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Monitoring of the Compressibility Characteristics of Asphalt Stabilized Subgrade

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Abstract. The subgrade soil is the foundation plate form of the roadway; it should sustain its structural characteristics throughout the design life of the roadway with minimal requirements for maintenance. When Gypseous soil is implemented in the construction of subgrade, problems regarding collapsibility and poor structural capacity usually occur when the subgrade came in touch with excess water. Asphalt stabilization could furnish a proper solution to such problems. In this investigation, an attempt has been made to monitor the variations in compressibility characteristics of asphalt stabilized subgrade soil subjected to 30 cycles of (freezing-thawing) and (heating-cooling). Data have been observed after each 10 cycles, and compared with that of reference mix. Specimens of (75) mm diameter and (20) mm height have been prepared at optimum fluid content with various asphalt emulsion percentages. Testing was carried out using the standard odometer to determine the compressibility characteristics at dry and soaked test conditions. It was concluded that for samples exposed to (10, 20 and 30) cycles of (freezing-thawing), the compression index (Cc) had increased with the increase of cycles in soaked condition but it decreases with increased number of cycles in dry condition. Initial void ratio decreased with number of cycles in dry condition; but remains constant with increased number of cycles in soaked condition. For samples exposed to (10, 20 and 30) cycles of (heating-cooling), (Cc) decreased with the increase of cycles in both soaked and dry condition. Initial void ratio increased with number of cycles while it slightly changed for dry and soaked condition respectively.

Key words: Asphalt emulsion; compressibility; durability; Gypseous soil; void ratio

1. INTRODUCTION

Gypseous soil covers large area in Iraq, it is considered as a problematic soil for roadway subgrade or embankment construction, it exhibit stiff properties after compaction at dry condition, but it is collapsible when come in touch with water.

1.1. Effect of Gypsum on Compressibility

In Gypseous soil, Gypsum acts as a binder between soil particles, causing the soil to be very hard when it is dry. Thus, Gypseous soils are reliable for construction under dry conditions and even under short-term of water flow, but become problematic, collapsible, and undergo large settlement under long term flooding with water (Al-Barzangi, 2003). Wetting and the accompanying solution of gypsum in the soil cause softening, formation of cavities, enlarged pores, increasing permeability and excessive settlement. Therefore, most of the investigations studied the compressibility of Gypseous soils included the negative effects of wetting, soaking or leaching process. (Sarsam et al, 2010). (Ramiah, 1982) studied the effect of gypsum content on the compressibility of Baghdad silty clay. It was found that the compression index (Cc) increases as the gypsum content increases to (3%) and then decreases when the gypsum content increases to (6%). (Seleam, 1988) investigated the behavior of Gypseous sandy soil. It was concluded that the total volume changes and the compression index (Cc) and rebound index (Ct) decrease with the increase in gypsum content. It was also, reported that the soil exhibits secondary (delayed) compression due to continuous dissolution of gypsum and reorientation of the soil particles. (Al-Quissy, 1989) reported that the compression index (Cc) and the total volumetric strain at the end of the one – dimensional compression test decrease as the gypsum content increases. The study also showed that a significant decrease in swelling index was observed as the gypsum content increases in the soil. (Al-Heeti, 1990) studied the engineering properties of a compacted Gypseous clayey soil. The results showed that the compressibility decreases and the compression index (Cc) slightly decrease as the gypsum content increases. (Al-Aithawi, 1990) studied the compressibility characteristics of Gypseous silty...
soil obtained from Baiji. The results showed that the soil exhibits low compressibility and a small time are required for the completion of primary consolidation. The tested soil exhibited secondary compression.

(Abood, 1994) reported that the compression index \(C_C\) in Gypseous soils decreases with the increase in gypsum content of the soil, while rebound index \(C_r\) increases for sandy soil with the increase in gypsum content. The coefficient of consolidation \(C_V\) remains almost constant with the increase in applied pressure.

(Sheikha, 1994) reported that the compressibility decreases as the gypsum content increases. This behavior was attributed to the cementing action of gypsum. (Al-Mufty, 1997) reported that the rebound index \(C_r\) does not follow the same trend. Its value depends highly on the type of soil constituents other than gypsum and the way the gypsum and other particles are cemented. (Al-Dulaimi, 2004) reported that the compression index \(C_C\) and volumetric strain increase as gypsum content of the soil increases. This behavior may be attributed to the fact that the gypsum acts as cementing agent between soil particles of the dry sample and thus increases the resistance to deformation.

1.2. Effect of Asphalt Stabilization on Compressibility

(Al-Deffaee, 2002) found that Consolidation test results showed that total volumetric strain, coefficient of consolidation, and compression index of treated soil samples decreased upon increasing the percentage of emulsified asphalt. (Al-Qhralosy, 2003) showed that both volumetric strain and compression index decreased with increasing emulsified asphalt content up to optimum and then increased, while the rebound index increased with increasing emulsified asphalt content. (Sarsam and Ibrahim, 2008) showed that the addition of emulsified asphalt considerably reduces the void ratio and permeability. When the stabilized Gypseous soil was tested for rebound consolidation, it indicated that the addition of emulsified asphalt created a type of elastic properties and behavior in the soil at high stress application, and the permanent strain was reduced. The test was carried out on dry and soaked conditions. (Sarsam and Hamza, 2015) studied the impact of asphalt emulsion on permeability and unconfined compressive strength. It was concluded that emulsified asphalt has a positive effect on strength improvement, waterproofing and reduction of permeability potential of compacted Gypseous soil.

(Sarsam et al, 2014-a) studied the failure behavior of two types of liquid asphalt (cutback and emulsion) in an asphalt stabilized embankment model. For the stabilized soil with Cut-Back Asphalt, the number of load repetitions at failure was 436 with vertical displacement of 9.62 mm, the strength was improved by nine folds, and the vertical displacement reduces by 23% as compared to untreated soil. For the stabilized soil with emulsion, the vertical displacement was 7.72 mm under 950 load repetitions, the strength was improved by twenty folds, and the reduction in vertical displacement shows an improvement by 38.5% as compared to untreated soil.

(Sarsam et al, 2014-b) stated that the addition of asphalt emulsion has positive impact on soil behavior; it changes the hydraulic conductivity of the soil, the embankment model was able to sustain an applied stress of \((4 - 4.5 \text{ MPa})\) before failure and shows 0.12 mm of vertical deformation at dry and absorbed test conditions under monotonic loading. However, under repeated load condition, the stabilized soil was able to sustain 911 and 897 load repetitions at failure for dry and absorbed test conditions respectively. The impact of water absorption was not significant. The aim of this investigation was to monitor the variation of collapsibility and void ratio of Gypseous soil at both dry and soaked conditions when asphalt emulsion is introduced as a stabilizing agent.

2. MATERIALS AND METHODS

2.1. Gypseous soil

The Gypseous soil sample was brought from AL Karma, which is located in AL Anbar Governorate, the top 30 cm of the soil layer was discarded, and the portion beneath was excavated up to a depth of 0.75 m for this investigation. Fig. 1 shows the grain size distribution. Table 1, demonstrates its chemical composition, while Table 2 illustrates the physical properties of the soil. Fig. 2 exhibits the compressibility characteristics of the soil under dry and absorbed testing conditions. It can be observed that the voids ratio decreases after soaking by 5% as compared to that at dry test, the impact of repeated loading and rebound is more pronounced at the soaked test condition.
### Table 1: Chemical composition of the soil

| Chemical composition                     | %   |
|------------------------------------------|-----|
| Total soluble salts (TSS)                | 8.25|
| Total SO₃                                | 25.06|
| Total CO₃                                | 0.27|
| PH Value                                 | 8.7 |
| Gypsum content (CaSO₄) as per [Mufty and Nashat, 2000] | 40  |

### Table 2: Physical properties of the soil

| Property                                      | Test results |
|----------------------------------------------|--------------|
| Specific gravity                             | 2.45         |
| Liquid limit (%)                             | 34           |
| Plasticity index (%)                         | Non plastic  |
| Maximum dry unit weight (standard compaction ASTM D698-00a) | 16.29        |
| Optimum moisture content (%)                 | 16.5         |
| Maximum dry unit weight (ASTM D4253-00)      | 15.5         |
| Minimum dry unit weight (ASTM D4254-00)      | 11.7         |
|Cc (coefficient of curvature)                 | 1            |
|Cu (coefficient of uniformity)               | 5            |
|Unified classification system                 | SP-SM        |

### Fig. 1: Grain size distribution of the Gypseous soil

### Fig. 2: Compressibility properties of soil

2.2. Asphalt emulsion

Asphalt emulsion was obtained from local market, it is locally manufactured with low cost. The specifications as supplied by the manufacturer are as given in Table 3.

### Table 3: Properties of asphalt emulsion

| Property                          | Particle charge | Viscosity Cst. @60 C | Setting time (hr.) | Coating ability | Water resistance |
|----------------------------------|-----------------|----------------------|--------------------|-----------------|------------------|
| Test result                      | +ve             | 45                   | 19                 | Good            | Fair             |

2.3. Preparation of Specimen

A series of one-dimensional compression test was conducted according to the procedure by (ASTM D 2435 –00) to study the effect of the environmental factors on the void ratio, compressibility index and rebound compression index under (Freezing-thawing) and (heating-cooling) cycles. This test was carried out on specimens of untreated soil and on specimens prepared at the optimum fluid content of 16.5% to study the effect of fluid content on the compression properties. The soil was mixed with the required amount of fluid content and then left for aeration at room temperature of 23±2 °C for two hours before being compacted. The predetermined weight of the stabilized soil that gives the maximum standard dry density of 16.29 (kN/m³) was compacted in a mold of 75mm diameter and 19mm height using static compaction. The prepared specimens were allowed for curing at 25 ±2 °C for seven days as recommended by (Sarsam and Ibrahim, 2008), then were divided into two groups; the first group was tested in dry condition, while the second group was flooded with water for (24) hrs and then was tested using the rapid test procedure. The settlement was recorded with the increments of load application.
2.4. Durability Test

2.4.1. Freezing - Thawing Cycles

To simulate the effect of winter conditions on the deformation under compressive stress, the cycles of (freezing-thawing) were used to evaluate the strength performance and durability of the Gypseous soil samples stabilized with emulsified asphalt. Durability in terms of (Freezing-thawing) test was conducted in this work according to the procedure provided by the (ASTM-D560, 1996) and (US Army corps of Engineering, 1989). This test was proposed to examine the durability of geotechnical materials. In brief, after completing the curing time of 7 days, the specimens were subjected to freezing for 6 hrs at temperature of (-18°C) and then followed by thawing at (40°C) for 6 hrs. This process represented one cycle of (freezing-thawing), which requires 12 hrs.

2.4.2. Heating – Cooling Cycles

The cycles of (heating-cooling) were used to evaluate the performance of strength and durability of the Gypseous soil samples stabilized with emulsified asphalt. These tests were proposed to examine the durability of geotechnical materials used in road and highway construction against the actions of weather of hot to moderate conditions. The procedure used in this test is approximately similar to that presented in the (US Army Corp of Engineers, 1989) for test with the expectation regarding the number of cycles, the curing time and the soil loss. In brief, after completing the curing time of 7 days, the specimens were stored in an oven and subjected to heating for 6 hr at temperature of (60°C) and then, the specimens were withdrawn from the oven and were cooled at (20°C) for 6 hours this process represented one cycle of (heating-cooling), which requires 12 hrs.

2.5. Testing for One - Dimensional Confined Compression

The test was carried out on two specimens of untreated Gypseous soil and fourteen specimens of stabilized soils starting with emulsion content of 3% to 15% (2% increments) for each of the durability cases assessed. For untreated soil, the first specimen was tested at dry condition while the second specimen was tested at soaked conditions. The specimens of stabilized soil were divided in two groups. The first group was tested at dry condition and the second group was tested at soaking condition. The asphalt stabilized soil specimens were cured for (7) days before the test. The test was conducted as per (ASTM-D2435, 1996).

3. RESULTS AND DISCUSSIONS

3.1. Impact of asphalt emulsion content and testing condition on consolidation behavior

Consolidation tests were performed to determine the consolidation characteristics of the prepared soil and treated soil with different percentages of emulsified asphalt. The test results are presented as void ratio versus effective stress as shown in Figures 3 and 4 for both dry and soaked conditions. For tested specimens, it can be observed that the addition of emulsion reduces the void ratio until reaching 11% of emulsified asphalt content, and then the voids ratio increased with further addition of emulsion. This might be attributed to the more lubrication effect of emulsion on soil particles which affect in interlocking and void blocking. The impact of rebound loading is more pronounced at 11% emulsion, and more reduction in voids ratio could be observed. When the load was released from (800 to 200) kPa, the void ratio increases which indicate the creation of elastic properties in the mix. When the load was increased again to 800 kPa, higher reduction in the void ratio could be detected. Such behavior was in agreement with that reported by (Sarsam and Ibrahim, 2008).

The summary of the results of consolidation tests for dry condition are given in Table 4. It can be observed that the compression index (C_c) decreases in general when emulsion asphalt was introduced up to 11% of emulsion, then it increases with further increments of the binder, this may be attributed to the fact that the asphalt is binding the cohesionless soil particles and create a type of cohesion which resist the compressibility.
At higher binder content of more than 11% (which could be considered as the optimum requirement), the asphalt film thickness increases and causes more lubrication for particles movement with negative impact on the ability to sustain loading and to resist the compressibility under the applied load.

The first rebound compression index \( C_r1 \) exhibit slight increment at lower percentages of emulsion then decreases at optimum asphalt content of 11%. The second and third rebound compression index \( C_r2, C_r3 \) shows similar behavior of reduction as asphalt content increases up to the optimum, then increases again. The initial void ratio \( e_i \) generally decreases when emulsion asphalt was introduced.

### Table 4: Summary of one dimensional confined compression test variables for dry test

| Emulsion content | \( C_c \) | \( C_r1 \) | \( C_r2 \) | \( C_r3 \) | \( e_i \) |
|------------------|---------|---------|---------|---------|---------|
| Untreated soil   | 0.075   | 0.014   | 0.014   | 0.013   | 0.504   |
| 3% emulsion      | 0.047   | 0.016   | 0.016   | 0.014   | 0.503   |
| 5% emulsion      | 0.053   | 0.014   | 0.013   | 0.013   | 0.502   |
| 7% emulsion      | 0.046   | 0.016   | 0.009   | 0.009   | 0.504   |
| 9% emulsion      | 0.013   | 0.015   | 0.003   | 0.015   | 0.500   |
| 11% emulsion     | 0.018   | 0.011   | 0.013   | 0.013   | 0.504   |
| 13% emulsion     | 0.053   | 0.027   | 0.014   | 0.014   | 0.500   |
| 15% emulsion     | 0.083   | 0.022   | 0.020   | 0.019   | 0.500   |

The results of soaked condition are presented in Fig.4 as void ratio versus logarithm of effective stress. For specimens tested at soaked condition, the addition of emulsion reduced the void ratio up to 7% of emulsified asphalt content and then the voids ratio increases. This might be attributed to the more lubrication effect of emulsion on soil particles which affect in interlocking and void blocking. The impact of emulsion asphalt addition is well pronounced after 7% content in reduction of voids ratio. At 9% asphalt, the lowest void ratio of 0.24 after the third rebound of loading could be detected.

The summary of the results of consolidation test for soaked condition are given in Table 5. It can be noticed that \( C_c \) increases with the increment of emulsified asphalt. The initial void ratio \( e_i \) generally increases with the increment of asphalt content. The first, second and third rebound compression index \( C_r1, C_r2, \) and \( C_r3 \) increases as asphalt content increases.
Higher void ratio and higher compression indices were observed at the soaked test conditions as compared to those at dry test. This may be attributed to the fact that the role of asphalt is blocking the voids, binding and waterproofing the soil particles which could be clearly visible at the soaked testing condition.

### Table 5: Summary of one dimensional confined compression test variables for soaked test

| Emulsion content | C1  | C11 | C12 | C13 | C15 |
|------------------|-----|-----|-----|-----|-----|
| Untreated soil   | 0.072 | 0.013 | 0.013 | 0.015 | 0.490 |
| 3% emulsion      | 0.100 | 0.021 | 0.015 | 0.016 | 0.484 |
| 5% emulsion      | 0.102 | 0.019 | 0.014 | 0.003 | 0.499 |
| 7% emulsion      | 0.103 | 0.017 | 0.044 | 0.017 | 0.500 |
| 9% emulsion      | 0.139 | 0.016 | 0.027 | 0.025 | 0.493 |
| 11% emulsion     | 0.138 | 0.051 | 0.023 | 0.023 | 0.483 |
| 13% emulsion     | 0.093 | 0.026 | 0.053 | 0.051 | 0.504 |
| 15% emulsion     | 0.089 | 0.026 | 0.024 | 0.022 | 0.504 |

### 3.2. Behavior of asphalt stabilized soil under (freezing-thawing) cycles

As demonstrated in Fig.5, the cyclic (freezing-thawing) exhibits pronounced impact on the void ratio. For dry test condition, the void ratio decreases by 6% after 20 cycles of (freezing–thawing) when compared to the case after 10 cycles, while after 30 cycles the change in the void ratio came to a standstill.

However, void ratio exhibits reduction by 41% when the number of (freezing-thawing) cycles increases from 10 to 20 at soaked test condition, higher number of cycles of 30 shows negligible impact on void ratio. On the other hand, the impact of soaking on the void ratio is very well pronounced, the soaking process had reduced the void ratio by (26, 52, and 47) %, after (10, 20, and 30) cycles of (freezing-thawing) respectively.
Fig. 5: Impact of freezing-thawing cycles on compressibility characteristics of the soil

Table 6 summarizes the compressibility properties for dry test after (freezing-thawing) cycles, the compression index ($C_c$) decreases by (34, 38, and 47) % after (10, 20, and 30) cycles of (freezing-thawing) respectively, while the first, second and third rebound compression index ($C_{r1}$, $C_{r2}$, and $C_{r3}$) generally increases as the (freezing-thawing) cycles increases. Similar behavior was observed regarding the change in the initial void ratio.

| Number of cycles | $C_c$   | $C_{r1}$ | $C_{r2}$ | $C_{r3}$ | $e_i$  |
|------------------|---------|----------|----------|----------|--------|
| Reference mix    | 0.0834  | 0.0215   | 0.0197   | 0.0192   | 0.5001 |
| 10 cycles        | 0.0546  | 0.0401   | 0.0251   | 0.5008   |
| 20 cycles        | 0.0453  | 0.0388   | 0.0110   | 0.5005   |
| 30 cycles        | 0.0438  | 0.0389   | 0.0124   | 0.5000   |

Table 7 summarizes the compressibility properties for soaked test after (freezing-thawing) cycles, the compression index ($C_c$) increases by (32, 107, and 93) % after (10, 20, and 30) cycles of (freezing-thawing) respectively, while the first, second and third rebound compression index ($C_{r1}$, $C_{r2}$, and $C_{r3}$) generally increases as the (freezing-thawing) cycles increases. The initial void ratio exhibits reduction as the (freezing-thawing) cycle's proceeds.

| Number of cycles | $C_c$   | $C_{r1}$ | $C_{r2}$ | $C_{r3}$ | $e_i$  |
|------------------|---------|----------|----------|----------|--------|
| Reference mix    | 0.0894  | 0.0262   | 0.0242   | 0.0216   | 0.5039 |
| 10 cycles        | 0.1186  | 0.0376   | 0.0381   | 0.0399   | 0.5040 |
| 20 cycles        | 0.1859  | 0.0279   | 0.0268   | 0.0268   | 0.4878 |
| 30 cycles        | 0.1728  | 0.0552   | 0.0263   | 0.0237   | 0.4931 |

3.3. Behavior of asphalt stabilized soil under (heating-cooling) cycles

As demonstrated in Fig.6, the cyclic (heating-cooling) exhibits pronounced effect on the void ratio. For dry test condition, the void ratio increased by (43 and 25) % after (20 and 30) cycles of (heating-cooling) respectively when compared to the case after 10 cycles. However, void ratio increases by (23 and 20) % when the number of (heating-cooling) cycles increases to (20 and 30) at soaked test condition. On the other hand, the impact of soaking on the void ratio is very well pronounced, the soaking process had increased the void ratio by (21, 0.3, and 14) %, after (10, 20, and 30) cycles of (heating-cooling) respectively.
Fig. 6: Impact of heating-cooling cycles on compressibility characteristics of the soil

Table 8 summarizes the compressibility properties for dry test after (heating-cooling) cycles, the compression index ($C_c$) decreases by (68, 97, and 48) % after (10, 20, and 30) cycles of (heating-cooling) respectively, while the first, and second rebound compression index ($C_{r1}$, $C_{r2}$) generally increases after

| Number of cycles | $C_c$   | $C_{r1}$ | $C_{r2}$ | $C_{r3}$ | $e_i$ |
|------------------|---------|----------|----------|----------|-------|
| Reference mix    | 0.0834  | 0.0215   | 0.0197   | 0.0192   | 0.5001|
| 10 cycles        | 0.0266  | 0.0252   | 0.0458   | 0.0087   | 0.5034|
| 20 cycles        | 0.0018  | 0.0005   | 0.0005   | 0.0008   | 0.5040|
| 30 cycles        | 0.0435  | 0.0145   | 0.0116   | 0.0126   | 0.5022|

Table 9 summarizes the compressibility properties for soaked test after (heating-cooling) cycles, the compression index ($C_c$) decreases by (83, 99, and 98) % after (10, 20, and 30) cycles of (heating-cooling) respectively, while the first, second and third rebound compression index ($C_{r1}$, $C_{r2}$, and $C_{r3}$) generally decreases as the (heating-cooling) cycles increases. The variations in the initial void ratio was not significant as the (heating-cooling) cycle’s proceeds.

| Number of cycles | $C_c$   | $C_{r1}$ | $C_{r2}$ | $C_{r3}$ | $e_i$ |
|------------------|---------|----------|----------|----------|-------|
| Reference mix    | 0.0894  | 0.0262   | 0.0242   | 0.0216   | 0.5039|
| 10 cycles        | 0.0151  | 0.0013   | 0.0016   | 0.0076   | 0.5040|
| 20 cycles        | 0.0005  | 0.0005   | 0.0008   | 0.0005   | 0.5038|
| 30 cycles        | 0.0018  | 0.0016   | 0.0008   | 0.0011   | 0.5040|

4. CONCLUSION

Based on the testing program, the following conclusions are drawn

1- The compression index ($C_c$) decreases by (34, 38, and 47) % after (10, 20, and 30) cycles of (freezing-thawing) respectively at dry test, while it increases by (32, 107, and 93) % after (10, 20, and 30) cycles of (freezing-thawing) respectively at soaked test.

2- The compression index ($C_c$) decreases by (68, 97, and 48) % after (10, 20, and 30) cycles of (heating-cooling) respectively at dry test, while it decreases by (83, 99, and 98) % after (10, 20, and 30) cycles of (heating-cooling) respectively at soaked test.

3- The first, second and third rebound compression index ($C_{r1}$, $C_{r2}$, and $C_{r3}$) generally increases as the (freezing-thawing) cycles increases for both dry and soaked test conditions.

4- The first, second and third rebound compression index ($C_{r1}$, $C_{r2}$, and $C_{r3}$) generally decreases as the (heating-cooling) cycles increases at soaked test, while the variation was not significant at dry test.

5- The soaking process had reduced the void ratio by (26, 52, and 47) %, after (10, 20, and 30) cycles of (freezing-thawing) respectively, while it increased the void ratio by (21, 0.3, and 14) %, after (10, 20, and 30) cycles of (heating-cooling) respectively.
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