International Conference on Advanced Experimental Unsaturated Soil Mechanics, EXPERUS 2005, Teronto, Italy

Advancement in oedometer testing of unsaturated soils

El- Sohby, M.
Professor, Faculty of Engineering, Al- Azhar University, Nasr City, Cairo Egypt
Mazen, O.
Professor,Housing&Building Research Center, Dokki, Cairo, Egypt
Aboushook, M.
Professor, Faculty of Engineering, Al- Azhar University, Nasr City, Cairo Egypt
Tel. 20101573415, Fax. 2022601706, E-mail: prof_dr_aboushook@hotmail.com

ABSTRACT: Determination of swelling and collapse characteristics of unsaturated soils involve the study of the stress volume change behaviour with the variation of moisture content. The best known and most popular procedure utilized for this is the oedometer test. It has been reported that values of swelling pressure and collapse potential were found to vary dramatically. This could be attributed to various factors such as boundary and placement conditions, preparation of sample as well as experimental difficulties that arise when testing unsaturated soils. The present paper is a part of a comprehensive and broad research work for studying some of the problems that pertain directly to laboratory testing of unsaturated soils. It is based on standard techniques with the intelligent utilization of the one dimensional oedometer apparatus. This part of the research work presents results obtained from studying the effect of some of the factors on the value of swelling pressure such as method used, side friction between sample and ring in the oedometer and deformability of the apparatus. Also techniques to reduce or minimize their effect for better and accurate measurements of swelling pressure are introduced and discussed.

1 INTRODUCTION

Classical soil mechanics has been concerned with saturated soils and this soil has been treated extensively in the literature. However, unsaturated soils do not conform to the classical soil mechanics. Firstly because they are unsaturated; and secondly because they include phenomena not encountered in fully saturated soils such as swelling and collapse behaviour.

Soil properties are determined with the help of laboratory testing techniques and equipments originally designed for saturated soils. However, these techniques and equipments are utilized for determination of the characteristics of unsaturated soils. Method of predicting volume changes in soils can be grouped into empirical methods, soil suction methods and oedometer methods.

The oedometer methods of determining the potential expansion of clay soils represent more direct methods. In the oedometer methods, undisturbed or compacted samples are placed in the oedometer and a wide range of testing procedures are used to estimate the likely vertical strain due to wetting under vertical applied pressures. However, it has been reported that these values of swelling pressure and collapse potential vary dramatically and accurate measurements and reproducible results are not always obtained.

This could be attributed to various factors because characteristics of unsaturated soils are affected by specified conditions adopted during the test including boundary and placement conditions. In addition, there are experimental difficulties that arise when testing such soils. For example, in the case of collapsible soils, available samples are of high sand and silt contents. However, they are tested in the oedometer which is made for clayey soils. Therefore, samples are not easily manipulated to assess their mechanical properties, and in most cases, considerable disturbances are unavoidable. Also, in cases of expansive soils, available samples for laboratory are usually very hard. This dictates the application of high pressures during their testing and the range of stresses is relatively high. Therefore, high frictional force is developed between sample and ring and apparatus deformability is very likely to occur.

This study is a comprehensive and broad research for the investigation of some of the problems that pertain directly to laboratory testing of unsaturated soils. It is based on standard techniques with the intelligent utilization of one dimensional oedometer. As the research is very broad, the main task of the present paper is to deal only with problems relevant to the measurement of swelling pressure of expansive clayey soils in the oedometer such as effect of method used, effect of side friction between sample and ring and effect of apparatus deformability.

2 EFFECT OF METHOD USED IN MEASURING SWELLING PRESSURE

By the use of one dimensional consolidation apparatus, there are various methods for the determination of swelling pressure. Two widely used methods of them are investigated in the present work. They are: 1) Different pressures method and 2) Preswelled sample method. The technique of oedometer test in the application of these two methods are described as follows:

2.1 Different pressures method

In this method the swelling pressure is defined as the pressure required for keeping a soil sample at constant volume when it is flooded. For the determination of swelling pressure, in this case, three or more identical specimens are loaded by different loads and allowed to swell until the swelling ceases. The final percentage swelling is then drawn versus the vertical applied pressure. Then the pressure corresponding to zero swelling can be determined either by interpolation or by extrapolation and considered as the swelling pressure (Rabba, 1975; El- Sohby and Mazen, 1980; Tarek et al., 1982 and El- Sohby et al., 2000) (see Figure 1). It's denoted Ps1.

2.2 Preswelled sample method

The swelling pressure in this method is defined as the external pressure required for consolidating a preswelled sample until it goes back to the initial voids ratio. In this method the test sample is first allowed to completely swell under a light load, then it is consolidated by the increase of load until the sample reaches its initial volume. The pressure required for this is the swelling pressure(Youssef et al., 1957; Zacharias and Ranganathen, 1972; El-Sohby and Mazen, 1980 and Tisot and Aboushook, 1983) (see Figure 2). It's denoted Ps2.

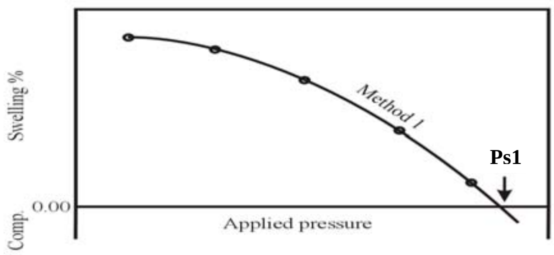

Figure 1. Determination of swelling pressure (method 1).

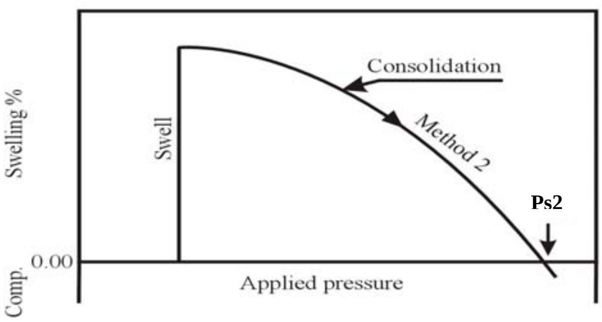

Figure 2. Determination of swelling pressure (method 2).

2.3 Experimental work

Soils used were taken from arid newly developed area known for its formation of expansive clayey soils. Blocks were taken from open pits with their natural conditions. Their engineering properties and mineralogical compositions were determined. For determination of swelling pressure, identical natural specimens were used and tested according to the previously mentioned methods.

2.4 Results and analysis

The results are summarized in table 1. The following observations were made:

- Although the specimens were identical and tested under the same conditions, the two methods yielded different values of swelling pressure.
- In all cases (six different samples), the preswelled method yielded higher values of

swelling pressures than the different pressures method.

- The differences were found to be correlated to the mineralogical composition of clay present in the sample.
- In the case of different pressure method, the amount of load controls the amount of volume change. As far as the load is less than that required for zero volume change, some expansion will be allowed to occur until the internal forces are in balance (A balance between the urge of clay minerals to suck in water and tendency of applied load to squeeze out water.
- In case of preswelled sample method, the amount of load controlling volume change is very slight, therefore the amount of volume change will be nearly maximum allowing an initially water to enter the pores on the surface of clayey particles (first category). This is followed by water entering between unit layers in case of expanding lattice clay mineral (second category). When the sample is than loaded, the water will be again removed. According to Grim (1968), the water of the first category requires generally little energy for its removal , while that of the second category requires higher energy for its complete removal.
- Consequently, results obtained from above mentioned tests show that the different pressures method allows reasonable simulation of conditions to occur in the field; whereas, the values of heave using preswelled sample method give rise to over predictions , particularly in case of expanding lattice clays.
- The over prediction mentioned above may be also explained as follows: In case of preswelled sample method, the sample is exposed, at the consolidation stage to high pressure increments in excess of the swelling pressure. These are due to the high energy required to removal of the second category of water existing between lattice sample structure and fabric to regain the initial volume before expansion.
- Furthermore, the effect of structure and fabric of the sample is involved in case of preswelled sample method rather than in case of different pressures methods. This adds to the over prediction of the value of swelling pressure.

Table 1. Summary of swelling pressure measurements and mineralogical composition of samples.

Sample number	Swelling pressure* (Ps1) - kPa	Swelling pressure* (Ps2) - kPa	Ps2 / Ps1	Mineralogical composition of clay fraction
1	1000	1900	1.90	Ca^{++} (montmorillonite- vermiculite) – 42% Kaolinite – 17%
2	2000	4000	2.00	Na^{+}(montmorillonite- vermiculite) – 20%
3	1000	1500	1.50	Ca^{++} (montmorillonite- vermiculite) – 46%
4	530	580	1.10	K^{+} (montmorillonite- vermiculite) – 44%
5	1250	2050	1.64	Ca^{++} (montmorillonite- vermiculite) – 62%
6	900	1175	1.30	K^{+} (montmorillonite- vermiculite) – 39% Kaolinite – 11%

*using different pressures method
**Using preswelled sample method

3 EFFECT OF SIDE FRICTION BETWEEN SAMPLE AND RING IN OEDOMETER APPARTUS

Side friction has a significant effect on measured swelling characteristics of expansive soils depending on factors such as the adopted technique and the followed stress path during the test. The side frictional stresses between the sample and brass mould occurs due to the horizontal confining pressure and the interlocking stress due to compaction. Therefore, the effect of side friction is greater for remolded samples than for undisturbed samples.

Side friction has been the subject of study since Taylor's work (1942) who estimated the side friction quantitatively. He indicated that the magnitude of side friction force can be about 12% to 22% of the applied load for remolded clay and about 10% to 15% for the undisturbed clay. Lambe (1951) stated that the friction is a function of the intergranular pressure and therefore it varies during the consolidation process.

3.1 Methods to minimize side friction

Methods to minimize side friction were investigated by research workers. Thomson & Ali (1969) reported that side friction was reduced by polishing the inside surface and then applying thin coat of silicon grease. Ramakrishna (1972) found that the use of rubber membrane decreased the effect of side friction. Rabba (1975) noted that the friction can be minimized by using floating ring rather than the fixed ring one. The investigation of this effect is based on the work done by Abdel Baky (1980) as a part of M Sc. thesis supervised by professor El-Sohby at Al- Azhar university.

In the present work four techniques were investigated: the minimum clearance method, the stripped ring method, the greased ring method and the ring with thin coat of wax method.

3.1.1 Minimum clearance method

This method is based on providing a clearance between the ring and the soil sample to get minimum contact and thus, the minimum possible side friction. The procedures are as follows:

a- Three filter papers were cut with the same circumference and height as for the specimen, and then adjusted on the internal surface of the mould.

b- The calculated weight of soil was poured into the mould and statically compacted to the required density.

c- The specimen is then extracted from the mould and three filter papers removed. The specimen is then reinserted carefully in the mould.

d- Two filter papers are then put on both end surface of the specimen. Two perforated aluminum plates used as porous plates are then put above and below the specimen.

e- The mould is then put in the oedometer trough and the specimen is then tested according to " different pressures method ".

3.1.2 Stripped ring method

The purpose of this method is to reduce the intensity of side friction stress distribution over the height of the ring. Furthermore, this method allows more uniform distribution of side friction and provides spring action of the ring group.

In the present work the ring was divided into six small rings each of height 4 mm.

3.1.3. The greased ring method

In this method the inside surface of the ring is lubricated. In the present work, high vacuum silicon grease was used.

3.1.4 Ring with thin coat wax method

This method was suggested to study the effect of using a thin layer of wax as lubricating material instead of the high vacuum grease as the latter is relatively expensive.

3.2 Results and analysis

The following table summarizes the results obtained using the previously mentioned techniques:

Table 2. Technique used and corresponding swelling pressure

Technique of reading side friction	Swelling Pressure using different pressures method (KPa)
Ordinary Ring	800
Minimum clearance	1300
Ring with grease	1500
Stripped ring	1700
Ring with wax	1900

From the above table it is indicated that:

i- Side friction has a significant effect on the value of swelling pressure (different pressures method was used as it was proven previously to yield maximum reliable values of swelling pressure).

ii- The values of swelling pressure using different techniques are always higher than that when using the usual ordinary ring. This indicates that the value of swelling pressure is usually under estimated due to the effect of side friction.

iii- Ring with wax gave the highest value of swelling pressure. This means that this technique is the most efficient to reduce the side friction and this is the nearest of the accurate value of swelling pressure.

4 EFFECT OF APPARATUS DEFORMABILITY

In the conventional one dimensional oedometer test, the axial pressures are directly measured and the axial displacement is measured by dial gauge or displacement transducer. With this technique, the measured displacement includes not only the soil deformation but also the deformability of several parts of the system (El- Sohby et al. 1989).

Therefore, the effect of apparatus deformability was investigated to determine the values of these deformations to be deduced or added by calibration rather than eliminating their effect.

The investigation of this effect is based on the work done by Abu Taha (1980) as a part of M. Sc. thesis supervised by Professor El- Sohby at Al-Azhar University.

4.1 Technique for measurement of swelling pressure

The conventional consolidation apparatus was utilized and swelling pressure was determined by different pressures method and preswelled sample method mentioned before. Prepared remolded samples were used and high vacuum grease was utilized as it was proven previously to be " very efficient in eliminating the effect of side friction.

4.2 Technique for measurement of deformability

In order to study the effect of deformability on measured swelling pressure, steel disc was utilized, instead of the soil sample and the loads were applied in a similar technique used for soil loading. As the elastic deformations of the steel disc is negligible in the range of the applied loads, the registered strains could be considered as the elastic deformation of the parts of the oedometer system.

4.3 Magnitude of deformability

4.3.1 Deformability of the apparatus

Four steel disks of diameters 63 , 88.8 , 126.8 and 177.4 mm were used. Their diameters were the same as those of soil samples used in the present work.

Figure 3 shows the deformability of the apparatus at different applied pressures and for different steel disk diameters. This figure shows the amount of deformability and it indicates that the oedometer deformability increases with the increase of steel disk diameter.

4.3.2 Deformability of porous plates and filter papers

To investigate the effect of the porous plates and filter papers on the magnitude of the total deformation value, the deformability of oedometer was measured by the same technique mentioned above without using them. It was found that the deformations of the porous plates and filter papers represent 14.4% , 25% , 32.9% and 37.7% of the predetermined deformations when steel disks of diameters 63 , 88.8 , 126.8 and 177.8 mm were used. These values were measured at the maximum applied pressure for each diameter.

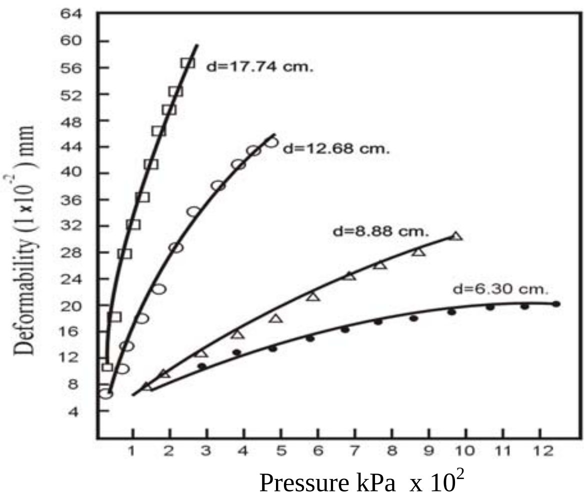

Figure 3. Deformability of apparatus for different steel disk diameters (steel disk thickness = 30 mm).

4.4 Deformability and calibration of swelling pressure

The effect of oedometer deformability on the swelling pressure is in excess of its measured value. This is indicated in Figures 4 and 5 and may be explained as follows:

In case of different pressures method, at the swelling stage, two opposite deformations occur simultaneously, the swelling of the sample and the deformability of the appartus. Assuming that the dial reading registered a swelling of the sample at the applied load as shown in Figure 4 . This reading is the difference between actual sample swelling and the deformability of the apparatus. Therefore, the actual swelling of the sample is the summation of apparatus compression value plus the dial reading.

In case of preswelled sample method, at the consolidation stage, the sample is exposed to high increments of pressures. The dial readings represent the measured height decrease between two successive points and its value includes a deformability of the apparatus itself. Therefore, the actual compression of the sample is the difference between the dial reading and the deformability of the apparatus corresponding to each load increment as shown in Figure 5.

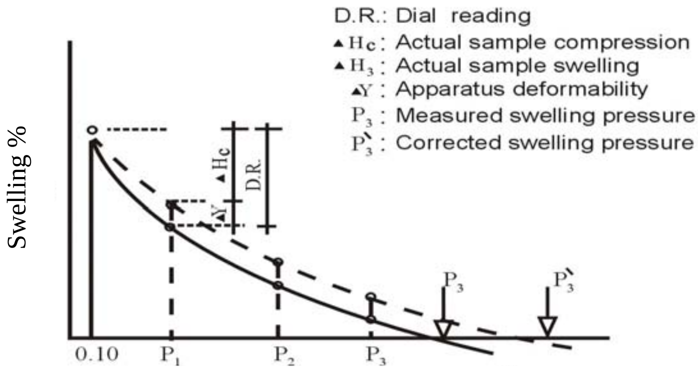

Figure 4. Effect of oedometer deformability on the measured swelling pressure using (preswelled sample method).

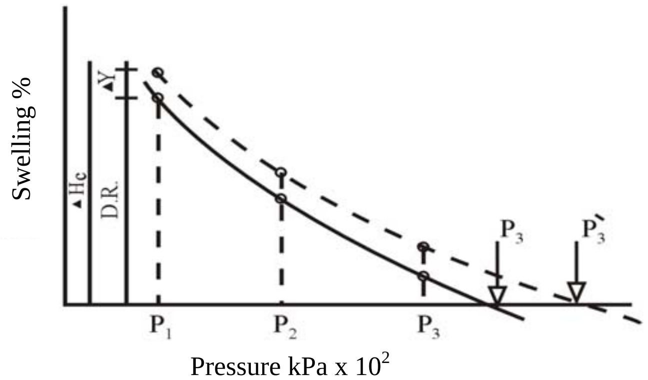

Figure 5. Effect of oedometer deformability on the measured swelling pressure using (different pressures method).

5 CONCLUSIONS

a- Due to boundary conditions and experimental difficulties relevant to testing of unsaturated soils values of swelling pressure and collapse potential were found to vary dramatically.

b- Ttwo methods were investigated for the determination of swelling pressure namely different pressures method and preswelled sample method. The study indicated that the different pressures method allows reasonable simulation of conditions to occur in the field whereas, using preswelled sample method give rise to over prediction.

c- Four methods were investigated for minimizing side friction between sample and ring in oedometer. It was found that the value of swelling pressure is usually under estimated due to the effect of side friction. Also using ring with thin coat of wax is the most efficient method to reduce side friction.

d- The study of oedometer deformability indicated that its effect on swelling pressure is in excess of its measured value. Also it was indicated that deformations of porous plates and filter papers represent 14.4% , 25% , 32.9% and 37.9% of total deformations when disks of diameters 53 , 88.8 , 126.8 and 177.4 mm were used.

6 REFERENCES

Abdel Baky, T.F. 1980. Some factors affecting the deformation characteristics of clayey soils. *M.Sc. Thesis, Al- Azhar Univ., Cairo.*

Abu Taha, M.M., 1980. Deformations of Expansive soils under foundations. *M.Sc. Thesis, Al- Azhar Univ., Cairo.*

El- Sohby, M.A;. Abou- Taha, M.M. and Mazen, S.O., 2000. Effect of mode of wetting on deformational behaviour of unsaturated soils. *Proc. Of Asian Conf. on Unsaturated Soils – From Theory to Practice, Singapore,* 645-650.

El- Sohby, M.A; Mazen, S.O. and Abou- Taha, M.M., 1989. Effect of apparatus deformability on swelling pressure. *Proc. XII Int. Conf. on SFME,Rio de Janeiro,* 1: 589-592.

El- Sohby, M.A; Mazen, S.O., 1980. On measuring swelling pressure by two methods. *7th Regional Conf. of SMFE for Africa, Accra*, 2:775-783.

Grim, R.E., 1968. *Clay mineralogy*. Mc. Graw-Hill Book Company Inc.

Lambe, T.W.,1951. *Soil tsting for engineers*. Wiley Eastern Limited, New Delhi, 80-81.

Rabba, S.A., 1975. Factors affecting engineering properties of expansive soils. *M. Sc. Thesis, Al- Azhar Univ., Cairo.*

Ramakrishna, B.K., 1972. Effect of structure on swelling and swelling pressure characteristics of Black Cotton soil. *Symposium on Strength and Deformation of Soil, Mysore Center of Indian Geotechnical Society, 2:139*.

Tarek, M.F.; El- Sohby, M.A. and Aboshi, H. 1982. Effect of boundary conditions on swelling characteristics of soils. *Momories of the Fac. Of Eng., Hiroshima Univ.*, 1,18: 69-79.

Taylor, D.W., 1942. Research on consolidation of clays. Department of Civil and Sanitary. Eng., *Massachusetts Institute of Technology*, Serial No. 81.

Thomson, S. and Ali, P., 1969.A laboratory study of the swelling properties of sodium and calcium modifications of Lake Edmonton clay. *2nd Int. Conf. on Expansive Soils, Texas*, 256-262.

Tisot, J.P. and Aboushouk, M.I., 1983. Triaxial study of swelling characteristics. *Proc. Of 7th Asian Conf. on SMFE*, 1: 94-98.

Youssef, M.S.; Sabry, A.A.and Tewfik, M.M., 1957. Substantial consolidation and swelling of clay to cause two interesting cases of serious damages to hospital buildings in Egypt. *4th Int. Conf. on S.M.F.E., 1:462.*

Zacharias, G. and Ranganathan, B.V., 1972. Swelling and swelling characteristics of synthetic clays. *Symposium on Strength and Deformation of Soil, Mysore Center of Indian Geotechnical Society, 1:129*