Effect of sand cushion on swelling and swelling pressure of expansive silty clay

L'effet d'une couche sableuse sur l'expansion et sur les pressions expansives de l'argile limoneuse

A. A. MOUSSA, Prof. of Soil Mechanics & Foundation, Faculty of Engineering, Ain-Shams University, Cairo, Egypt
(Presently, Chairman of Civil Engineering Department, College of Engineering, Qatar University, Doha, State of Qatar)
M. A. ABD-EL-MEGUID, Undersecretary of State, Rehabilitation and Irrigation System for Development Project, Cairo, Egypt
S. M. OKDAH, Lecturer in Soil Mechanics and Foundations, Faculty of Engineering, Ain-Shams University, Cairo, Egypt
A. H. HEIKAL, Engineer, Research Institute of Construction, Soil Mechanics & Foundations, Ministry of Irrigation, Egypt

SYNOPSIS The use of sand cushions to eliminate the swelling and swelling pressure of expansive soil is considered to be one of the most effective and cheapest remedial methods used today. This paper investigates the effectiveness of sand cushion in controlling the swelling characteristics of expansive soils. Several configurations of boundary conditions are used concerning the placement of sand cushion and the confinement or partial confinement of its top surface. Also, the effect of gradation and density of sand on the performance of the cushion are investigated.

INTRODUCTION

Today, there is a world-wide interest in studying the behaviour of expansive soils. Engineers all over the world have contributed immensely to the knowledge and proper design of structures on expansive soils.

In practice, the destructive effect of expansive soils on structures can be avoided or minimized by either soil replacement, chemical treatment or using special type of foundation. The use of sand as a cushion layer for stabilizing expansive soils has been increasingly favoured. Sand cushion can adequately modify the volume change characteristics, lower the swelling pressure, and improve the foundation medium.

As the authors are aware, that available literature in this field is few (Satyanarayana, 1973) and still needs further investigations. Due to this paucity it was thought advisable to carry out the present work. It investigates the corrective treatment of an expansive silty clay soil obtained from Medinet Nasr, a suberb of Cairo, if sand cushions are used for different configurations of boundary conditions.

PROPERTIES OF THE TESTED SOILS

The expansive silty clay soil used in this study is obtained from the site of the Faculty of Engineering, Al-Azhar University, where the main building suffered from damaging effect due to swelling of the foundation soil.

The physical properties of the soil are: w = 10.94%, γ = 17.5 KN/m^3, w_L = 0.54, w_P = 0.29, w_{SL} = 0.13, and e = 0.51. The mineralogical composition is: 64.42% by weight montmorillonite, 6.10% mica, 2.70% kaolonite, 6.10% amorphous materials, and 20.68% other minerals. The chemical analysis indicates that: 64.27% by weight

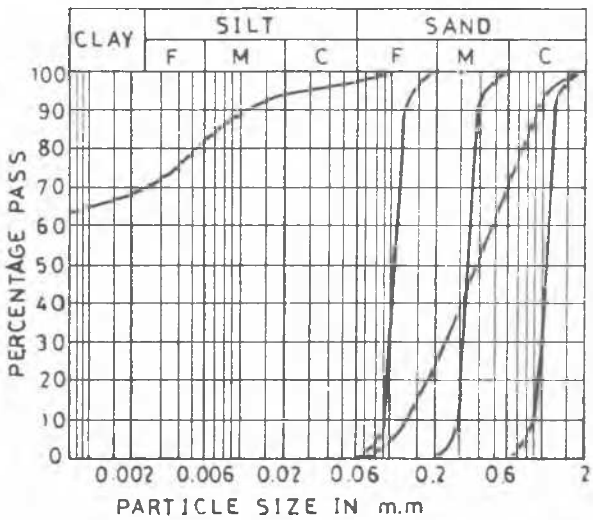

Fig. 1: Grain Size Distribution Curves of the Silty Clay and the Sands used as a Cushion.

SiO_2, 21.60% AL_2O_3, 4.43% Fe_2O_3, 0.61% K_2O, 1.61% Na_2O, 2.32% Mg O, 1.34% Ca O, 1.44% total soluble salts, and 1.92% Ca Co_3.

The sand used to form the cushion is clean yellow silicious sand with fine, medium, coarse or graded sand gradations. The grain size distribution curves of the sands and the silty clay are shown in Fig. 1 .

SAMPLE PREPARATION AND TESTING

The air dried silty clay soil is pulverized and statically compacted in an oedometer ring and brought to its natural density. The soil samples are 2 cm. high and 5.05 cm. or 7.50 cm. in diameter. The sand cushions are placed at relative densities varying from 25% to 80%. The sand is placed either on the top surface of the silty clay sample, at the bottom, or on the top and around the sample. The sample diameter is 7.5 cm. in the case of top and bottom sand cushions, while it is 5.05 cm. in the later case where the diameter of the sample together with the sand is 7.5 cm. The thickness of the sand cushion is 2 cm. The boundary conditions of the tested silty clay samples are illustrated in Fig. 2 .

SYMBOL	DESCRIPTION	SWELLING TEST	SWELLING PRESSURE TEST
A	CONFINED SAMPLE WITHOUT SAND CUSHION	X	X
B	CONFINED TOP SAND CUSHION	X	X
C	CONFINED BOTTOM SAND CUSHION	X	X
D	CONFINED TOP AND AROUND SAND CUSHION	–	X
E	PARTIALLY CONFINED TOP SAND CUSHION	–	X
F	PARTIALLY CONFINED TOP AND AROUND SAND CUSHION	–	X

FIG. 2: BOUNDARY CONDITIONS OF TESTED SAMPLE.

The swelling and swelling pressure tests have been carried out on the oedometer apparatus. Small surcharge loads of 3.5 KN/m^2 and 7.0 KN/m^2 are used as seating load in swelling and swelling pressure tests, respectively (Chen, 1975). The constant volume test procedure suggested by Holts and Gibbs (1956) has been followed in the swelling pressure tests.

TEST RESULTS AND DISCUSSION

This paper discusses the effect of sand cushion on the swelling and swelling pressure of the tested silty clay. The time corresponding to the swelling or the swelling pressure to take place depends on the density and the gradation of the sand used as a cushion as well as on the boundary conditions presented by Fig. 2 (Heikal, 1982).

(I) Swelling Test

The swelling test results are summarized in Fig. 3 as a relationship between the relative density "D_r" and the relative swelling "S_R" for the four gradations of the sand cushions. S_R is the ratio between the swelling of sample with sand cushion and that of sample without a cushion. The solid-lines are for samples with top sand cushion, while the dash-lines are for samples with a bottom cushion. The test results lead to the following observations :

(i) Either confined top or bottom sand cushion reduces the swelling of the tested soil samples by 0.25% to 30.83%. Similar findings were reported by Satyanarayana (1973).

(ii) The bottom sand cushion is more efficient in reducing the swelling than the top one. This also was observed by Satyanarayana (1973). This may be partly attributed to the loss of adhesion between some of the silty clay grains on saturation and dropping in the voids of the bottom sand cushion. The relative swelling of samples with top sand cushion "S_{RT}" could be statistically related to that of samples with bottom sand cushion "S_{RB}" by:

$$S_{RT} = 0.195 + 0.837\, S_{RB} \quad (1)$$

with a correlation coefficient of 98.13%. Equation (1) is independent of sand gradation and relative density.

(iii) For any sand gradation, the relative swelling increases with the relative density of sand. Therefore, well compacted sand cushions are inefficient in reducing the swelling. On the other hand, loose sand cushions are not recommended in practice because of their low bearing capacity and stiffness which lead to large deformations under foundation loads.

(iv) The relative swelling decreases with finer grain size. Thus, cushions made of fine sand are more efficient in reducing the swelling.

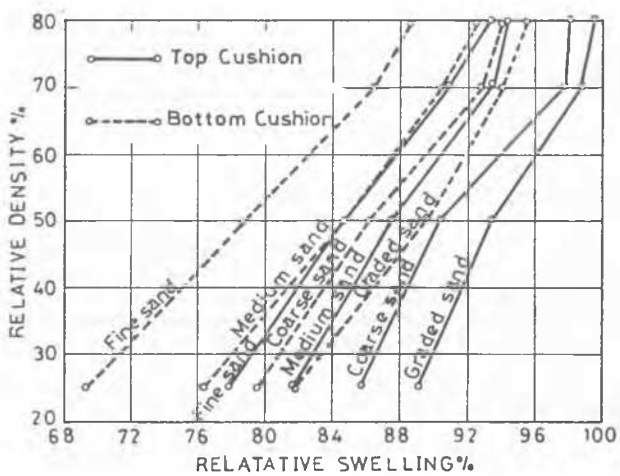

Fig. 3: Relative Density - Relative Swelling Relationships for the Confined Top and Confined Bottom Sand Cushions with Different Gradations.

It is therefore, suitable to use cushions of fine sand compacted to a relative density in the order of 50% to 70%; as the density of naturally deposited sands falls within this range.

(II) Swelling Pressure Test

The effect of sand cushion on the swelling pressure induced in the tested silty clay soil samples, under constant volume test procedure, is thoroughly investigated for the previously mentioned different configurations of boundary conditions, Fig. 2. The test results shown in Fig. 4 are for sand cushions compacted at a relative density of D_r = 80%. Fig. 4 represents the relationship between the relative swelling pressure and the sand gradation expressed by "$C_u \cdot d_{50}$", where C_u is the uniformity coefficient and d_{50} is the diameter corresponding to 50% percentage pass. The relative swelling pressure "σ'_{SR}" is the ratio between the induced swelling pressure in the sample with cushion to that without a cushion. Line A represents the results of silty clay sample without sand cushion. Lines B to F are for the remaining boundary conditions.

According to Fig. 4, the following observations and conclusions are made :

(i) For all the sand gradations, the top sand cushion records an increase in the swelling pressure. The graded sand gives the maximum increase in the swelling pressure, +61.84%, while the fine shows the smallest increase, +15.49%.

(ii) The use of confined bottom sand cushion, line C, or confined top and around sand cushion, line D, reduces the swelling pressure. The amount of decrease is significant in case of cushions made of fine or medium sands, while it is insignificant for graded and coarse sands. Surrounding the tested silty clay samples with fine or medium sand has a pronounced effect in decreasing the swelling pressure, as indicated by points I and II on lines D and C.

(iii) Partial confinement of the top surface of cushioned samples reduces the swelling pressure by more than 90% as illustrated by lines E and F. It appears that the sand gradation has practically no effect on swelling pressure developed under this boundary condition. Lines E and F are straight lines and represented by the equations :

$$C_u \cdot d_{50} = 42.55\ \sigma'_{SR} - 1.397 \qquad (2)$$

for the case of partially confined top sand cushion, line E, and :

$$C_u \cdot d_{50} = 165.86\ \sigma'_{SR} - 1.51 \qquad (3)$$

for the case of partially confined top and around sand cushion, line F.

where, σ'_{SR} is the relative swelling pressure. The corresponding correlation coefficients are 97.40% and 89.24% respectively.

Also, a relationship between the induced swelling pressures for the cases confined top and bottom sand cushions has been found to be a straight line with the equation :

$$\sigma_{SRT} = 1.676\ \sigma_{SRB} - 0.126 \qquad (4)$$

where, σ_{SRT} and σ_{SRB} are the swelling pressures when using confined top and bottom sand cushions respectively. The coefficient of correlation of equation (4) is 94.18%.

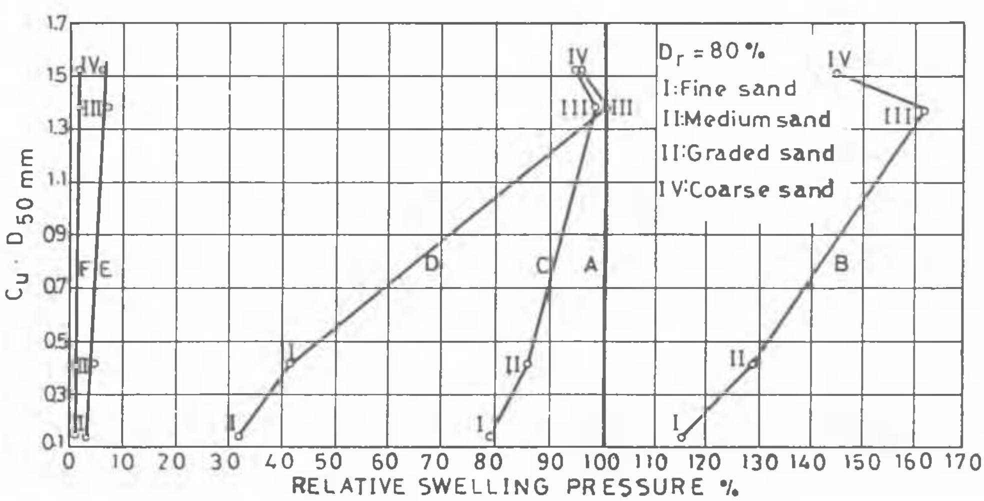

Fig. 4: Grading of Sand Cushion Versus Relative Swelling Pressure for Different Boundary Conditions.

SUMMARY AND CONCLUSIONS

The corrective treatment of expansive soil by using sand cushion has been investigated. Swelling and swelling pressure tests have been carried out on expansive silty clay samples. The samples are tested either with or without sand cushions. The sand is of different gradations and placed at different densities. The conditions of placing the sand cushion are either on the top surface, at the bottom, or on the top and around the sample. The top surface of the tested samples is either confined or partially confined.

The test results lead to the following conclusions :

(i) Swelling Tests

In these tests either top or bottom confined sand cushions are used. The use of sand cushion reduces the swelling. However, bottom sand cushion is more efficient than top one in reducing the swelling. Both gradation and density of sand affect the swelling. The efficiency of the sand cushion to control the swelling becomes more pronounced in case of loose fine sand.

(ii) Swelling Pressure Tests

Constant volume swelling pressure tests are performed on the samples using sand cushion for different configurations of boundary conditions. The test results presented in this paper are for sand cushions compacted at a relative density of 80%. Confined top sand cushion proved to increase the swelling pressure dramatically. Confined bottom or top and around sand cushion can reduce the swelling pressure if fine or medium sand is used. On the other hand, cushions made of graded or coarse sand practically do not reduce the swelling pressure. Partial confinement of the top surface of samples with top sand cushion reduces the swelling pressure by more than 90%. It is, therefore, considered that fulfilling this boundary condition in practice is potentially useful for satisfactory performance of foundations on expansive soils.

A current extension research work is being carried out at the Faculty of Engineering, Ain Chams University, Cairo, Egypt, to investigate the behaviour of large diameter and thick expansive soil samples provided with sand cushions (Abd-El-Fattah).

REFERENCES

Abd-El-Fattah, A. Study on the behaviour of some Egyptian expansive soil. Unpublished M.Sc. Thesis, Ain-Shams University, Cairo, Egypt.

Chen, F. H. (1975). Foundations on expansive soils. El-Sevier Scientific Publishing Company, Amesterdam, Oxford, New York.

Heikal, A. H. (1982). Study of geotechnical properties of some swelling clays in Egypt. M.Sc. Thesis, Ain-Shams University, Cairo, Egypt.

Holtz, W. G. and Gibbs, H. J. (1956). Engineering properties of expansive clays. Proc. of the American Society of Civil Engineers, Transactions, Vol. 121, pp. 641-663, USA.

Satyanarayana, B. (1973). Behaviour of expansive soil treated or cushioned with sand. 3rd Int. Conf. on Expansive Soils, Haifa, pp. 308-16, Israel.