New approach for estimating the permanent strain of collapsible soil–sand mixtures

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Collapsible soil deposits cover many locations in desert areas in Egypt. New roads have been constructed in such areas. Reliable characteristics of the permanent strain of collapsible subgrade soil are necessary for the satisfactory design of pavement using analytical methods. It is difficult, however, to determine the required permanent parameters of subgrade soil since soil behavior depends on many variables such as water content, dry density, and stress level. The influence of these variables on permanent strain can be investigated by repeated load triaxial tests in the laboratory. However the cost of this type of testing may be prohibitive for most road design projects. New approach is therefore needed. This paper directly adresses this point. A simple method is proposed for estimating the permanent strain of collapsible soil located in Egyptian western desert and mixtures of collapsible soil and sand with different concentrations from quasi-static laboratory tests. The influences of water contents, stress levels and percentages of sand on permanent strain of collapsible soil were investigated. To achieve this objective, five different mixtures made of collapsible soil and sand were investigated. The results show that the permanent strain is very sensitive to changes in sand concentration and water content. Moreover, the characteristics of collapsible – sand mixtures were affected by changing in water content than changing in stress levels.

تتواجد التربة القابلة للانهيار بالصحراء الغربية المصرية بمواقع عديدة. وتمثل هذه التربة إحدى المشاكل الرئسية لمصممي الطرق. لذا فانه يلزم معـرفة سـلوك التشـكل لهذه التربة لتصميم أسماك طبقات الرصف. ويتوقف مقدار التشكل اللدن لتربة التأسيس على عدة عوامل منها محتوى الرطوبة ومستوى الاجهادت المؤثرة. وقد أجريت أبحاث عدة لتحديد سلوك التربة القابلة للانهيار بإستخدام جهاز الضغط ثلاثى المحاور والتحميل الديناميكى التكرارى. ونظرا لأن هذه الاختبارات عالية التكاليف لذا فإن هذا البحث يهدف الى دراسة سلوك التربة القابلة للانهيار باستخدام طريقة التحمـيل الشـبة أسـتاتيكى ذو التكاليف الأقل والمتاح. وقد أجرى هذا البحث على تربة مدينة برج العرب بغرب الإسكندرية تحت تأثير ثلاثة متغـيرات هى محتوى الرطوبة ومستوى الاجهادات ونسبة الرمال المضافة الى التربة القابلة للانهيار. وقد أظهرت نتائج الاختبارات تحسن قيم التشـكل اللـدن للتربة القابلة للانهيار بإضافة الرمل إليها إلا أن مقدار هذا التحسن يتوقف على نسبة الرمل المضافة. كذلك أوضحت النتائج أن التشـكل اللدن للتربة القابلة للانهيار أو المضاف إليها الرمل تتأثر بشكل ملحوظ بتغيير محتوى الرطوبة بدرجة أعلى عن تأثرها بتغيير مستوى الاجهادات. وقد أنتهى البحث باستنباط علاقة رياضية تربط بين مدار التشكل اللدن بالتربة القابلة للانهيار ونسبة الرمل المضاف إليها.

Keywords: Collapsible soils, Collapsible–sand mixtures, Standard proctor test, Quasi-static test, Permanent strain

1. Introduction

The collapsible soils are covering vast areas of Egypt. They are widely distributed throughout the areas of Egyptian western desert, especially New El-Ameria city, Borg El–Arab city, and elswhere. Collapsible phenomenal is one of the important problems confronted by geotechnical engineers allover the world. In Egypt, many studies concerning the behavior of the collapsible soils have been previously published [1- 5].

The collapsible soils are generally composed of uniform silt-sized particles, which are loosely deposited, and are bonded together with relatively small fraction of clay forming the typical loess structure. Typically, loess has high shearing resistance and many withstand high loading without great settlement, when natural moisture contents are low. However, upon wetting, the clay bond tends to soften and causes collapse of the loess structure inducing large settlement under low loading, and hence many lead to loss of shearing strength. However, it is dangerous to construct on these soils without improving their characteristics to ensure safety [6].

The subgrade deformation necessary for the satisfactory design of a flexible pavement depends greatly on the water content and dry density of subgrade soil, and also on the applied stresses and other factors. In the present research, an experimental program involving semi-dynamic load has been carried out to investigate the influence of water contents, stress levels and content of sand on the permanent strain of collapsible soil-sand mixtures.

2. Test materials

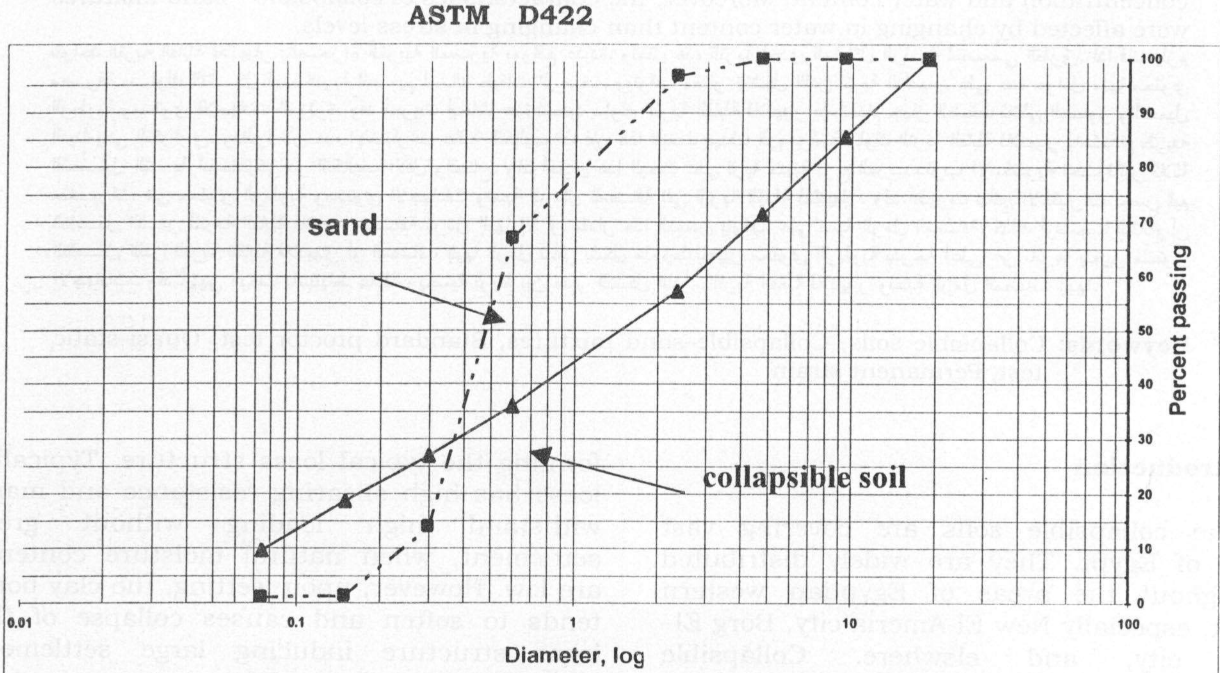
Collapsible soil covers a large area of Egyptian western desert and forms the predominant subgrade material in the local road system. Collapsible soil taken from Borg-El-Arab city was used throughout the program. The physical properties of collapsible soil including natural water content, natural bulk density and the collapsible potential (Cp) [7] are presented in table 1. Sand taken from Borg Al-Arab was used in this study. Grain size distribution curves of collapsible soil and sand are shown in fig. 1. Different mixtures used are outlined in table 2.

Table 1
Properties of test collapsible soil used in this study

Properties	Results
Liquid limit	27
Plastic limit	13
Plasticity index	14
Natural water content , [%]	1.2
Natural bulk density, [g/cm^3]	1.5
Cp, %	10

Table 2
Mixtures used in this study

Mixture types
100% collapsible soil
75% collapsible soil + 25% sand
50% collapsible soil + 50% sand
25% collapsible soil + 75% sand
100% sand



Percent passing							
Sieve No.	No. 200	No. 100	No. 50	No. 30	No. 8	No. 4	3/8"
Collapsible soil	9.64	18.74	27.01	35.97	57.34	71.53	85.63
Sand	1	1.22	13.88	66.94	96.73	100	100

Fig. 1. Grain size distribution curves for collapsible soil and sand.

3. Optimum water content and maximum dry density for collapsible soil-sand mixtures

It is essential to determine the maximum dry density and optimum water content for every subgrade soil. In fact, if the subgrade soil has high dry density, it will give a minimum deformation under traffic loading repetitions during lifetime of the pavement. Also, it allows the layers to bear heavy wheel load without suffering excessive deformation.

One of the main objectives of performing standard compaction test [8] is to determine the maximum dry density and optimum water content for each type of mixture investigated herein.

The relationship between dry density and water contents is plotted in fig. 2. From this figure, it can be seen that the maximum dry density is higher and optimum water content is lower than for sand comparable values for others mixtures. On the other hand, it can be seen that the collapsible soil yields the lowest dry density and highest optimum water content. Maximum dry densities are 1.78 g/cm^3 and 1.67 g/cm^{3}for sand and collapsible soil, respectively. Also, it may be noticed that the sand concentration in the mixtures affects the maximum dry density. The maximum dry density of these mixtures decreases from 1.78 g/cm^{3}3 to 1.69 g/cm^3 by decreasing the percentage of sand from 100% to 25%. This reduction in the maximum dry density is about 5%. On the other hand, increasing the percentage of sand in the mixtures decreases the optimum water content. This may be attributed to the decrease in the percentage of fine materials (passing through sieve size 0.075 mm) associated with the increase in the percentage of sand.

The plot of the maximum dry density versus percentage of sand in the mixtures is shown in fig. 3. Using the method of least squares, the best-fit line is given by the following formula:

$$\delta = a + b\,x + c\,x^2. \tag{1}$$

Where:

δ is the maximum dry density, [g/cm^3];

x is the percentage of sand in mixtures, [%],

a, b and c are constants equal to 1.67, 5.83E-04, and 4.57E-06, respectively, and

r is the correlation coefficient = 0.99.

4. Definition of the permanent strain

The permanent strain ε_p is calculated as the ratio between accumulative permanent strain P_d at N number of load applications (each 50 cycles) and average original height of the sample tested, H, as in the equation;

$$\varepsilon p = P_d \;/\; H, \tag{2}$$

where:

ε_p is the Permanent Strain , [‰],

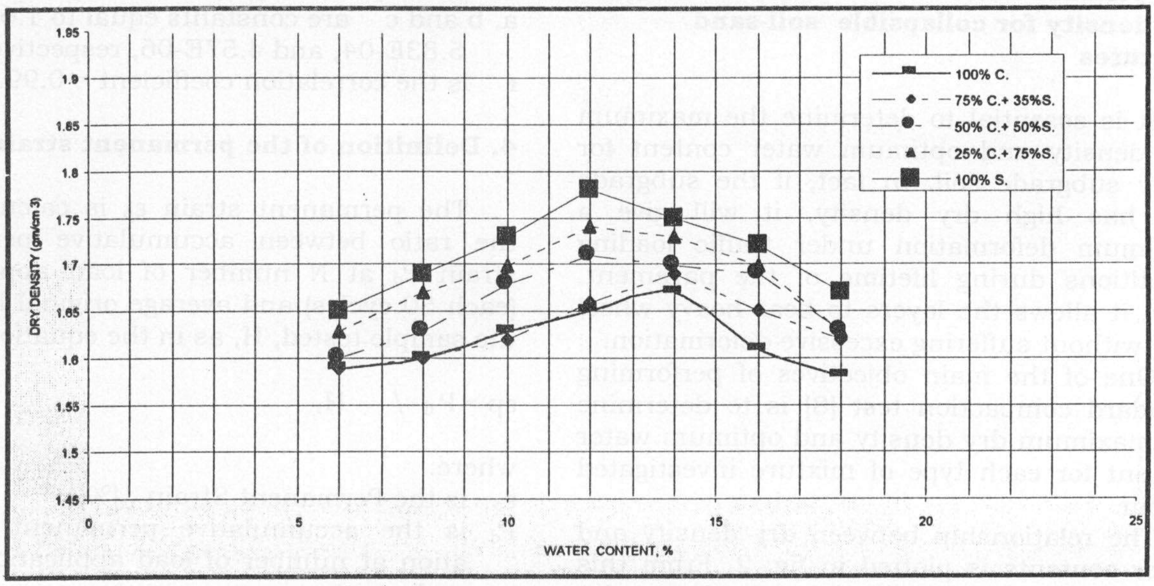
P_d is the accumulative permanent deformation at number of load application, [mm] and

H is the original height of the tested sample, [mm].

5. Testing procedures

5.1. Experimental procedure

Quasi-static loads were applied on collapsible soil specimens (h=11.7 cm, d= 15cm) in unconfined condition subjected to compressive uniaxial loading. Fig. 4 shows the schematic diagram of the compression machine. The loading history given in fig. 5 was followed throughout the tests. The cycle time was 40 second. The axial load was increased from a minimum stress (0.055 MPa) to a maximum stress within a period of 5 seconds followed by a rest period of 15 second at the maximum stress and then another period of 5 seconds through which the load was released from the maximum value to 0.22 MPa. Finally, a period of 15 seconds between each two cycles of loading was selected. Each sample was exposed to 500 cycles of load application in 5 hours 33 minutes and 20 seconds. The permanent deformation was measured every 50 cycles. Prior to load application, each sample was conditioned by applying a repeated load equal to 0.055 MPa for 10 cycles in order to insure full contact between the loading head and the sample, and also to avoid a "hammering" effect



C. = Collapsible soil.
S. = Sand

Fig. 2. Water contents versus dry densities for different mixtures.

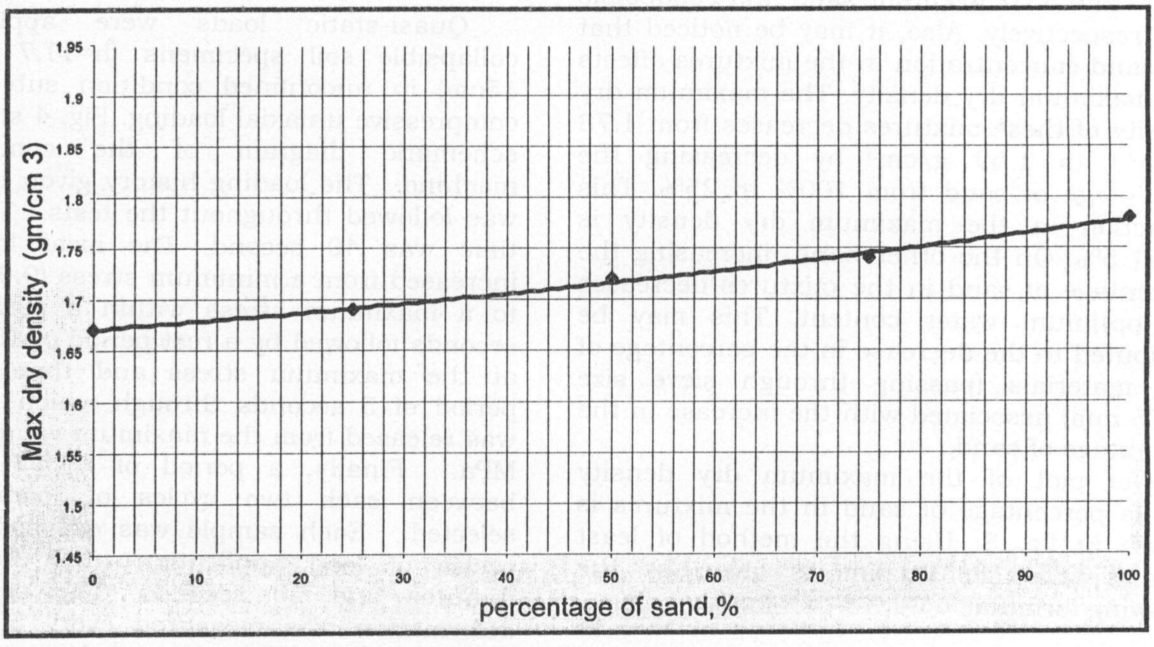


Fig. 3. Percentage of sand in the mixtures versus maximum dry densities.

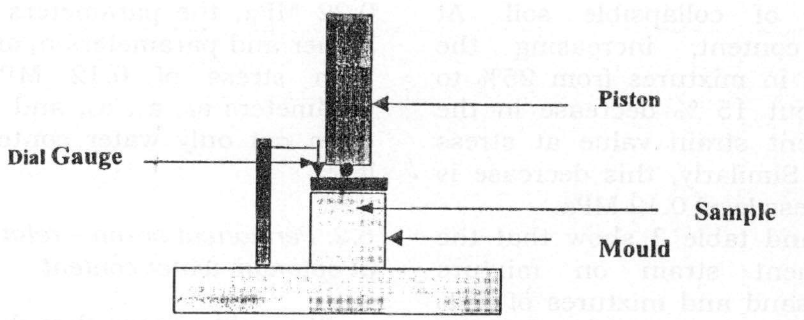


Fig. 4. Schematic diagram of compression machine.

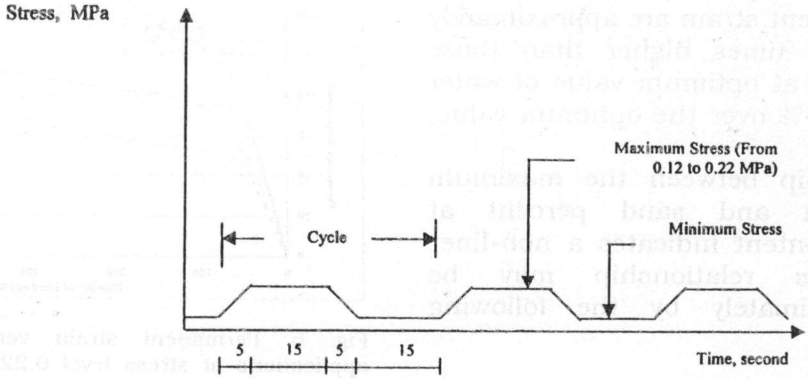


Fig. 5. Specified loading history.

during the testing stress. All tests were performed at laboratory temperature.

5.2. Variables studied

The studied variables for their influence on soil characteristics and behavior under traffic loading are: type of soil, gradation, density, water contents, wheel loading or stress level. It is belived that these factors strongly affect the behavior of soil and hence the permanent strain of pavement. It should be pointed out that a number of investigators haveperviously examined the permanent strain of subgrade soils [9]

Three percentages of water were selected to investigate their influence on the properties of collapsible- sand mixtures.. These degrees were; optimum water content, which produced by standard proctor test, 2% and 4% is excess of the optimum value. In the present study two stress levels are selected to perform the quasi-static load applications. These levels were 0.12 MPa and 0.22 MPa. These values are practically simulating the effects of heavy truck. More details of these stresses can be seen elsewhere [10].

6. Test results and discussions

6.1. Permanent strain – related to load applications

The character of permanent strain phenomenon of the soil as affected by the mixture type, may be seen in figs. 6 to 10 for different mixtures at maximum stress of 0.22 MPa, and also in fig. 11 at maximum stress of 0.12 MPa. Concerning these groups of curves, the following interpretation could be made.

The permanent strain values measured at different type of mixtures increased rapidly during the first loading and thereafter, increased at a decreasing rate with increasing number of load applications or remained relatively constant. Table 3 gives the maximum permanent strain for the five studied mixtures at different stress levels, water contents. From this table it can be noted that the percentage of sand in the mixtures has substantial influence on the permanent strain of collapsible soil. At optimum water content, increasing the percentage of sand in mixtures from 25% to 100% leads to about 15 % decrease in the maximum permanent strain value at stress level of 0.22 MPa. Similarly, this decrease is about 17.5 % at stress level 0.12 MPa.

Figs. 6 to 11 and table 3 show that the maximum permanent strain on mixture compsed of 100% sand and mixtures of 25% collapsible soil and 75% sand are almost similar. Moreover, at constant stress level of 0.22 MPa, in the collapsible soil, the values of maximum permanent strain are approximately 1.3, 1.3 and 1.6 times higher than those produced by sand at optimum value of water content, 2% and 4% over the optimum value, respectively.

The relationship between the maximum permanent strain and sand percent at optimum water content indicates a non-liner relationship. This relationship may be presented approximately by the following polynomial form;

$$e_m = a_0 + a_1 x + a_2 x^2 + a_3 x^3 , \qquad (3)$$

where:
em is the maximum permanent strain, ‰,
x is the percentage of sand, % and
a_0, a_1, a_2, and a_3 are constants.

Table 4 represents the four proposed constants a_0, a_1, a_2, a_3 and the correlation coefficient R.

Parameters a_0, a_1, a_2, and a_3 were calculated for each quasi- statically tested sample used in this study. The parameters are believed to be a function of water content and stress level. According to results given in table 4 it is clearly seen that at stress level 0.22 MPa, an increase in the water content from optimum to 2% and 4% over optimum value leads to an increase the parameters a_0, a_1, a_2, and a_3. Moreover, according to the value of correlation coefficient R, it can be concluded that there is a strong correlation between percentage of sand in mixtures of collapsible soil and sand and maximum permanent strain.

The influence of changing the axial stress from 0.12 MPa to 0.22 MPa on the parameters is shown in table 4. From this table it can be noticed that, in general, at higher stress level, 0.22 MPa, the parameters a_0 and a_2 become higher and parameters a_1 and a_3 become lower than stress of 0.12 MPa. Therefore, the parameters a_0, a_1, a_2, and a_3 seem to depend upon not only water content but also stress level.

6.2. Permanent strain – related to stress levels at optimum water content

It would appear that the major difficulties in the predicting permanent strain is the lack of knowledge concerning the mechanical behavior of collapsible-sand mixtures Therefore, one of the major factors influencing the permanent strain of collapsible sand mixtures is the magnitude of the axial stress. The influence of stress levels on the maximum permanent strain of different mixtures at different water contents is shown in table 3. The experimental results show that the performance of the samples as affected by the changes in stress depends on mixtures type.

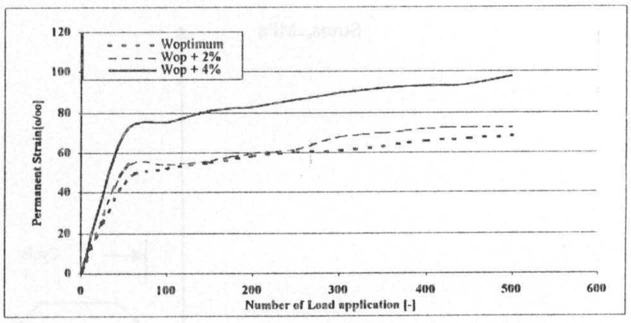


Fig. 6. Permanent strain versus number of load applications at stress level 0.22 MPa 100% collapsible soil.

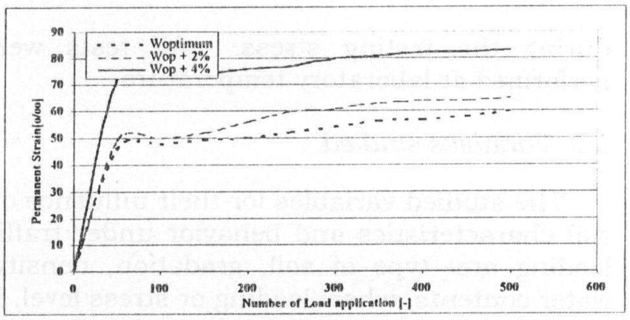


Fig. 7. Permanent strain versus number of load applications at stress level 0.22 MPa 75% collapsible soil + 25% Sand.

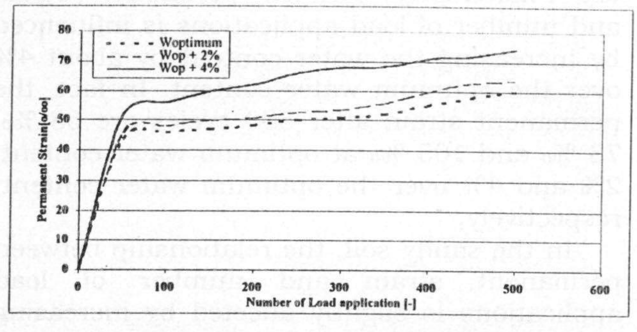


Fig. 8. Permanent strain versus number of load applications at stress level 0.22 MPa 50% collapsible soil + 50% sand.

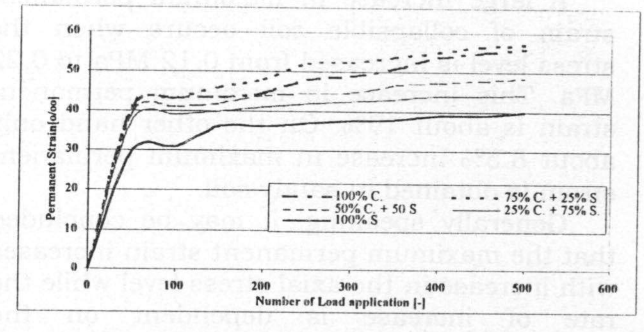


Fig. 10. Permanent strain versus number of load applications at stress level 0.22 MPa 100% sand.

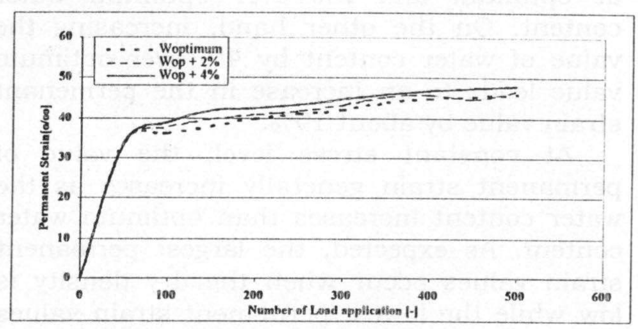


Fig. 9. Permanent strain versus number of load applications at stress level 0.22 MPa 25% collapsible soil + 75% Sand.

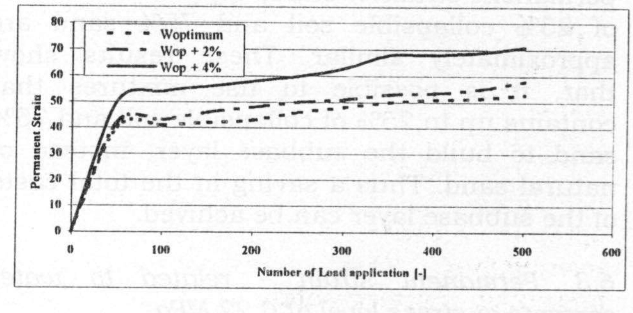


Fig. 11. Permanent strain versus number of load applications at stress level 0.12 MPa for different mixtures.

Table 3
Maximum permanent strain [after 500 cycles], (‰)

Mixture	Maximum axial stress level 0.22 MPa Optimum w. content	Wop +2%	Wop +4%	0.12 MPa Optimum w. content
100% C.	68	73	105	57
75% C.+25% S.	60	65	82	51
50% C.+50% S.	58	63.5	74	50
25% C.+75% S.	53	58	71	48
100% S.	51	55	60	47

C. = collapsible soil
S. = sand

Table 4
Regression coefficient of eq. (3)

Correlation factors	0.22 MPa Wop.	Wop. + 2%	Wop. + 4%	0.12 MPa Wop.
a_0	+6.80E+01	+7.26E+01	+10.524E+01	+5.69E+01
a_1	-5.81 E-01	-2.56E-01	-1.56E+00	-3.21E-01
a_2	+1.23 E-02	+1.03E-03	+2.864E-02	+4.32E-03
a_3	-8.53 E-05	-1.07E-05	-1.87E-04	-2.10E-05
R	1.0	0.986	1.0	0.987

Wop. = Optimum water content

A large increase in maximum permanent strain of collapsible soil occurs when the stress level is increased from 0.12 MPa to 0.22 MPa. This increase in maximum permanent strain is about 19%. On the other hand only about 8.5% increase in maximum permanent strain is obtained in sandy soil.

Generally speaking, it may be concluded that the maximum permanent strain increases with increase in the axial stress level while the rate of increase is dependent on the percentage of sand in the mixtures.

Also, it can be noted that the maximum permanent strain of sandy layer and mixtures of 25% collapsible soil and 75% sand are approximately similar. These results show that, it is possible to use mixtures that contains up to 25% of collapsible soil and 75% sand to build the subbase layer, instead of natural sand. Thus a saving in the total costs of the subbase layer can be achived.

6.3. Permanent strain – related to water contents at stress level of 0.22 MPa

The effect of water content on the permanent strain was examined. Table 3 shows the influence of increasing the water contents from the optimum value by about 4% over the optimum value on the maximum permanent strain for different mixtures. The results show that the permanent strain values are very sensitive to changes in water content. As expected, the largest permanent strain values occur when the water content is high while the lowest permanent strain values are found when the water content is low for different types of mixtures. Also, for a particular type of mixture, the minimum permanent strain value occurs at the optimum water content. On the other hand, the maximum permanent strain values are found at 4% over the optimum water content for different mixtures. Moreover, it can be observed that collapsible soil-sand mixtures yield the lowest permanent strain while collapsible soil yield the higher values at different water contents.

In the collapsible soil, the effect of changing the water content on the permanent strain is shown in table 3 at the three water contents. The table clearly demonstrates that the relationship between permanent strain and number of load applications is influenced by increasing the water content by about 4% over the optimum water content. In fact, the permanent strain after 500 cycles are 68 ‰, 73 ‰ and 105 ‰ at optimum water content, 2% and 4% over the optimum water content, respectively.

In the sandy soil, the relationship between permanent strain and number of load applications is slightly affected by increasing the water content above the optimum value by about 2%. These results are 51 ‰ and 55‰ at optimum and 2% over optimum water content. On the other hand, increasing the value of water content by 4% over optimum value leads to an increase in the permenant strain value by about 19%.

At constant stress level, the value of permanent strain generally increases as the water content increases than optimum water content. As expected, the largest permanent strain values occur when the dry density is low while the lowest permanent strain values are found when the dry density is higher and water content is low.

7. Conclusions

Based on the results of this investigation, the following conclusions appear to be warranted:

- Test results show that the maximum dry density for sand is higher than value for others mixtures. On the other hand, the collapsible soil yields the lowest dry density.
- At constant stress level, the value of permanent strain generally increases as the water content increases than optimum water content. As expected the largest permanent strain values occur when the dry density is low while the lowest permanent strain values are found when the dry density is higher and water content is low.
- Test results show that the maximum permanent strain is strongly correlated with percentage of sand in the mixtures of collapsible soil and sand. This relation is in the form shown in eq. (3). Permanent strains parameters a_0, a_1, a_2, and a_3 depend upon not only water content but also, stress level.

• A large increase in maximum permanent strain of collapsible soil occurs when the stress level increases from 0.12 MPa to 0.22 MPa. This increase in maximum permanent strain represents 19%. On the other hand only about 8.5% increase in maximum permanent strain is obtained in sandy soil.

• Test results show that at constant stress value of 0.22 MPa, the maximum permanent strain values occured in collapsible soil are approximately 1.3, 1.3 and 1.6 times that those produced by sandy soil at optimum water content, 2% and 4% over optimum value of water content, respectively.

• The maximum permanent strain increases with increase in the axial stress level while the rate of increase is dependent on the percentage of sand in the mixtures.

• It is possible to use mixtures that contains up to 25%of collapsible soil and 75% sand to build the sub base layer, instead of natural sand. Thus a saving in the total costs of the subbase layer can be achieved.

References

[1] El- Gindy, A. A., " Collapsible of three Egyptian Desert Formations," Civil Eng. Res. Magazine, Faculty of Engineering, Al-Azhar Univ., Vol. 13 (7) (1991).

[2] Mansour, S. A., " A study of Geotechnical Characteristics of some Egyptian Collapsible Soils," pH. D. thesis Faculty of Engineering, Zagazig Univ. (1992).

[3] Radwan, A., et al, " Geotechnical studies at New Ameriya City." Civil Eng. Res. Magazine, Faculty of Engineering, Al-Azhar Univ., Vol.2, pp. 1-21 (1980).

[4] Darwish M. et al, " K value for an Egyptian Collapsing Soil" Proceeding of the Eleventh European Conference on Soil Mechanics and Foundation Engineering, Copenhagen, 28 May - 1 June Vol. 7, pp7.51- 7.59 (1995).

[5] Mansour S. A. et al, " Effect of K Value and Model of Inundation on Collapsible Characteristics of an Egyptian Soil." Conference on Soil Mechanics and Foundation Engineering, Beijing, China, 29 August 2 September, pp. 1-6 (1995).

[6] Samy A. M. et al., " Shear Strength Characteristics of an Egyptian Collapsible Soil." Al-Azhar Engineering Third International Conference, 18-21 December, pp. 131-140 (1993)

[7] Mansour S. A. et al, " Fabric and Mineral Characteristics of some Collapsible soil from Northern Egypt." 7th International congress, International Association of Engineering Geology, Lisboa- Portugal, 5-9 September, pp. 3511-3521 (1994).

[8] American Society for Testing and Materials: paving Materials, Manual Book of ASTM Standard: American National Standards sec. 4 Vol. 04.08 (D698-91) pp. 166-173 (1992).

[9] Monismith, C. L. et al, " Permanent Deformation Characteristics of Subgrade Soil Due to Repeated Loading." Transportation Research Board, record 537, pp. 25-35 (1975).

[10] Eisenmann J., " Beanspruchung von Bituminosen Strassendecken unter Besonderer Beruck-Sichtigung des Zustandes Sommer" Strasse und Autobahn, Vol. 30 (5), pp. 204-209 (1979).

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