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Variation on Shear Strength of Unsaturated Subgrade Causes Road Cracks

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Abstract: In Jordan, considerable amount of construction activity is carried out at relatively shallow depths where soil is likely to be unsaturated and subjected to low stresses level. One particular example is the pavement. The occurrence of damage to road founded on unsaturated subgrade in Karak, Jordan is due to the collapse of the soil structure upon wetting-wetting process, has come to be well recognized. It has recently become apparent that these unsaturated soils can cause damage to roads because of the change in the shear strength of unsaturated soil as the degree of saturation changes. An experimental program was designed to study the behavior of unsaturated soil as the degree of saturation changes. Direct shear was used for the testing program on unsaturated silty clay that was carried out as part of this research program. Specimens were prepared with initially different saturation to simulate different climate conditions. The results showed that; as the initial degree of saturation increases up to 50%, the shear strength increases and then decreases as the initial saturation increases beyond 50%. Also, as the normal stress and the density increase the strength increases.

Key words: Unsaturated subgrade, degree of saturation, climate, shear strength, direct shear test

INTRODUCTION

Unsaturated soils cover wide areas in the world especially in the Middle East. The first essential step towards achieving a satisfactory design for road foundation is the recognition of the soils and these inherent dangers. Compacted soils are used in earthworks such as construction of embankments and road foundation. These compacted soils are unsaturated soils and often have low degree of saturation (i.e. high negative pore water pressure) particularly in arid and semi arid regions such as Jordan. The engineering properties of these compacted soils are influenced by the matric suction. It is well known that the volume change is more significant than the change in shear strength for the cracks. However, the changing in the strength due to change water content has been received a little interest in the literature.

The main objective of this study is to investigate the effect of changing in the degree of saturation (wetting-drying) on the shear strength of subgrade in north of Karak city, Jordan. This variation in water content can be considered climate dependent. The changes in the strength of subgrade during the year as a result of changing the degree of saturation may cause failure in the foundation of the road. Subsequently, this failure results in the formation of cracks in the wearing course and then may lead to failure. This kind of road failure is due to the changing shear strength of the unsaturated soil, which is explored here. Hamarneh[1] classified nineteen kinds of road cracks in Karak roads but his study did not analyze the reason of these cracks. The climate plays a significant role in initiate cracks in Karak road. Tighe[2] raised the significant of how subgrade and climatic factors influence pavement performance and can be applied to performance trend analysis of other pavements with similar climatic, subgrade and traffic loading conditions.

Most of the roads in Karak received pavement rehabilitation comprising of various thickness of asphalt overlays, as part of the Jordan long-term pavement performance. Some findings from this study include (I) in summer, dry, strength of subgrade increase; (ii) in winter, high wet and-some freeze zones, the subgrade strength decreases, regardless of loading condition and (iii) traffic, seemed to have a limited effect on cracks that occurs in the Karak roads because the traffic volume is small.

In order to achieve the aim of this study various investigations have been carried out to study the Geotechnical aspects of the silty clay soils of Karak, which form most of the foundation of the north Karak roads. In addition, many direct shear test were conducted to investigate the effect of wetting and normal stress on the shear strength of unsaturated soils.

Shear strength of unsaturated media: Critical state models for unsaturated soils have been proposed in

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recent years. However, the proposed models have been based on limited experimental data. Compacted specimens have generally been used for research and the complications of soil fabric resulting from the compaction procedures have brought difficulties into the interpretation of fundamental soil behavior[3].

The shear strength usually increases as the suction increases. Alonso, *et al.*[4] Wheeler and Sivakumar[5,6] and Wheeler and Karube[7] have reformatted the relationship between the mean net stress and deviator stress, which is given in detail. They show the effect of matric suction in the p-q diagram by introducing an intercept in the Cam Clay model as follows:

$$q=Mp'+C(s) \qquad (1)$$

where

- q : The deviator stress.
- p′ : The mean effective stress.
- C(s) : The intercept in the (p-q) diagram, which is function of suction,
- M : The slope of the critical state line (almost independent of suction

The shear strength of unsaturated soil has been related to matric suction[4,6]. The suction measurement is costly, time consuming, unreliable enough and needs accurate techniques, which limit the theories to academic nature[8]. In contrast, the degree of saturation is simple to measure. Also, the degree of saturation gives a clear view about the sample's mechanical behavior[9,7]. The frictional behavior of the soil-to-soil contacts is the same dry and saturated soil[10-12].

The behavior of unsaturated soil changes as the degree of saturation changes. For example, at low saturation (i.e. $S_r < 45\%$), gravity will not be able to pull pendular water (i.e. at the point of contact between particles). In most cases the air pressure is atmospheric (drained condition) and therefore the effective stress defined is equal to the total stress. Thus, shear strength of unsaturated soil mainly depends on the effect of water at the point of contact. At high saturation stage the strength can be treated under classic soil mechanics umbrella but will not model compression behavior of soil[13]. Saturated soil mechanics can be considered as a special case when the degrees of saturation is close to one.

Maaitah[14] developed a theoretical model to predict the increase in shear strength of unsaturated soil due to suction and surface tension based on the pore and meniscus geometry. His model assumes that the strength is a function of two component, namely pore water force and normal stress. The pore water force that pulls the soil particle together is a function of three competent: suction (u_a-u_w), surface tension T and pore geometry.

MATERIALS AND METHODS

Two groups of tests have been conducted using direct shear device. The first group was tested under fully saturated condition to obtain the effective angle of internal friction, ϕ'. Test for the second group were carried out with different initial degrees of saturation, initial void ratio and normal stress. The samples were prepared under initial saturation is 0.02, 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80 and 0.90%. The samples were mixed with water and then were sieved to make sure the water well distributed. The normal stress is of 10 kPa, 47 kPa and 147 kPa and different initial void ratio is of 80 and 68%. Soil used in the tests was silty clay, which is typical from north of Karak. Tests have been carried out under the well-known producers of direct shear test.

RESULTS AND DISCUSSION

Many drained direct shear tests were performed. The results of these tests show an increase in strength as the normal stress and degree of saturation increases. The stress strain behavior is nearly ductile for all the tests, with some strain softening taking place. Specimen has a similar influence on the stress-strain behavior and critical state characteristics as that of increasing its density through applying a higher normal pressure. The critical state lines for the unsaturated soil corresponding to different degree of saturation are parallel to those for the saturated soil. The friction angle or CD tests, in this work, are taken at a strain of around 8-10% (i.e. peak angle) to be consistent with measured unsaturated shear strength (i.e. the void ratio and stress level should be identical). The effective angle of internal friction, ϕ', is found equal to 23±0.5° for the soil sample that used in the experimental program. The measured shear strength for unsaturated samples has been considered at a strain around of 8-10%. Liquid and plastic limits are 40 and 20%, respectively. The specific gravity is of 2.7.

Samples could be prepared at a high degree of saturation, in which the air is initially uniformly distributed, but this will be a temporary state and the case with which air can move through the pore spaces determines how long this temporary state will last. This means that the air in such a soil will tend to aggregate, so that the soil becomes separated into regions of full and low saturation. Therefore, the experiments here are

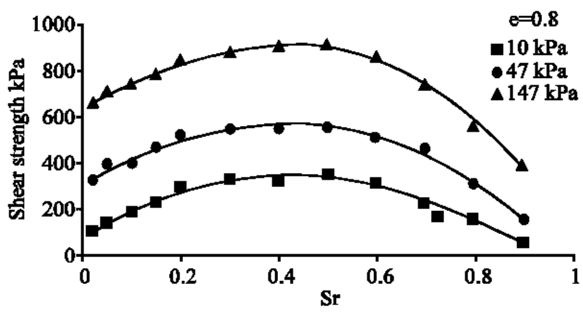

Fig. 1: Shear strength versus degree of saturation for initial void ratio of 0.8

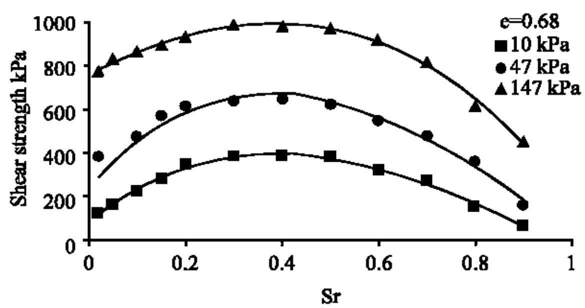

Fig. 2: Shear strength versus degree of saturation for initial void ratio of 0.68

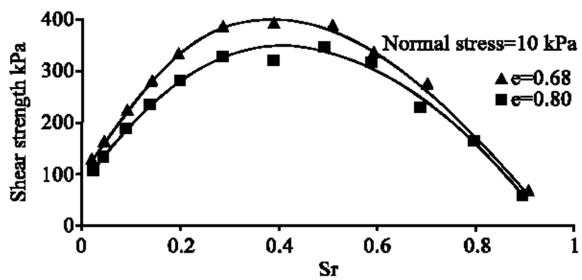

Fig. 3: Effect of initial void ratio on unsaturated strength

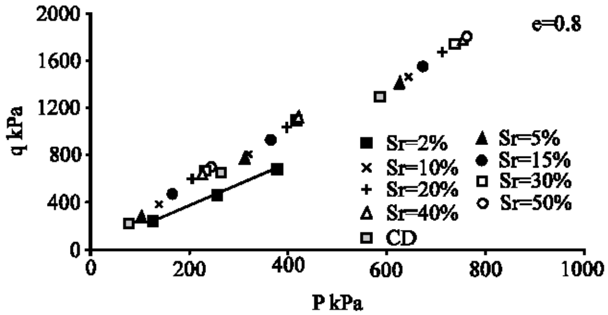

Fig. 4a: Effect of saturation on the strength in P-q diagram when the degree of saturation is less than 50%

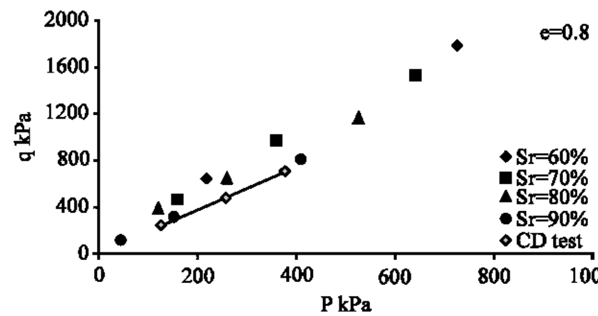

Fig. 4b: Effect of saturation on the strength in P-q diagram when the degree of saturation is greater than 50%

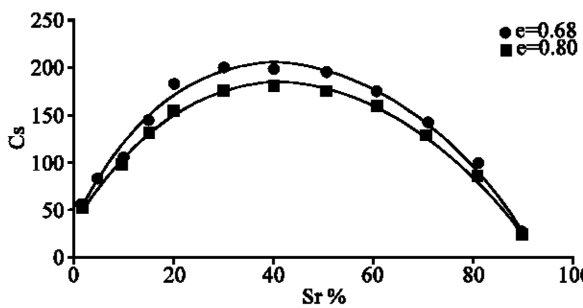

Fig. 5: Intercept of the critical state line versus degree of saturation

conducted under drained conditions to avoid any kind of segregations. At low degree of saturation the capillary force is greater than the gravity force.

For low degrees of saturation and normal stress, the rise in pressure is very low and can be ignored. On the other hand, the rise in pore air pressure for high normal stress (i.e., greater than 100 kPa) should be considered if the test is undrained. In this paper, the pore pressure is atmospheric because it is dranied direct shear.

Figure 1 and 2 showed the relationship between the degrees of saturation and shear strength. As the degree of saturation increases upto 25% the shear strength increases and then it becomes nearly constant between saturation 25 to 50%. In terms of suction, the shear strength increases as the suction increases and then decreases to a fairly constant value. This pattern is also seen in the results of other workers[15-17]. The shear strength may increase, decrease or stay constant as the suction increases beyond a certain value. As the saturation increases more than 60% the shear strength decreases. The shear strength of pavements is strongly influenced by the presence of water in base and sub-base granular materials as illustrated in Fig. 1 and 2. With yearly freeze-thaw cycles, seasonal variations of degree saturation in structural layers affect pavement performance and subgrade. Furthermore, when degree of saturation are close to saturation values (Sr=1), development of excess pore-water pressures under wheel loading may cause drastic loss of the subgrade strength of the pavement structure layers.

On the other hand, in winter, the temperature drop below zeros during night in Jordan whereas it varies between 5 to 10°C in the day. Therefore, it should be noted that pavement is subjected to thawing during the day break-up period causing frost boils and is subjected to differential frost heaving during night. Differential frost heaving is caused by the formation of ice lenses and ice within the soil matrix immediately below the pavement structure. To develop the pavement performance, the pavement materials must have good drainage capacity to dissipate any excess water and minimize pavement damage due to moisture.

Comparison between Fig. 1 and 2, which is concluded in Fig. 3, showed that the shear strength increases as the void ratio decreases. This means that the shear strength is affected by the density and the number of contact between the soil particles. In other words the better compaction beneath the roads the better shear strength can be obtained.

Figure 4 and 5 showed the results of the comparison between the consolidated drained tests (CD) on fully saturated samples and the tests on the unsaturated samples. It is obvious that the values of deviator stress obtained from the CD tests is lower than that obtained from the unsaturated samples. The slope of the critical state line M is nearly constant[17] the variation in the value of M is equivalent to the variation in the effective angle of friction with the applied load. The slope M has been found as the saturation changes from 2 to 90% when the void ratio is of 68% equals 2.21±0.04 and 2.17±0.04.

The reduction in the intercept Cs, as shown in Fig. 5, decreases rapidly as the degree of saturation exceeds 60%. This means that during the summer where the degree of saturation is less than 50, the foundation of the roads exhibit higher strength and looses this strength during winter where the soil becomes nearly saturated. The variation in the strength during the years causes cracks and then failure in the roads foundation.

This study confirms that the perfect presentation shear strength of unsaturated subgarede in term of degree of saturation, Sr, (i.e. climate role) rather than suction, s. This is because the degree of saturation, Sr, is easy to measure. In contrast, the suction measurement is costly, time consuming and difficult. Therefore, using suction to present the behaviour of unsaturated subgarede is not practical. In addition for a given soil the relation between degree of saturation and suction will not be non-unique[18].

Based on the shear tests on the soil used in this research program, conclusions on shear strength for unsaturated soils can be reached.

- The shearing behavior for unsaturated soil specimens are similar to those for saturated soil specimens. Applying a suction to a saturated soil specimen has a similar influence on the general shearing behavior as increasing its density by applying a higher confining pressure.
- The critical state lines for the unsaturated soils corresponding to different soil suctions are lines parallel to those for the saturated soil on the (q : p),
- plane. More experimental results on simple soil fabric specimens would be of value.
- It is clear that the degree of saturation and density plays an important role in determining the shear strength for unsaturated subgrade where the shear strength varies with the degree of saturation. This means that the shear strength may be considered as a function of climate.
- Shear strength increases as saturation increases up to saturation range between 30 to 40% and decreases as saturation exceeds 60%.
- Shear strength increases as the normal stress increases.
- Shear strength increases as the void ratio decreases.
- The variation in strength due to change in saturation causes cracks in roads.

The prediction of ground response to shallow construction processes requires sophisticated stress analysis techniques using a suitable stress-strain model. Current paper is analyzing the problem at shallow depth by using simple experimental program.

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