from Hadiitha city, 260 km west of Baghdad. A trial pit was dug using hand shovel to a depth of 1 m below N.G.L. The disturbed samples were collected from the bottom of the pit. The samples were put in air-tight plastic bags and transported to the laboratory of soil of Dijlah University. The average gypsum content of the soil is 34% and The grain size distribution curve of the soil is shown in Figure 1. The properties of the soil are shown in Table 1.
Figure 1. Grain size distribution for gypseous soil

Table 1. The physical properties of the soil

| property                  | Value | Specification no. |
|---------------------------|-------|-------------------|
| Liquid limit (L.L)        | 45    | BS 1377:2A        |
| Plastic limit (P.L)       | 42    | BS 1377:3         |
| Plasticity Index (P.I)    | 3     |                   |
| Specific gravity (G_s)    | 2.54  | BS 1377:6B        |
| Sand %                    | 60    |                   |
| Passing sieve no. 200(%)  | 40    |                   |
| Maximum Dry density(g/cm³)| 1.71  | ASTM D698, 2000   |
| Optimum moisture content (O.M.C)% | 14 | ASTM D698, 2000 |
| Grain size distributions  |       | ASTM D422         |

Depending on the "Unified Soil Classification System (USCS)", the soil is classified as silty sand (SM).

2.2 The crude oil

The crude oil used in this study was carried out from Al-Doura refinery in Baghdad. The physical properties of this product are presented in Table 2. The physical properties of this product were tested at Al-Doura refinery in Baghdad.

Table 2. Physical properties of crude oil

| Index property | Viscosity @21.1°C | Density @15 °C | API gravity @15.6°C | R.V.P kg/cm² | Specific gravity@ 15.6 °C | Total Distil. Vol.% |
|----------------|-------------------|----------------|---------------------|--------------|---------------------------|---------------------|
| Value          | 15.0              | 0.8676         | 31.5                | 0.52         | 0.8681                     | 47.0                |

3. Specimens Preparation

Four types of samples were used in this study, three of which were contaminated by crude oil and the fourth sample was uncontaminated. The contaminated samples were prepared by mixing the gypseous soil with predetermined percentages of crude oil (3%, 6%, and 9% of dry weight). The specimens were prepared by mixing the soil samples with appropriate water content depending on the test type. For mechanical tests, the samples were compacted using the energy of standard compaction test.

4. Results and Discussion

4.1 Atterberg Limits Test:

This test was done for the four samples (contaminated and uncontaminated) after passing it through the sieve #40 to determine the liquid limit and plastic limit. The results of these tests are shown in Figure 2. The results designated that the liquid limit of soil increases as the crude oil content increases, while the soil changes from non - plastic for gypseous soil before adding crude oil to plastic material
for all percentages of crude oil added to the soil by increasing plasticity index from 3% to 28% as the crude oil increase from 0% to 9%, respectively.

![Figure 2](image2.png)

**Figure 2.** Effect of crude content on consistency limit.

### 4.2 Compaction Characteristics Test

#### 4.2.1 Compaction Test

"Standard compaction tests" are conducted on soil samples to determine the moisture content–dry density relationship according to (ASTM D698). The relationship between dry density and water content is shown in figure (3) while the crude oil – max. dry density & crude oil-optimum water content relationships are shown in figures (4) and (5). The results illustrate a slight increase in maximum dry density of gypseous contaminated soils as the crude oil increases except 3% crude oil decreases the dry density, and decrease in the optimum water content with the increase in crude oil contents.

![Figure 3](image3.png)

**Figure 3.** Relationship between Dry density and moisture content of Gypseous soil for different crude oil content.

![Figure 4](image4.png)

**Figure 4.** Relationship between crude oil content and maximum dry density
4.3 Shear Strength Properties:
4.3.1 Direct Shear Test: Direct shear test is conducted to examine the effect of crude oil on shear strength parameters of gypseous soil (C and $\phi$). Figures 6, 7 and 8 demonstrate the results of the direct shear test of gypseous soil with different crude oil percentages. It can be observed from the test results that there is an increase in the value of cohesion (C) as the crude oil increases, while the angle of internal friction ($\phi$) decreases with increasing of crude oil content except 6% crude oil gives the peak value. This phenomenon was attributed to the crude oil viscosity, where the crude oil connects the soil particles together and increases soil resistance.

![Figure 6](image6.png)

**Figure 6.** Relationship between shear stress and normal stress for gypseous soil for different crude oil content from direct shear test

![Figure 7](image7.png)

**Figure 7.** Relationship between Soil Cohesion and crude oil content
Figure 8. Relationship between Angle of shearing resistance and crude oil content

4.3.2 Unconfined Compression Test:
Unconfined compression tests were conducted on specimens of 38 mm diameter and 76 mm length to examine the crude oil’s effect on the unconfined compressive strength of gypseous soils. The unconfined compression test results of gypsum soil are shown in figures 9 and 10. The figures illustrate increase in the unconfined compressive strength (qu) as the crude oil content increases to a peak value, then decreases. The increase in the compressive strength with the increase of crude oil is due to the increasing cohesion between the gypseous soil particles in addition to a relative increase in the angle of internal friction of the gypseous soil particles by a continuous films that crude oil formed surrounding the gypseous soil particles. After continuing adding crude oil, it can be noticed that there is a decrease in compressive strength because of the reduction in the internal friction between gypseous soil particles and that can be attribute to the increase in thickness of membrane of the crude oil coating the particles.

Figure 9. Stress-strain relationship for specimens compacted (MDD & OMC) with different crude oil content
Figure 10. Maximum values for unconfined compression strength with crude oil content relationship.

Figure 11. Samples of unconfined compression test: (a) gyp0, (b) gyp3 (c) gyp6, (d) gyp9

4.3.3 California Bearing Ratio (CBR) Test:
The CBR test is considered the common test to evaluate the bearing capacity of subgrade soils. In this test, the strength needed to cause a plunger to penetrate (2.5 mm or 5 mm) into a soil sample compacted into a cylindrical mold with a diameter of (152 mm) is measured. The measured force is taken as a percentage of a standard strength. The tests were conducted on uncontaminated and contaminated samples under the effect of unsoaking and soaking with water and the results are shown in figures 12 and 13, respectively. The variation of CBR with respect to crude oil content is shown in figures 14 and 15. The maximum value of CBR obtained at 6% for unsoaking samples then decreases while the value of CBR increases with increasing crude oil for soaking samples and the value of CBR at 9% for soaking samples is nearly the same as that for uncontaminated and unsoaking sample. This behavior is attributed to the effect of crude oil which works as a waterproof coating to prevent water from reaching the soil particles resulting in decrease in the dissolution of gypsum.
Figure 12. Unsoaked Penetration curves for CBR tests for gypseous soil with different crude oil content

Figure 13. Soaked Penetration curves for CBR tests for gypseous soil with different crude oil content

Figure 14. Variation of unsoaked CBR with addition of different percentages of crude oil
4.4 Collapsibility Properties:
The single collapse test proposed by "Jennings and Knight, 1975" was used to determine the collapse potential for uncontaminated and crude oil contaminated samples. The specimens were loaded in a suitable pressure increment up to 200 kPa without the addition of water. When equilibrium reached, water was added so that the specimen became totally submerged. The movement of the compression dial gauge was recorded. The vertical line of the e-log p curve due to the change in void ratio under the constant pressure represents the collapse due to saturation. The results of e-log p are shown in figure 16 and the variation of collapse potential with respect to crude oil content is shown in figure 17. It is seen from the figures that the collapse potential decreases with increasing crude oil content. For the uncontaminated sample, the saturation has led to dissolution of the cementing material (gypsum) between gypsum soil particles and resulting destruction of the inter particle bonds and new particle rearrangement which represent the collapse of the soil. The use of crude oil prevents water to be in contact with gypsum so that the minimum value of collapse potential was received at 9 percentage of crude oil.

Figure 15. Relationship between crude oil content and soaked CBR

Figure 16. Relationship between vertical stress and void ratio for gypseous soils with different crude oil content in single oedometer test (e-log p) curve
5. Conclusions
The following conclusions are obtained depending on the results obtained in this study:

1- From the liquid, plastic limit and plasticity index results, it can be noted that the soil changes from non-plastic material to plastic material as the P.I increases from 3% for uncontaminated soil to 28% for contaminated soil with 9% crude oil.

2- The 6% crude oil content is the optimum value that gives the max. dry density and unconfined compressive strength. While, the optimum water content decreases with the increasing of the crude oil content.

3- The cohesion determined by shear test increases from 21 kPa to 82 kPa for uncontaminated and soil contaminated with 9% crude oil, respectively, while the angle of internal friction decreases.

4- The use of 9% crude oil eliminates the effect of soaking on gypseous soils and improves the collapse potential from 3.1% to 1.3%.

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