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FIELD STUDY OF THE DISTRIBUTION OF LATERAL SWELLING PRESSURE OF EXPANSIVE SOIL ON RETAINING STRUCTURE

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ABSTRACT

The important requirements for civil engineer are economic and technical in the field and this appears in fill work. The civil engineer needs a suitable soil for fill works, so the expansive soil is studied as one of the possible solution.

For this research the physical, mechanical and field tests are performed. The purpose of the present paper is examining the distribution of lateral swelling pressure developed in clay soils on retaining walls after adding water and to predict the values and shape of pressures distribution for design purposes.

So, five cells of strain gauges were prepared, the distance between them equals 50cm. and they were fixed at wooden sheet on bedroom's wall in one of Assiut el gadida city projects.

Prediction of lateral earth pressures has been a problem to civil engineers for a long time. The first rational approach by which lateral earth pressures could be estimated was simple and practical, and they have come to be known as the classical methods of prediction of lateral earth pressure.

The behaviour of soil is swelling after adding water then affects on retaining structures. The effect of soil is depending on many factors like water content, depth, the type and quantity of mineral in soil composition, the time, … etc.

The results of this research give a good knowledge about the value and the distribution of lateral swelling pressure, and the results showed that the swelling pressure on retaining structure increases by increasing the water content and montmorillonite minerals content in soil. Then, the results enable the civil engineers to attain safe and suitable design for retaining structure without engineering problems...

Keywords: Lateral swelling, expansive soil, Assiut el Gadida city

1. Introduction

Expansive soils are found in almost all parts of the world. Clay soils in semiarid areas shrink during dry periods forming cracks as shown in Photo1. and swell during wet periods causing a considerable amount of damage to lightly loaded structures.

(a)

(b)

Photo 1. a)expansive soil in nature. **b)** Shrink during dry periods forming cracks.

The cost associated with damage due to swelling soils is more than double the cost associated with damage from floods, hurricanes and earthquakes (Holtz, 1984). The damages will be much greater in coming years if expansive soils are not recognized before builders start to build structures in/on expansive soils.

Expansive soils swell laterally as well as vertically. Lateral volume changes will be accommodated by the cracks and fissures if there are cracks and fissures in the soil mass. However, when there are no cracks or when the cracks are very small and close up without accommodating all of the volume increase that is required by the expansive soil, the swelling soil becomes restrained in the lateral directions.

In the classical earth pressure analyses, the retaining structure is assumed to yield in such a way as to develop active pressures. When rigid structures are considered, the at-rest earth pressure is sometimes used in the design of structures, although there is little guidance on the values to adopt; estimates are frequently based on the at-rest coefficient for normally consolidated deposits (Jakky, 1944).

In 1973, researchers surmised that 60 percent of all residential foundations built on expansive soils would experience some degree of distress because of differential foundation movement .So heave of clayey soils poses a difficult problem to civil engineers.

Most retaining wall designs, both rigid and flexible, specify the use of granular materials (sand and/or gravel) as the backfill behind those structures, primarily because the methods for calculating earth pressures on the walls are relatively simple and well established (Coulomb, 1776; Rankine, 1857) . This simplicity is due, in part, to the relatively inert nature of granular materials, i.e., the particles do no appreciably interact chemically with each other, with the surrounding soil particles, or with water. While a considerable majority of retaining wall systems designed and constructed around the world perform satisfactorily, a significant number of retaining wall failures occur each year.

Example of wall failure can be seen in Photo 2. Some of these failures can be attributed to construction outside of the original design criteria (Marsh and Walsh, 1996), particularly the use of cohesive backfill as a substitute for granular backfill materials. The main reasons that cohesive materials are ever considered for use in these situations are always economic.

Photo 2. Severe Wall Distress.

If soils are compressed by a retaining structure and there is sufficiently large movement of the structure into the soil, this strain condition is known as the passive state. Most retaining walls or structures, with the exception of fully embedded retaining walls, require placement of backfill material adjacent to the wall. This placement can be accomplished by one or the other of two methods.

1- the walls can be constructed in the excavation; then the gap left between the completed structure and the natural ground can be filled.

2- the walls are constructed above the original ground level, and then the full height of the structure is back filed.

It has conventionally been considered wise to backfill with granular materials because of their good drainage and self-settlement characteristics and because their strength properties are not time dependent. However, in several areas of the world, free draining granular material is scarce and its price is set by its value as a constituent of concrete (Clayton et al., 1991). The use of cohesive materials as backfill introduces additional uncertainties into the retaining wall design since there is little information allowing estimation of the pressure produced by volume changes occurring after construction.

Classical methods cannot be used to estimate the lateral pressure of expansive soils behind a retaining structure. There is no reliable method presently available that allows the designer to predict the pressures on retaining structures or basement walls due to swelling soils despite many methods available to design professionals by which they can predict the lateral earth pressures expected to be acting on a structure from non expansive soils. When geotechnical engineers are faced with swelling type soils, the engineering properties of the problem soil may be improved to make them suitable for construction.

2. Field measurements of swell and swell pressure

Limited research has been published where field measurements of lateral swell pressure have been attempted.

2.1. Instrumented field studies

In an effort to further understand the complex interactions between expansive soils undergoing moisture changes and structures built against such materials, Richards and Kurzeme (1973) and Richards (1977) describe the installation of instrumentation, the recorded measurements, and the observations and analyses conducted on a retaining wall constructed in 1971 against expansive soil in Adelaide, Australia. In this study, a 7.5m high reinforced-concrete basement wall was to be constructed against a highly expansive stiff fissured clay and a marl that was known to seep water. Because of concerns of potential heaving of the clay soils subsequent to any wetting, it was decided to conduct an extensive study investigating the performance of the wall over time through the installation and monitoring of a test section comprised of twelve vertical series of psychrometers and six vertical series of earth pressure cells spaced across a 25m length of the wall.

The earth pressure cells were installed at the back face of the retaining wall to directly measure the applied lateral soil pressures generated as the soil moistures increased. The psychrometers were installed to measure changes in soil suction as the soil moisture increased at different distances from the back of the wall. However, the psychrometer installations nearest to the wall were a full 2m away. A diagram of the overall wall and monitoring layout is shown in Fig.1and Fig.2

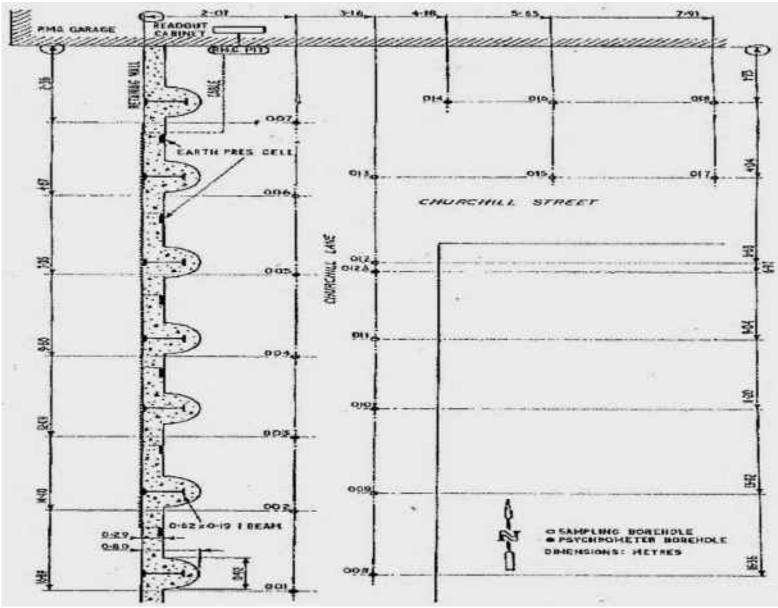


Fig. 1. Retaining Wall Instrumentation Plan (from: Richards and Kurzeme, (1973)

Instrumentation measurements were obtained at regular intervals from the time of installation in mid-1971 at least through mid 1975. Though significant or consistent decreases in soil suction were not measured in the psychrometers, the dramatic increase in the lateral earth pressures of up to five times the vertical overburden pressure, as measured in the lower levels of earth pressure cells, indicates that water seeping from above migrated down the soil-concrete interface, resulting in soil swelling at the bottom of the wall. As the first row of psychrometers behind the wall registered no significant or consistent changes in soil suction values, it was apparent that the wetting front had not yet penetrated that far behind the wall. Further, it was found that the lateral earth pressure increases that were measured migrated upward over time Fig. 3

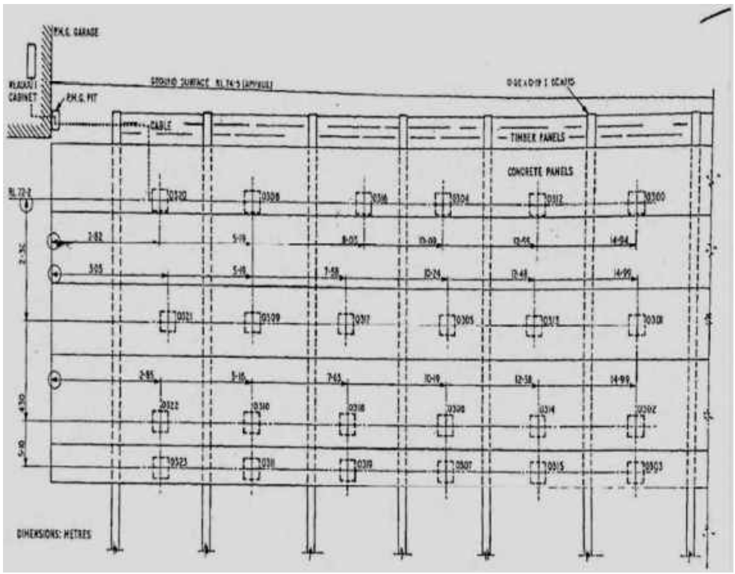


Fig. 2. Retaining Wall Instrumentation Profile (from: Richards and Kurzeme, (1973)

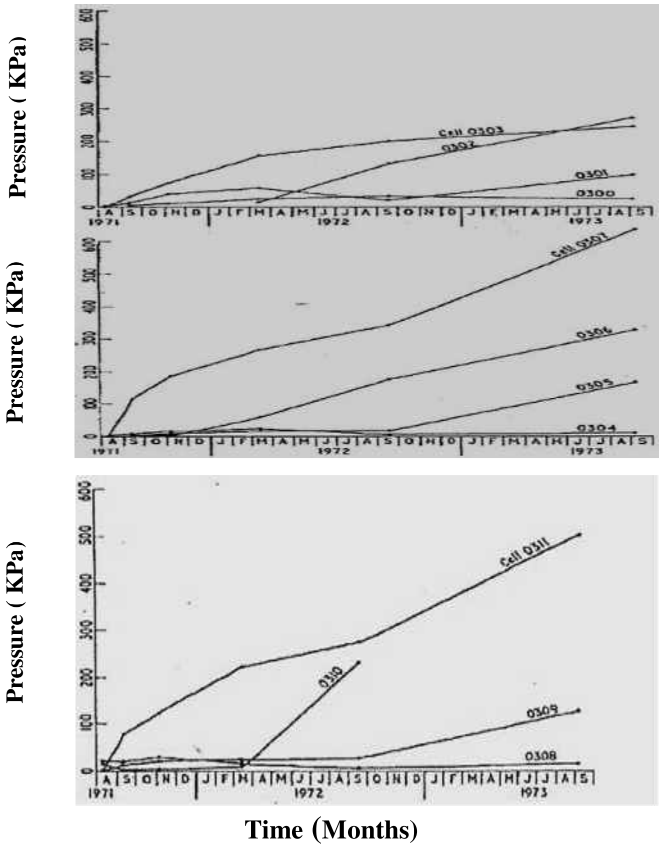


Fig. 3. Lateral Earth Pressure Development over Time for Selected Earth Pressure Cells (from: Richards and Kurzeme, (1973)

To explain this phenomenon for this project, it is suggested that as the water seepage from above reached the lowest soils, those soils swelled laterally against the wall and sealed the water migration path along back face of the wall at those levels. By progressive repetition of this process, the lateral pressure increases migrate upward with time. It was also postulated that when free water is no longer available, soil suction decreases would eventually dissipate through he surrounding soil mass, resulting in an overall total reduction of lateral earth pressure.

2.2. Large-scale study

Katti et al., (1983) conducted large-scale experiments investigating lateral swell pressure development on retaining structures with and without use of non-swelling clay materials (cohesive non-swelling materials, or CNS) both atop high-plasticity expansive clay fill, and between the structure and the clay fill. These studies built on research published by Katti et al, and Katti dating from the late 1960's (1967, 1969,1975,1980,1981,1982). The experiments were conducted on sand, CNS and expansive clay soils layer-compacted into a reinforced frame with dimensions adjustable up to about feet wide, 2.4m deep and 3.6m tall. One of the four vertical walls of the experiment frame was instrumented and equipped to restrain horizontal deflections. By maintaining zero deflections along the vertical length of wall after fill compaction was complete, the lateral swelling pressures generated after both compaction and saturation could be measured. Saturation for each test increment was conducted for a period of 60 days ,though the means of saturation were not explicit. The overall experimental setup is shown in Fig.4

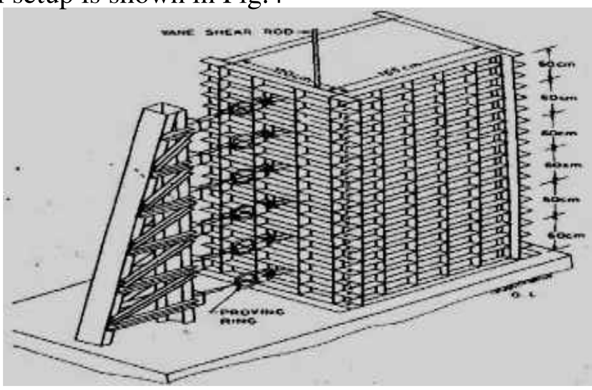


Fig. 4. Large-scale Experiment Setup (from: Katti et al., (1983))

Four types of tests were conducted:

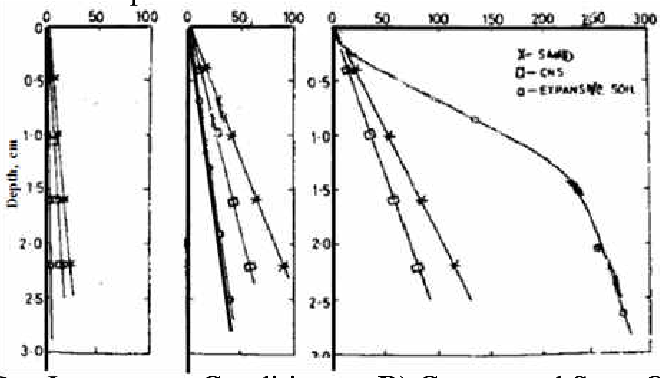
Case 1. Evaluation of lateral pressures developed with depth for granular materials (sand), CNS and expansive clay soils in loose dry, compacted dry and compacted saturated conditions.

Case 2. Evaluation of lateral pressures developed with depth of expansive clay fill having varying thicknesses of CNS inserted between the wall and the expansive clay fill.

Case 3. Evaluation of lateral pressures developed with depth of expansive clay fill with varying thicknesses of CNS placed and compacted atop the expansive fill.

Case 4. Evaluation of lateral pressures developed with depth of the expansive clay fill having CNS both placed between the wall and the expansive fill, and atop the fill .

For the Case 1 experiments, the authors observed a linear relationship of lateral pressure with depth for the loose dry conditions of all three materials in close agreement with Ko values obtained from Jaky's equation: Ko = 1- sinφ For the compacted dry condition, the observed lateral pressure relationships were also linear with depth, but the calculated values for Ko were all in excess of 1, with the sand exhibiting the highest values (e.g. 2.33 at 1.00m depth). These high values are attributed to the addition of impact loads during compaction imparted to the self-weight of the fill at a given depth . Similarly, for the compacted saturated condition of the sand and the CNS, a linear relationship of lateral pressure with depth was observed. Compacted saturated expansive clay materials, however, exhibited a completely different behavior in this study; though it should be noted that these soils had been compacted in an air-dried Condition prior to saturation. For the compacted saturated condition of the expansive clay in the current experimental setup, the lateral pressures against the wall increase rapidly with depth to about 1.5m, then increase at a lesser rate below that depth.



A) Air Dry Loose state Condition **B)** Compacted State Condition
C) Compacted Saturated State Condition

Fig. 5. Lateral Pressure Development versus Depth (from: Katti et al., (1983)

At 1.5m depth the developed lateral pressures were measured to be about 230 kPa (~4800 psf). Calculations of the lateral pressures generated by the buoyant weight of soil, the water and the impact loads during compaction only amount to about 19 kPa (~400 psf) at that depth. The difference is taken to be the magnitude of lateral swell pressure generated by the absorption/adsorption of water into the crystal structure of the clay minerals (predominately a smectite type clay). Fig.5 is a graphic illustration of the measured data .In each of the above cases, the maximum lateral pressures developed were observed to decrease with time .The data developed from Cases 2 through 4 have important implications for the design of retaining structures using expansive cohesive backfill, but detailed assessment and treatment of these aspects of lateral pressure generation are beyond the scope of this current research. However, Fig.6 illustrates some of the beneficial impacts of using CNS backings (Case 2), in that lateral swell pressures applied to the back of the wall face are decreased with increased thicknesses of non-expansive backfill placed between the wall face and the expansive retained of reinforced backfill .

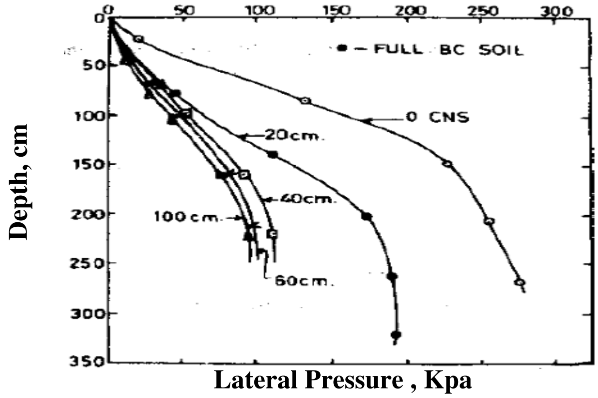


Fig. 6. Lateral swell Pressure versus Depth Using CNS (from: Katti et al., (1983))

Katti et al., (1983) used the data from preceding Katti et al., and Katti research to develop a finite element model to simulate the observed results. This effort employed the given soil parameters and incorporated assumed suction data for the given soils based on suction compressibility and strain equations proposed by McKeen (1977 and 1980). The numerical analysis correlates well with the experimental observations and the resulting lateral pressure distribution obtained is very similar to that shown in the original research. By assuming some small unreported wall displacement at the top of the wall, the numerical results generated were almost identical to the original observations. Katti et al., note that even minute lateral wall displacements result in a very large relief of lateral swelling pressure. They further stress the importance of the suction parameter in the numerical model, which is a function of the bulk clay content and mineralogy (and hence, related to the particle size distribution and PI of the soil mass . In a published response to Xin and Ling (1991), Aytekin (1992) reiterates the validity of the resultant lateral pressure distribution observed by Katti et al, (1983) and further indicates similar findings by Sudhindra and Moza (1987) (not referenced in the response article) .

2.3. Swelling pressure in the lateral direction

Boundaries of an expansive soil must not be restrained if the soil increases in volume, i.e., to swell. The ground surface increases in elevation as expansive soils swell vertically. The ground surface also swells laterally as well as vertically. If the ground surface is cracked and fissured, the lateral increase in volume is accommodated by the cracks or fissures closing as the soil mass expand into the voids of the cracks.

However, when there are no cracks or fissures or when they are very small, the soil becomes restrained in the lateral directions. Thus, no volume change occurs and a lateral swelling pressure develops. Most of the publications in the technical literature that address the subject of lateral swelling pressure can be divided into two groups. One is principally theoretical, the other is principally experimental. Many of the theoretical papers used laboratory tests to evaluate certain factors or the laboratory data were used to develop equations that could be used to estimate future results. Many of the experimental analyses discussed below used remolded or compacted soils in the experiments rather than in situ or undisturbed samples and did not have predictive models.

3. Material used apparatus model and testing procedures

3.1. Materials used

The soil used in this investigation is clayey silt; it's carried out from one of Assiut el gadeda city projects - Assiut. The soil was sieved using sieve No. 200 which has an equivalent opening equals to 0.002mm. The portion passed from sieve No. 200 was used in the tests, as shown Fig.7

Table 1.
The values of (Dmm) and (N%)

Dmm	0.13	0.09	0.06	0.04	0.03	0.02	0.01	0.005	0.003	0.002	0.002	0.0006
N%	100	98.4	94	92.1	90	80.4	51.2	20.1	12.7	9.6	8.1	6.5

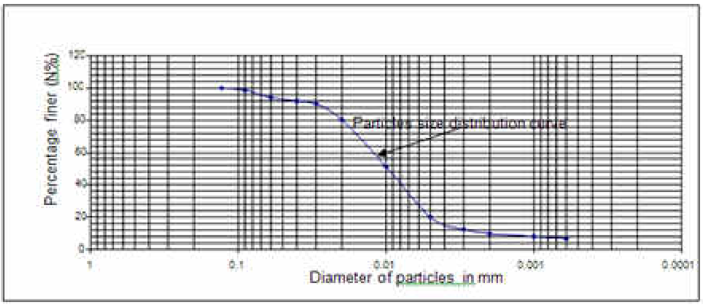


Fig. 7. Shows the relation between diameter of particles (D_{mm}), and percentage finer (N%).

Table and figure (1) show that the soil consists of (9.6 %) clay and (84.4 %) silt
a- the free swelling factor of clay equals 165 %
b- The vertical swelling pressure of soil equals 4.00 kg/cm^2
c- The lateral swelling pressure of soil equals 3.20 kg/cm^2

The vertical and lateral swelling pressure values of soil are measured According to "Different pressure Method". The chemicals analysis of soil was obtained from X-rays fraction (XRF) as in Fig. (8), *According to ASTM C114-00 and ASTM C114-10.

The results can be summarized as follows:

Oxides SiO2 AL2O3 Fe2O3 CaO MgO SO3 Na2O K2O TiO2 P2o3 LOI** TOTAL

Contents* 51.87 16.62 11, 45 1.50 2.37 0.02 3.33 0.57 1.62 0.50 9.97 99.82

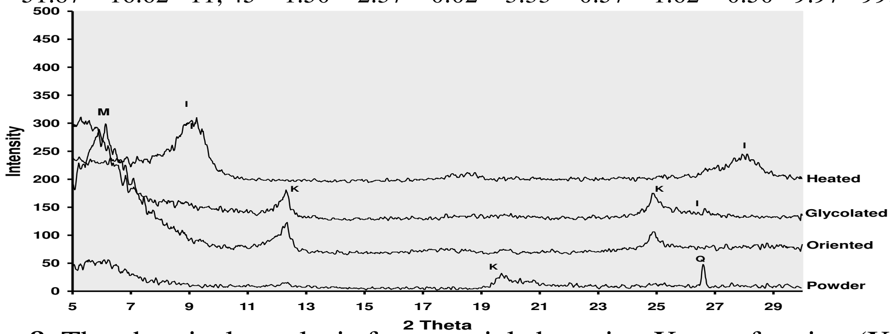


Fig. 8. The chemicals analysis for materials by using X-rays fraction (XRF)

Photo 3. The model test

3.2. Apparatus model for measuring

The model test was constructed of five parts of sheet of Perspex,

the part has dimensions of 3cm length x 20cm width in plan and 2.00cm thickness, Six holes 50cm distance from center to center is obtained, the hole has 4.00cm Dia. as shown in Photo 3. The model is formed of sheets of wood plates stiffened with the parts of measuring by riveted connections from two sides, the pressure cells were constructed to measure low stresses. It was made of Perspex diaphragm 0.3cm thick, 5cm external diameter; the strain gauge was of nominal resistance of 120 ohms. It was covered with a strip of steel has 0,10mm thick. The cells were calibrated under air pressure in a calibration chamber specially constructed for this purpose. the corresponding strain was measured by strain recording device P-3500 as shown in Photo 4.The cells were utilized to measuring the lateral swelling pressure on retaining structure with the depth, time and water content.

3.3. Testing procedures

The present investigation was conducted using field model. The size of test model was considered suitable enough to minimize the errors in the reading of lateral expansive earth pressure on retaining structure. Pressure cells were designed to measure the lateral expansive earth pressure on retaining structure which created from the swelling soil pressure . The field investigations study the relationship between the lateral expansive pressure on retaining structure and the depth of soil tested, the time with constant water content and density. The steps of testing procedure can be summarized as:

a) Prepare the excavated side of the field test,

b) Put the model adjustment the retaining wall (distances between cells = 0.5m, height of the model=2.5m),

C) Put the soil layer (every layer = 0.25m), compacted the layer to give bulk density absolutely = 1.43 t/m^3,

D) Prepared the setup to measure the lateral swelling pressure, and

E) Added the water to the expansive soil to start the test as shown photo 5

Photo 4. Shows the lateral swelling measuring by strain recording device P-3500.

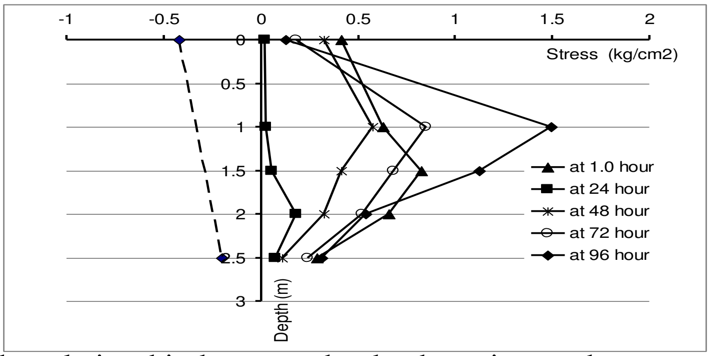
Photo 5. The model test

4. Field results and discussions

The results of the filed tests were obtained from Fig.9 and Fig.10.They represent the variation of stress distribution (σlat) with the depth and time at constant water content and density.

4.1 Lateral swell stress with depth during four days at both water content = 0.22% and density = 1.43 t / m^3 are constant.

Fig.9 shows the relationship between swell stress with difference depth at difference time when water content = 22% and bulk density = 1.43 t/ m^3.The water is added to soil every day when the soil dries and shrinks at the top layer of soil surface.



ig. 9. Shows the relationship between the depth, active earth pressure with/without swelling pressure at water content = 22% and density = 1.43t / m^3 during four days

It can be noticed that the distributions of stress within soil on retaining structure from test is different according to depth, the stress (σlat.) increases speedily as adding water to expansive soil , after passing one hour, (σlat.) values increase at top surface layer and decrease at depth equals 1.0m. At this depth, it increases to the maximum values. At h=2.5m (σlat.) values start to decrease gradually. When W% decreased in soil, (σlat.) value decreases consequently. Also, after one day, the values of stress on retaining structure from tests are less at the top layers, but the values increase at 2.00m depth.

Fig.10 explains that (σlat.) increases speedily from h = 0.00 to h = 1.00m, then it decreases with increasing the depth.

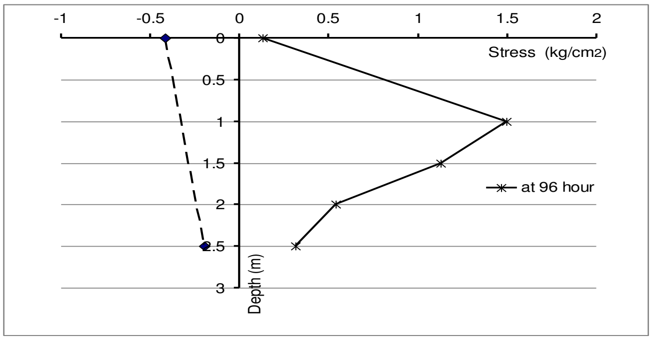


Fig. 10. The relationship between active earth pressure (with/without) swelling pressure and depth at water content = 22% and density = 1.43t / m^3 after four days

Fig.11 shows the relationship between active earth pressures (with/without) swelling pressure and depth at water content = 22% and density = 1.43t / m^3 after four days. The active earth pressure on retaining walls without swelling was calculated (Rankine,1857) according to:

$$\sigma a = \sigma v\, Ka - 2c\sqrt{Ka} = \gamma H\, Ka - 2c\sqrt{Ka} \qquad (1)$$

, active earth pressure on retaining walls with swelling was measured by pressure cells and swelling pressure was obtained from:

$$\sigma a(\text{total}) = \sigma a(\text{with swelling}) + \sigma a(\text{without swelling})$$

$$\sigma a(\text{with swelling}) = \sigma a(\text{total}) - \sigma a(\text{without swelling}) \qquad (2)$$

By applying in eq.(1) and (2)

where, γ=1.43 t/m^3, c=2.00 t/m^2, φ=6^o, Ka=0.81,$\sqrt{Ka}$=0.90.The values were got as shown in table(1)

Table 2.

The values of depth, active earth pressure (with/without) swelling and swelling pressure.

Depth (m)	active earth pressure without swell (Kg/cm^2)	Swelling pressure (Kg/cm^2)	Active earth pressure with swell (Kg/cm^2)
0.00	- 0.36	+0.49	+ 0.13
0.50	- 0.30	+1.10	+0.80
1.00	- 0.24	+1.73	+1.49
1.50	- 0.19	+1.29	+1.10
2.00	- 0.13	+0.67	+0.54
2.50	- 0.07	+0.37	+0.30

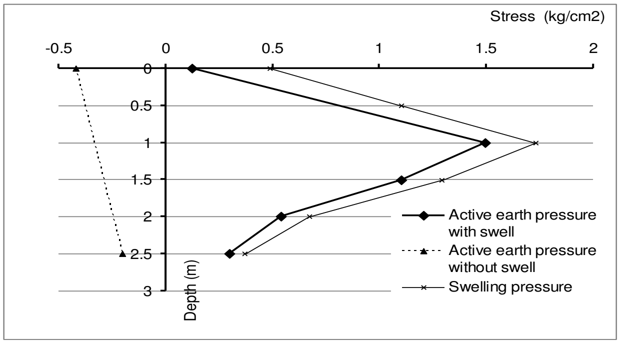


Fig. 11. Shows the relationship between depth, active earth pressure (with/without) swelling and swelling pressure at water content = 22% and density = 1.43t / m^3 after four days

5. Conclusions

Conclusions of the field study can be summarized as following:

1-The lateral swelling pressure (σ_{lat}) on retaining structures distribution due to expansive soil depends on the depth within soil, the water content and the type of the expansive soil.

2- Lateral swelling pressure on retaining walls increases with increasing the depth in the soil reaching the maximum values at average depth equals 1.50m from the soil surface.

3-The active earth pressure on retaining walls adjust the expansive soil with swelling Pressure equals approximately seven times the active earth pressure of soil without swelling pressure .

4-In the design of retaining walls Lateral swelling pressure distribution values must be taken into consideration.

List of symbols

h = the distance from surface of soil to any depth of soil (m)
T = time (hour)
Q = surcharge at surface of soil (kg / cm^2)
W % = water content percentage
(σlat.) = lateral swelling pressure (kg / cm^2)

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دراسة حقلية لتوزيع الاجهادات الانتفاشية العرضية للتربة المنتفشة على الحائط الساند

ملخص عربى:

من المتطلبات الهامة التي تقع على عاتق المهندس المدني تحقيق أقصى كفاءة فنيه واقتصادية في التصميم والتنفيذ ويظهر ذلك جليا في أعمال الردم فعندما يحتاج المهندس المدني لتربه مناسبة لأعمال الردم وسند جوانب الحفر فانه يقوم باستخدام التربة المتوافرة لديه وأحيانا تكون التربة المنتفشة إحدى البدائل المتاحة لذلك

لذا تعتبر دراسة الضغوط الجانبية للتربة الانتفاشيه على المنشات الساندة من الدراسات الهامة في مجال التربة و الأساسات ولهذه الدراسة تم تصميم نموذج عملي يتناسب مع الغرض المطلوب لتحديد مدى تأثير الضغوط الجانبية الناشئة من انتفاخ التربة المنتفشة على المنشات الملاصقة والساندة لها وقمنا بوضع الخلايا الحساسة على حامل خشبي والمسافة بين كل خليتين 50سم وتم تثبيتها على حائط ساند ملاصق لجانب الحفر بموقع إحدى المشروعات بمدينه أسيوط الجديدة أسيوط – مصر

ولقد اشتملت الدراسة على تأثير الماء المضاف على انتفاخ التربة و قياس شكل و توزيع الضغوط الجانبية المتولدة عن الانتفاش وذلك على أعماق مختلفة من السطح و بعد مرور فترات زمنيه مختلفة

ومن نتائج هذا البحث يتبين أن الضغوط الجانبية للتربة الانتفاشيه على المنشات الساندة تتأثر بدرجه كبيره بوجود الماء في التربة وكذلك الأملاح المعدنية المكونة للتربة ويتوقف مقدار الزيادة و النقص في الضغوط الجانبية للتربة الانتفاشيه على معدل توزيع الماء في التربة ونوعيه الأملاح بها كما وجد أن الضغوط الجانبية الناتجة عن ضغط الانتفاخ تكون اكبر ما يمكن بمجرد سريان الماء خلالها وتأثر الأملاح المعدنية و خصوصا أملاح المنتموريلونايت بالماء ومن النتائج الهامة أتاحه المعلومات للمهندس المصمم لتمكنه من التصميم المناسب و الآمن للمنشات الساندة في التربة الانتفاشيه.