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Assessing the Sustainability of Asphalt Stabilized Subgrade Soil for Embankment Construction

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Abstract

Gypseous soil is considered as a problematic soil for embankment construction, however, implementation of emulsified asphalt as a stabilization agent could be a proper solution for enhancing its properties as a subgrade soil. In this work, the sustainability of asphalt stabilized soil has been assessed in terms of its resistance to cyclic (freezing-thawing) and (heating-cooling) processes. Specimens have been prepared at optimum fluid content (moisture and emulsion) and tested under direct shear stresses while subjected to 30 cycles of (freezing-thawing) and (heating-cooling). Both of dry and soaked testing conditions have been implemented. Data have been observed after each 10 cycles, and compared with that of reference mix. It was concluded that for dry test condition, samples exposed to (10, 20 and 30) cycles of (freezing-thawing) exhibits irregular variation in the Angle of internal friction, it increases after 10 cycles and then decreased. However, the cohesion decreased while increasing the number of cycles. For soaked test condition, Angle of internal friction remained constant and then increased after 20 cycles then decreased with further increments of (freezing-thawing) cycles, while cohesion decreased with the increased number of cycles. On the other hand, the results of the direct shear test for unsoaked test condition on samples exposed to (10, 20 and 30) cycles of (heating-cooling) exhibits that the angle of internal friction increases after 10 cycles, then decreased with further increase in (heating-cooling) cycles, while the Cohesion increases after 10 cycles then decrease with increased number of cycles for both soaked and unsoaked testing condition.

Keywords

Emulsion, Freezing, Gypseous Soil, Heating, Shear, Sustainability, Thawing, Cooling

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1. Introduction

The stability of Gypseous subgrade soil is a function of cohesion between soil particles and the water content. Such cohesion is due to the chemical reaction which allows the gypsum to bind the soil particles in a cementation action, [1]. Such cohesion is not permanent and vanishes when the soil come in touch with water. Many studies have been made to investigate the possibility of stabilizing Gypseous soil with liquid asphalt (asphalt emulsion and cut back asphalt), [2]. Gypseous soils are stiff when they are dry but collapsible or compressed very quickly when flooded with water, [3] which may damage the engineering structures within the site since the element of structures cannot follow the sudden deformation by rearrangement of the inside forces or stresses [4]. For such condition, Gypseous soil is considered as a problematic soil. Implementation of liquid asphalt as a stabilizing agent could offer the required permanency in cohesion by providing a damp proofing action, blocking of the continuous voids and support the stability of the soil, [5]. The cohesion of the soil increases by increasing the liquid asphalt to an optimum value and then decreases, [6], while the angle of internal friction decreases with increasing the bituminous materials. [7] Found that the cohesion for unsoaked samples increased to an optimum value and then

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decreased while the angle of internal friction was unaffected, but after soaking, the cohesion of soil reduced as compared to the unsoaked case. [8] implemented the (used oil) for stabilization; the results showed that the cohesion of Gypseous soil decreased with the increasing of the percent of fuel oil. The friction component increased slightly with the increase of the fuel oil content, [9]. [10] And [11] showed that the cohesion parameter of treated soil samples by different percentages of emulsified asphalt increased and the angle of internal friction decreased as emulsified asphalt content increased.

1.1. Effect of Gypsum on Shear Strength

As stated before, gypsum acts as cementing agent between the particles of Gypseous soil, making these soils very stiff when they are dry. The shear strength usually decreases upon wetting as some of the cementing agent dissolves. The amount of loss in cementation depends on the original Gypsum content, void ratio, the amount of water added to the soil and the type and condition of the soil. [12] Conducted several laboratory tests on Gypseous soil. It was concluded that the angle of internal friction (Ø) increases with gypsum content, and that the larger the (Ø) the smaller the cohesion (C). Similar results were observed by [13]. [14] Reported that the strength parameters increase with the increase in gypsum content for sandy soil with gypsum content that varies between (26%) and (80%). The high value of the cohesion was attributed to the effect of gypsum cementation between soil particles.

1.2. Effect of Asphalt Stabilization on Shear Strength Parameters (C and Ø)

The cohesion of the soil increases with increasing the bituminous materials to an optimum value and then decreases, while the angle of internal friction decreases with increasing the bituminous materials. [10] Showed that the results of direct shear test showed that the cohesion parameter of treated soil samples by different percentages of emulsified asphalt increased and the angle of internal friction decreased as emulsified asphalt content increased. [11] Showed that the cohesion increased with increasing emulsified asphalt content, while the angle of internal friction decreased. [2] Found that the addition of emulsified asphalt had significantly increased the cohesion and the angle of internal friction.

2. Materials and Methods

2.1. Gypseous Soil

The Gypseous soil sample was obtained from AL Garma, west of Baghdad, the top 30 cm of the soil layer was removed, and the portion beneath was excavated up to a depth of 0.75 m for this investigation. Figure 1 exhibits the grain size distribution of the soil. Table 1, shows its chemical composition, while Table 2 illustrates the physical properties of the soil.

Table 1. Chemical composition of the soil.

Chemical composition	%
Total soluble saults (TSS)	8.25
Total SO_3	25.06
PH Value	8.7
Gypsum content ($CaSO_4$) 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, [15].	16.29
Optimum moisture content (%)	16.5
Cc (coefficient of curvature)	1
Cu (coefficient of uniformity)	5
Unified classification system	SP-SM

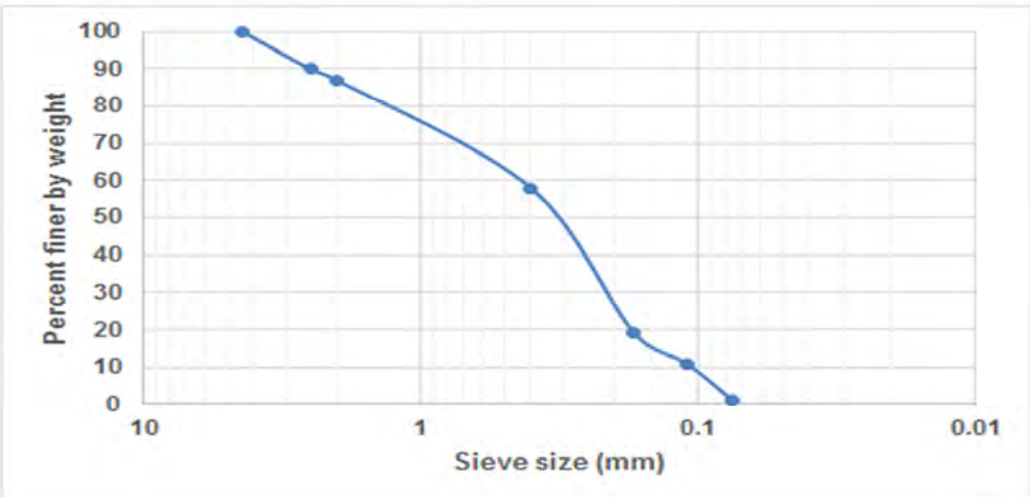


Figure 1. Grain size distribution of the soil.

2.2. Asphalt Emulsion

Asphalt cationic emulsion was obtained from local market, the specifications as supplied by the manufacturer are as given in Table 3.

Table 3. Properties of emulsified emulsion.

Property	Particle charge	Viscosity, Cst. @60°C	Setting time (hr.)	Coating ability
Test result	+ve	45	19	Good

2.3. Specimens Preparation

To prepare the specimen, the Gypseous soil passing sieve No. 4 was oven dried at a temperature of (45°C). The maximum dry unit weight of the soil was found through standard compaction test. It was 16.29 kN/m^3. Specimen were prepared at optimum fluid content of 16.5% (15% emulsified asphalt +1.5% water). The required percentage of water was thoroughly mixed by hand with the soil until water dispersed throughout the mixture; the emulsion was added and then mixed by rubbing the mixture between palms, so that the mixture has a homogenous character. The mixture was left two hours for aeration before compaction, then was compacted in a mold of (6x6x2) cm in dimensions using a static compaction. The compacted specimen were withdrawn immediately from the mold and subjected to curing at room temperature of 30±1°C for 7 days before testing. This procedure was recommended by [16] and [17]. Figure 2 shows part of the prepared direct shear test specimens.

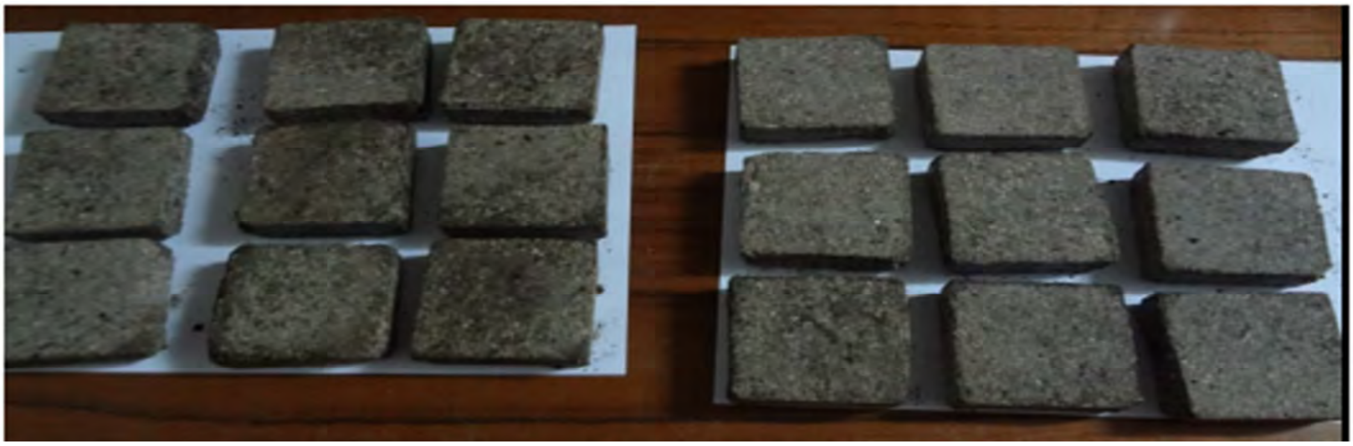


Figure 2. Part of prepared asphalt stabilized soil specimens.

2.4. Specimens Testing

To determine the shear strength parameters, (cohesion and angle of internal friction), a series of shear test was carried out using the direct shear apparatus according to the procedure proposed by ASTM [18]. A calibrated proving ring of (3 kN) capacity and (0.01 mm) precision dial gauge for deformation reading was used, while for horizontal deformation a (0.01 mm) dial gauge was used. The rate of strain was (1.2 mm/min).

The shear test was conducted for moulded specimens (stabilized with emulsion and for untreated soil). The prepared specimens were divided into two groups; the first group was tested in dry condition, while the second group was flooded with water for (24) hours and then was tested.

2.5. Testing for Durability

This test was conducted to study the effect of the environmental factors on the shear strength of asphalt stabilized soil subjected to cycles of (freezing-thawing) and (heating-cooling).

2.6. Freezing - Thawing Cycles

To simulate the effect of winter conditions on the shear strength, the cycles of freezing - thawing were used to evaluate the strength performance and durability of the Gypseous soil samples stabilized with emulsified asphalt. (Freezing-thawing) durability tests were conducted in this research according to the procedure provided by the [19]. In brief, after completing the curing time of 7days, the specimens were frozen for 6 hours at temperature of (-9°C) and then allowed for thawing at (40°C) for 6 hours. This process represented one cycle of (freezing-thawing), which requires 12hours.

2.7. Heating – Cooling Cycles

The cycles of (heating – cooling) were proposed to examine the durability of asphalt stabilized soil under the actions of moderate environment conditions. The procedure used in this test is similar to that presented in the [19]. In brief, after completing the curing time of 7days, the specimens were subjected to heating for 6 hour at temperature of (60°C) and then were cooled at (20°C) for 6 hours, this process represented one cycle of (heating-cooling), which requires 12hrs.

2.8. Direct Shear Test

The purpose of this test was to determine the shear strength parameters of the soil. All the specimens were tested under direct shear stresses while subjected to a total of 30 cycles of (freezing-thawing) and (heating-cooling). The test was conducted after each 10 cycles of the durability test. Fig. 3 presents direct shear test results of untreated soil at dry and soaked test conditions. The normal stresses used were (27.5, 55, and 110) kPa for untreated soil, while the asphalt stabilized soil specimens were subjected to normal stress of (27.5, 55, 83 and 110) kPa for better understanding of its behaviour.

3. Discussions

As demonstrated in Figure 3, it can be observed that for untreated soil specimens, as the normal stress increases, the shear stress also increases and the horizontal displacement decreases for the dry test condition. Similar behaviour could be detected at the soaked test condition except that the variation in the horizontal displacement was not significant. The shear strength decreases after soaking by (25, 37, and 26) % under (27.5, 55. and 110) kPa of normal stresses respectively. Such reduction may be attributed to the possible solution of gypsum under the soaking period of 24 hours which reduces the cohesion between soil particles.

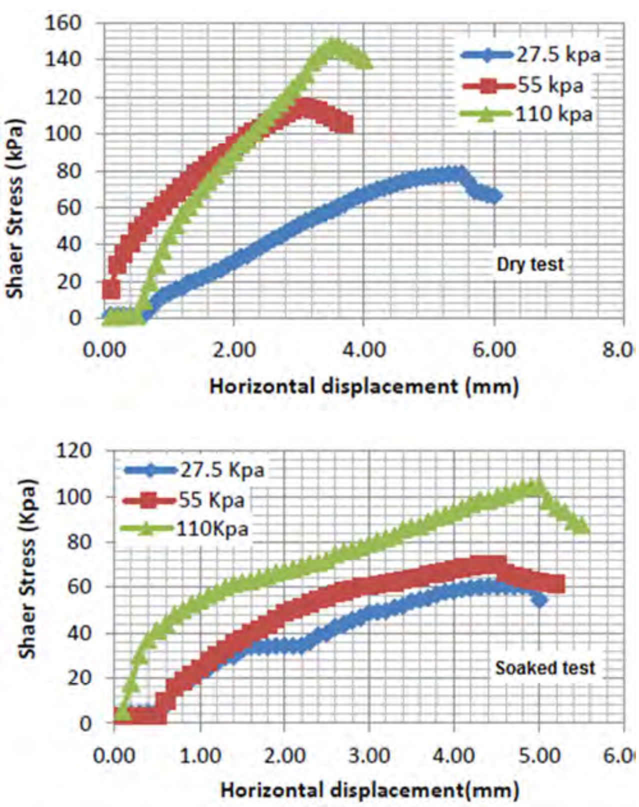


Figure 3. Direct shear test results for untreated soil.

Figure 4 shows that at dry testing condition, the shear strength of asphalt stabilized soil increases by (200, 92, and 113) % under (27.5, 55, and 110) kPa of normal stress respectively as compared to that of untreated soil. This could be attributed to the extra cohesion created between soil particles after implementation of asphalt. The variation in the horizontal displacement was not significant under various normal stresses, while it is lower than those of untreated soil. On the other hand, a pronounced reduction in shear strength could be noticed after soaking, and the shear strength decreases by (87, 80, and 87) % under (27.5, 55, and 110) kPa of normal stress respectively. These findings agrees well with [12] work.

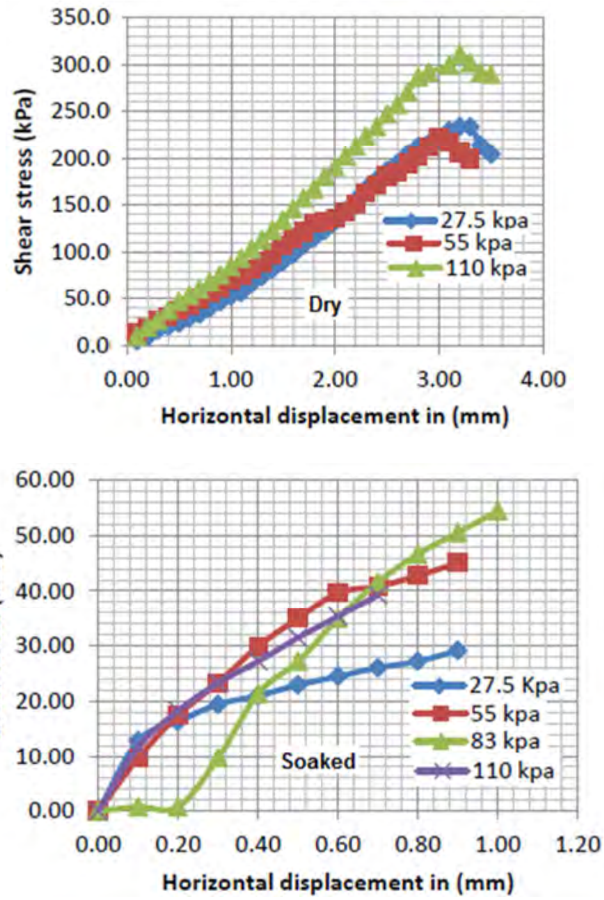


Figure 4. Direct shear test results for asphalt stabilized soil.

Figure 5 presents the behaviour of asphalt stabilized soil after practicing 10 cycles of (freezing-thawing), it can be observed that at dry test, the variations in horizontal displacement was not significant among various normal stresses applied, while it increases by 33% as compared to the case before the durability cycles. This may indicate the initiation of micro damage inside the specimen due to the (freezing-thawing) cycles. However, at soaked test condition, a pronounced variation in horizontal displacement could be observed especially at lower normal stresses. The shear strength decreases after soaking by (76, 72, 76, and 76) % under

(27.5, 55, 83, and 110) kPa of normal stresses respectively.

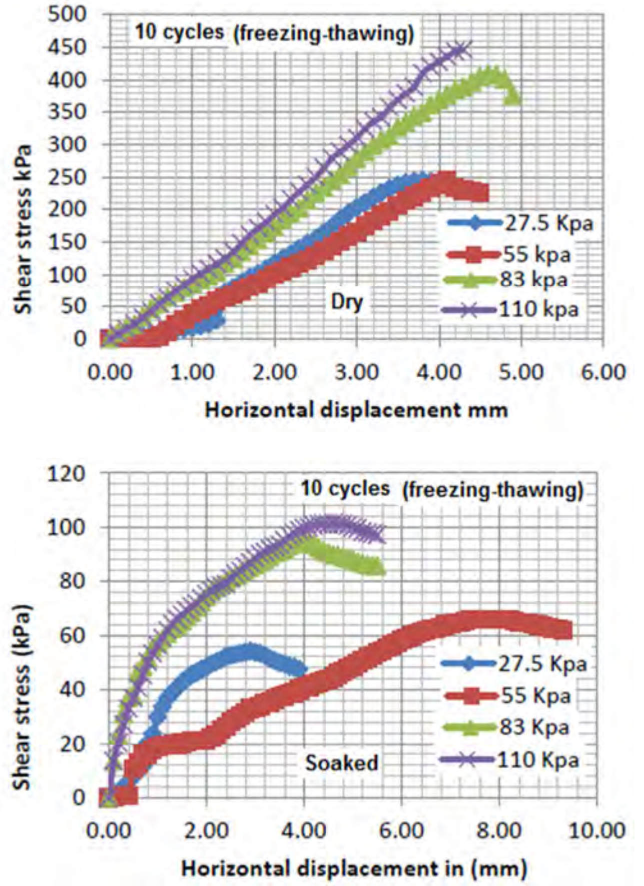


Figure 5. Behaviour of asphalt stabilized soil after 10 cycles of (freezing-thawing).

Figure 6 exhibits the impact of 30 cycles of (freezing-thawing) on asphalt stabilized soil, higher horizontal displacement could be detected at normal stress of 110 kPa at dry test, while the variation of horizontal displacement was not significant under the other normal stresses. At soaked condition, the shear strength decreases by (79.5, 68, 79.5, and 70)% due to soaking under (27.5, 55, 83, and 110) kPa of normal stresses respectively.

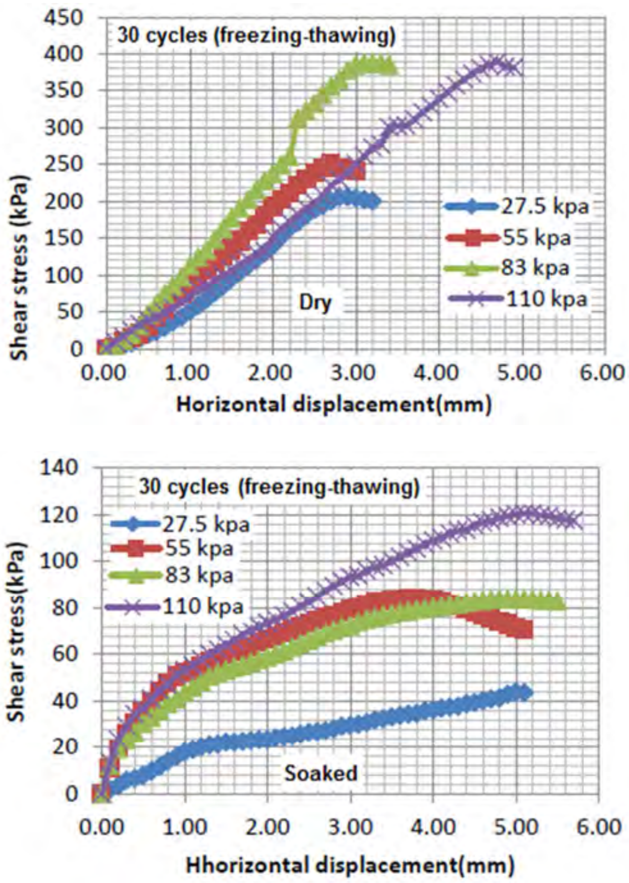


Figure 6. Behaviour of asphalt stabilized soil after 30 cycles of (freezing-thawing).

The Direct Shear test was carried out to study the effect of fluid content (emulsion with water) on shear strength parameters (c and Ø) of the Gypseous soils. Two groups of specimens are tested, the first group represents the untreated soil and the second group was the asphalt stabilized soil after process of aeration for two hours at room temperature before compaction and curing for 7 days after compaction, in soaked and dry condition. These results are shown in Table 4.

Table 4. Variation in shear strength parameters under freezing-thawing cycles.

Mix	Shear strength parameters				% Reduction after soaking	
	Dry test		Soaked test			
	Cohesion kPa	Angle of internal friction	Cohesion kPa	Angle of internal friction	Cohesion kPa	Angle of internal friction
Untreated	64	39	43	29	33	25
Reference	190	46	41	32	78	30
10 cycles	143	70	36	32	75	54
20 cycles	140	65	30	41	79	37
30 cycles	137	65	24	40	82	38

From the results, it can be noticed that the untreated soil specimens at dry test condition have the cohesion (C) and angle of internal friction (Ø) of 64 kPa and 39° respectively. This may be attributed to the cementation action of the gypsum. It can be noticed that the value of cohesion (C) and the angle of internal friction (Ø) decrease to 43 kPa and 29° respectively when the test was conducted under soaking condition.

This reduction may refer to the sensitivity of Gypseous soil to water, and to the possibility that gypsum in the specimen may dissolve in water throughout the soaking period of 24 hours, and cause possible weakness in particles interlock. When the direct shear test was conducted on asphalt stabilized specimens under dry test condition, the cohesion and the angle of internal friction of the soil increased to a high value and reach 190 and 46° respectively.

When testing stabilized soil under soaked conditions, the cohesion and the angle of internal friction of the soil changed to 41 and 32° respectively. The increment in cohesion and the angle of internal friction may be attributed to the adhesive properties of emulsion between particles of the soil. This cohesion and internal friction of stabilized specimens by emulsion were decreased when the test conducted in soaking condition. This reduction may be attributed to the effect of water on emulsion which reduces the cohesion in the emulsified soil system. When the specimens were subjected to (freezing-thawing) cycles, it can be noted that as the number of cycles increases, the cohesion decreases while the angle of internal friction increases. Angle of internal friction took irregular variation so it increased at 10 cycles and then decreased.

Figure 7 shows the Impact of (freezing-thawing) cycles on cohesion, it can be observed that at dry test, the reduction in cohesion is sharp after 10 cycles, while it is gentle after 20 and 30 cycles. On the other hand, at soaked condition, the reduction is continuous with the same trend.

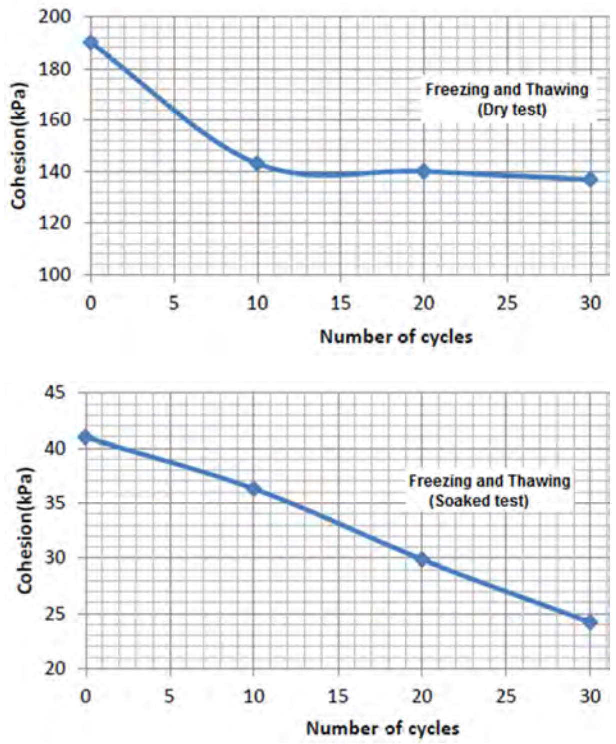


Figure 7. Impact of (freezing-thawing) cycles on cohesion.

As demonstrated in Figure 8, the shear strength of asphalt stabilized soil decreases as the number of (freezing- cooling) cycles increases because freezing - thawing caused additional stresses on the stabilized soil and that destroyed the micro structure of emulsified asphalt.

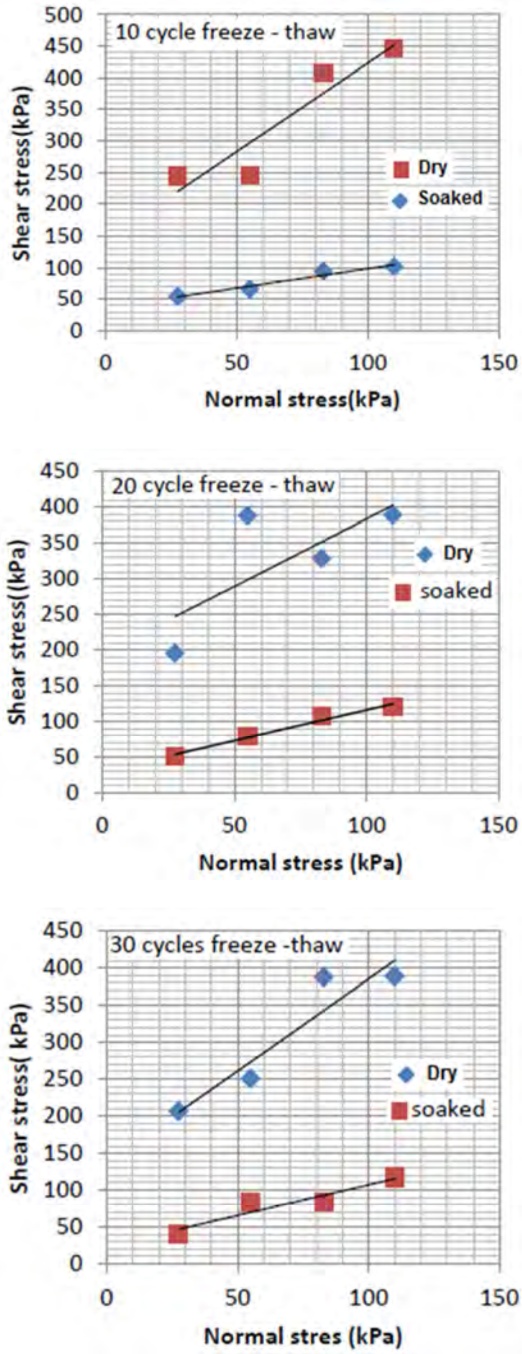


Figure 8. Details of the (freezing-thawing) influence on asphalt stabilized soil.

As far as the (heating-cooling) cycles are concerned, the stress - strain curves for dry and soaked specimens prepared are shown in Figure 9. It can be observed that the horizontal displacement is variable among various normal stresses at dry test, while such variation is not significant at soaked test.

The shear strength after 10 cycles of (heating-cooling) decreases due to soaking by (33, 37, 37, and 50) %, while the horizontal displacement decreases by 50% after soaking. Similar behaviour was noticed by [20].

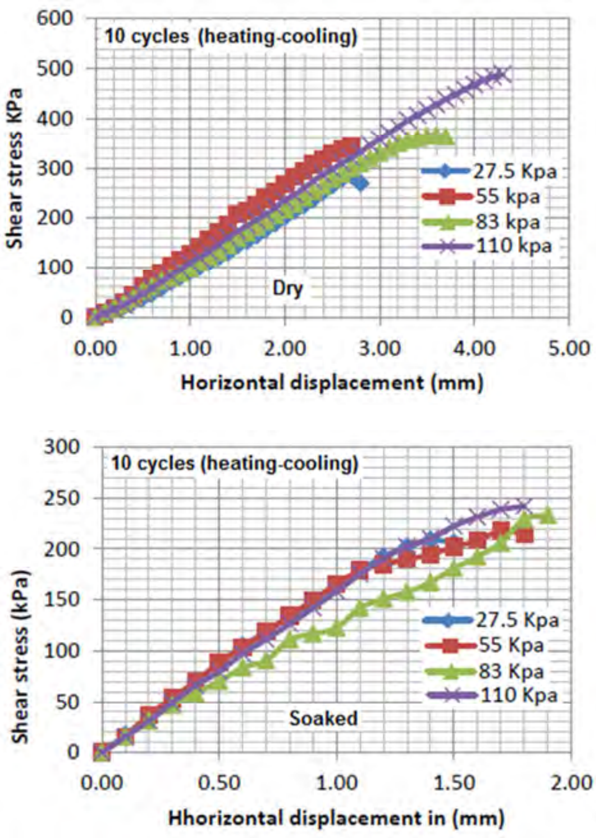


Figure 9. Behaviour of asphalt stabilized soil after 10 cycles of (heating-cooling).

will increase the viscosity of asphalt and the stiffness of the mixture. This could resist the impact of soaking. The horizontal displacement also decreases by 30% after soaking.

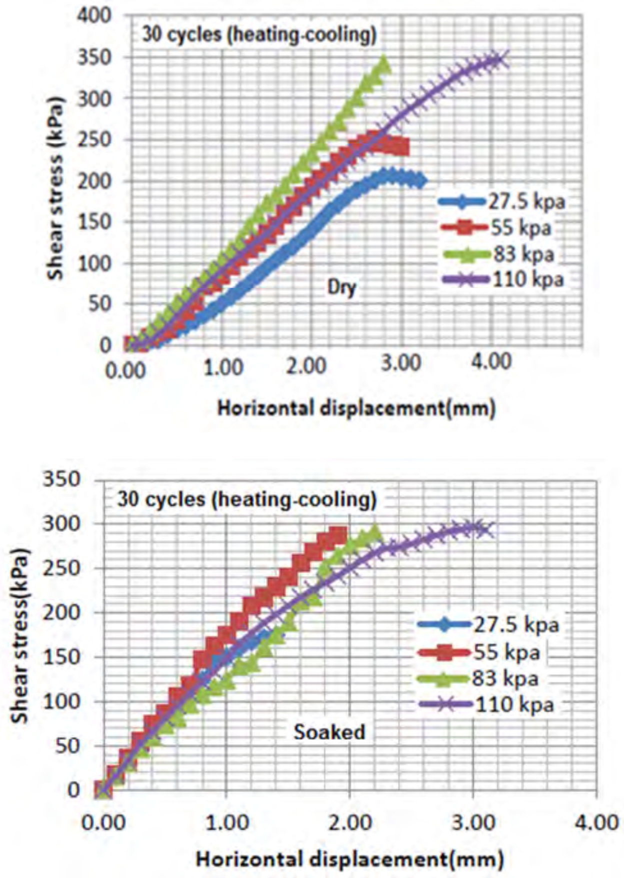


Figure 10. Behaviour of asphalt stabilized soil after 30 cycles of (heating-cooling).

Figure 10 exhibit the behaviour of asphalt stabilized soil after 30 cycles of (heating-cooling). The variation in shear strength under dry and soaked test conditions is not significant. This may be attributed to the fact that heating caused more volatiles to evaporate from the soil-emulsion structure, this

Table 5 summarizes the variation in shear strength parameters under heating-cooling cycles, the cohesion and the angle of internal friction increases after 10 cycles of (heating-cooling), then decreases with further increment in the cycles at dry test condition.

Table 5. Variation in shear strength parameters under heating-cooling cycles.

Mix	Shear strength parameters				% Reduction	
	Dry test		Soaked test			
	Cohesion kPa	Angle of internal friction	Cohesion kPa	Angle of internal friction	Cohesion kPa	Angle of internal friction
Untreated	64	39	43	29	33	25
Reference	190	46	41	32	78	30
10 cycles	212	67	197	24	7	64
20 cycles	195	61	177	54	9	11
30 cycles	162	61	171	52	6	15

However, at soaked test condition, the angle of internal friction increases with increment of (heating-cooling) cycles up to 20 cycles, then decreases with further increment in the cycles. The negative impact of soaking on shear strength parameters may also be detected at Table 5.

Figure 11 demonstrates that the cohesion at dry test gently increases after 10 cycles of (heating-cooling), while the cohesion decreases after 20 and 30 cycles. At soaked test condition, the cohesion increases sharply up to 10 cycles of (heating-cooling), while the variation in cohesion at 20 and 30 cycles was not significant as compared to 10 cycles.

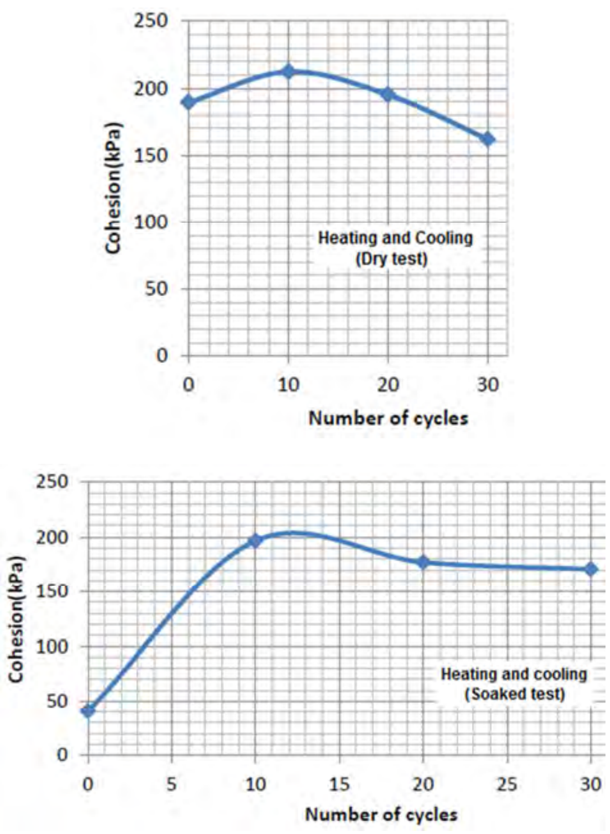
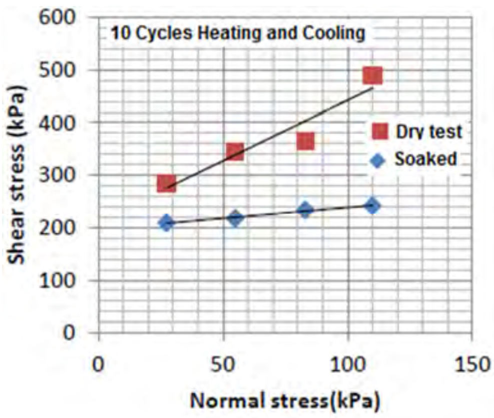
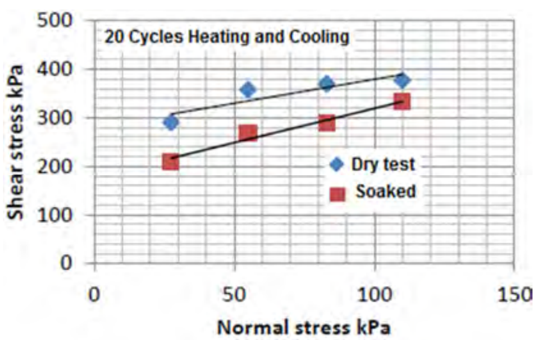


Figure 11. Impact of (freezing-thawing) cycles on cohesion.

As demonstrated in Figure 12, the shear strength decreases by (20 and 30)% after 20 and 30 cycles of (heating-cooling) at dry test condition, similar behaviour could be observed at soaked test.





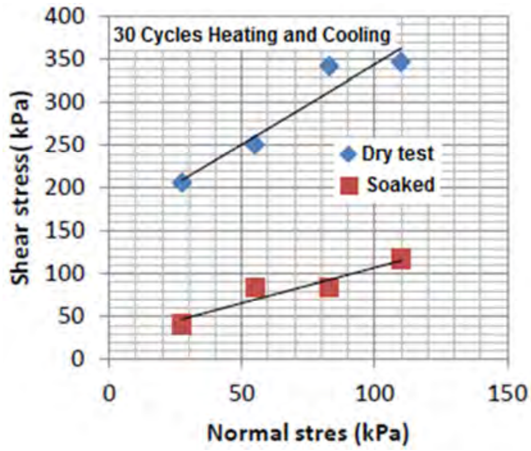


Figure 12. Impact of (freezing-thawing) cycles on shear strength parameters.

4. Conclusions

Based on the testing program, the following conclusions are drawn.

1. For untreated soil, the shear strength decreases after soaking by (25, 37, and 26) % under (27.5, 55. and 110) kPa of normal stresses respectively.
2. The shear strength of asphalt stabilized soil increases by (200, 92, and 113) % at dry test and decreases by (87, 80, and 87) % at soaked test under (27.5, 55, and 110) kPa of normal stress respectively as compared to that of untreated soil.
3. After 10 cycles of (freezing-thawing), the shear strength decreases after soaking by (76, 72, 76, and 76)% under (27.5, 55, 83, and 110) kPa of normal stresses respectively.
4. After 30 cycles of (freezing-thawing), the shear strength decreases by (79.5, 68, 79.5, and 70)% due to soaking under (27.5, 55, 83, and 110) kPa of normal stresses respectively.
5. The shear strength after 10 cycles of (heating-cooling) decreases due to soaking by (33, 37, 37, and 50) %, while the horizontal displacement decreases by 50% after soaking.
6. After 30 cycles of (heating-cooling), the variation in shear strength under dry and soaked test conditions is not significant.
7. Asphalt stabilized Gypseous soil has proved to be sustainable as subgrade under various weather conditions.

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