Journal of Al-Azhar University Engineering Sector

Vol. 17, No. 65, October 2022, 1221 - 1240

EXPERIMENTAL STUDY ON BEHAVIORAL PARAMETERS OF EXPANSIVE SOIL TREATED WITH SALT WATER

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Received: 13 June 2022   Accepted: 28 August 2022

ABSTRACT

Expansion and shrinkage are common features in the expansive soil because of the presence of clay minerals or chemically evoked changes. Chemical stabilization has been proved to be effective alternative solution to overcome the undesirable swelling behavior. This research highlights the effect of adding sodium chloride salts to expansive soil in improving swelling characteristics and change in soil index properties. An experimental program developed to investigate the effect of salt water on the engineering properties of high swelling clays. The laboratory tests were carried out in the soil mechanics laboratory of Al Azhar University. The materials used in this research were silty clay obtained from **Bait El Watan project** in **New Cairo city** and saline water at various NaCl concentrations of (5, 10,20,30,50 and 60%). A series of laboratory tests were carried out. Based on the obtained results, A concentration of 20% NaCl showed optimum improvement in swelling properties. To simulate field conditions, an experimental model was constructed to evaluate the effect of salt water with optimum concentration on expansive soil. However, the results showed that swelling properties of soil were optimized at 20%Nacl concentration. Swelling heave readings as recorded from large scale experimental model testing improved from 1.525mm to 1.355mm for original and treated soil, with a reduction of 11%. It is also observed that swelling heave values measured for the treated soil sample when re-immersed in fresh water increased by 145% at the top of soil.

Keywords: Expansive Soil, Chemical Stabilization, Laboratory Tests, Experimental Model.

تقييم تأثير إستخدام المياة المالحة لمعالجة التربة الإنتفاشية

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ملخص البحث

التمدد والانكماش من الخواص الشائعة للتربة الانتفاشية بسبب وجود معادن الطين والتي تسبب قابليتها للتغير كيميائيا. المعالجة الكيميائية أثبت انها احدى الوسائل الفاعلة للتغلب على الخواص الانتفاشية الغير مرغوب فيها. هذا البحث يلقى الضوء على تأثير إضافة أملاح كلوريدات الصوديوم الى التربة الانتفاشية على تحسين الخواص الانتفاشية وتغيير خواص مؤشر التربة. تم وضع خطة اختبارات معملية لاستكشاف تأثير المياه المالحة على الخواص الهندسية للتربة الطينية عالية الانتفاش. تم عمل الاختبارات المعملية بمعمل أبحاث ميكانيكا التربة بجامعة الأزهر. التربة المستخدمة بالبحث هي تربة طين طفلي تم الحصول عليها من منطقة بيت الوطن بالقاهرة الجديدة. وتم تجهيز المياه المالحة من إضافة كلوريد الصوديوم الى المياه العذبة بنسب ٥، ١٠، ٢٠، ٣٠، ٥٠، ٦٠٪. تم اجراء مجموعة من التجارب المعملية، بناء على النتائج المستنتجة وجد أن النسبة المثلى لإضافة كلوريد الصوديوم كمثبت كيميائي هي ٢٠٪ والتي أثبتت تحسن واضح للخواص الانتفاشية. لمحاكاة ظروف الموقع تم تصنيع نموذج معملي لتقييم تأثير المياه المالحة على محددات التربة الانتفاشية. أظهرت النتائج تحقيق أفضل الخواص عند نسبة ٢٠٪ تركيز لكلوريدات الصوديوم. كما سجلت قراءات قياس الانتفاش تحسن من ١,٥٢٥ مم الى ١,٣٥٥ مم للتربة الغير معالجة والمعالجة بانخفاض ١١٪. كما لوحظ أن قيم الانتفاش المقاسة لعينات التربة المعالجة بعد إعادة غمرها بمياه عذبه زادت ١٤٥٪ مقاسة عند سطح التربة.

الكلمات المفتاحية: التربة الإنتفاشية، المعالجة الكيميائية، الاختبارات المعملية، النموذج المعملي

1. INTRODUCTION

Expansive soils, with high swell and shrink behavior prove to be challenging for construction and pavement activities. Soil treatment using various techniques is commonly used to improve the expansive soil on the site to avoid excessive swelling. Chemical treatment is the most widely used site improvement technique. The frequency of rainfall, rate of evaporation, and activity of the clay are parameters in the eventual heave of expansive soils,**[1].** Chemical stabilization involves mixing or injecting soil with chemically active compounds such as cement, lime, fly ash, calcium or sodium chloride or with viscoelastic materials such as bitumen soils with high clay content have a tendency to swell at high moisture contents**.[2]**

This paper highlights on the effect of chloride salts on expansive soil in term of change in index properties and swelling characteristics. The use of chloride salts to stabilize expansive clays has been investigated by many researchers.as reported in available literature **[3-5]**. The salt water effect on the physical properties and compaction characteristics of expansive soil was studied by **[6]**. Results have shown that addition of salty water has great improvement in their Atterberg limits, compaction characteristics and swelling properties. Atterberg's Limits such as Liquid Limit decreases by 47.8 % in presence of salt water. Further, plasticity index also decreases by 68.5% due increase in salinity in water to 60% salt concentration. Maximum dry density of clayey soil increases from 17.83KN/m3 to 18.95 in presence of salt water comparing with the results obtained from tap water. Optimum Moisture Content of clayey soil decreases from 16.5% to 12% in case of Salt water. The effect of seawater on swelling characteristics of montmorillonite clay has been investigated by **[7]** .Their experimental results indicated that for clays containing montmorillonite mineral percentage higher than 72% and having a liquid limit higher than 140% when mixed with distilled water show that the liquid limit and the swelling potential are significantly reduced if saltwater is used in mixing. **[8]** studied salt water effect on swelling behavior, engineering properties and heave parameters. The results indicated that inundation of swelling soil by salt water may show reduction in swelling properties. When dry or semi-dry pretreated soil with salty water was continuously immersed in fresh water, the swelling percent increased by about 84% to 125% but when treated soil are subjected to seepage of fresh water, it may yield higher swelling potential. **[9]** have investigated the effect of NaOH solution on some geotechnical properties of the soil with low plasticity (LL=38%). Their results have shown that the liquid limit of the soil increases as NaOH solution concentration increases. **[10]** reported that NaCl allows forming ionic bonds with bentonite molecules, reaction products decrease the repulsive forces between the clay particles forming cementitious or binding particles resulting in reducing free swelling. **[11]** stated that by using sea water instead of tap water index properties of the soil get improved due to flocculation and cation exchange, where positively charged ions in solution are substituted for other species of ions which are attached to the clay mineral crystals. The influence of SLS solution concentration on the geotechnical properties of expansive soil was investigated by **[12]**. The results showed that for salt concentration 1 mol/lit, its improvement effect was the most obvious, and liquid limit, plastic limit, and plastic indexes were decreased by 22.1%, 11.5%, and 32.2%, respectively and the free expansion rates of modified expansive soil samples were decreased by 12.4% compared with those of unmodified expansive soil. **[13]** demonstrated that the presence of sea water as mixing water in the Lime treated soil has formed a new fabric structure of high rigidity as well as of high shear strength. Accordingly, the new fabric structure became capable to resist the compression process. **[14]** studied the effect of salt water on the physical properties of expansive soil and the obtained results showed that addition of salty water has great improvement in their Atterberg limits, compaction characteristics and unconfined compression strength. **[15]** studied the effect of various percentage of calcium chloride such as 0.5 %, 1.0%, 1.5% and 2% on the engineering properties of three expansive soils and the result shows reduced plasticity and increased the strength of the soils. **[16]** found that for wet state shear strength, ferric chloride had a significant effect on the shear strength of soil. It increased the soil's internal friction angle by about 10%, and 3% at 1gm/100ml, and 3gm/100ml ferric chloride content. In addition, the cohesion was increased by 6%, and 1% at 1gm/100ml, and 3gm/100ml ferric chloride content. **[17]** have investigated three techniques to reduce the swelling properties of expansive soil. Their results showed that the presence of sodium chloride in the pore fluid caused a decrease in swelling and swelling pressure. **[18]** studied the effect of some chloride salts on consistency and swelling characteristics of expansive Soil. The results inferred were the addition of chloride salt to the expansive clay decreased the liquid limit and the plasticity index of the treated soil. **[19]** have investigated effect of sea water on the geotechnical properties of cohesive soil. Results indicated that Atterberg's limits such as Liquid Limit decreases in presence of sea water. Further, plasticity index also decreases to a great extent due increase in salinity in water. This decrease is due to higher cation valance and increasing salt concentration. Also results showed that maximum dry density of clayey soil increases in presence of sea water comparing with the results obtained from tap water. and optimum moisture content of clayey soil decreases in case of sea water. **[20]** have studied the effect of common salt on the engineering properties of expansive soil and results showed that treatment of the studied expansive soil has the effect of reducing the values of the geotechnical index properties (liquid limit, Plasticity index and linear shrinkage, free swell index) of the soil and hence its tendency to swell; and increasing the strength characteristics (California Bearing Ratio, Maximum Dry Density and the Unconfined Compressive Strength).Moreover, on addition of 1.5% sodium chloride to the soil, maximum reduction percentage of 60.42% on liquid limit,42.86% on plastic limit, 71.26% 23.28%, on plasticity index, 66.64% on linear shrinkage,83.43% on free swell index, and 28.57% on optimum moisture content were obtained.

The main objective of this experimental investigation is to quantify the change in the consistency and swelling properties of Egyptian clayey soils when exposed to salt water environment.

2. EXPERIMENTAL PROGRAM

In this study, a large scale experimental model was constructed in order to study the enhancing performance of expansive soil of high swelling potential on its swelling properties when mixed with sodium chloride solution at the optimum salt concentration.

2.1. MATERIALS

The materials used in this research were: **Silty clay** obtained from **Bait El Watan project**, western of Suez Road in New Cairo city as shown in **figure 1.** A summary of the engineering properties of the natural soil is shown in **table 1**. The soil is classified as silty clay of high plasticity (CH) in accordance with Unified Soil Classification System, (USCS).

Figure 1: Selected Expansive Soil Sample

Table 1 Physical properties of selected expansive soil sample,[3].

Property	Value
Specific gravity (Gs)	2.63
Natural water moisture, %	8.56
Bulk Density KN/m^3	2.02
Liquid limit (LL), %	91.1
Plastic limit (PL), %	30.4
Plasticity index (PI), %	60.7
Clay content, %	64.0
Silt content, %	22.0
Sand content, %	14.0
Optimum moisture Content, %	16.5
Maximum dry density, KN/m^3	17.83
Free swell index (FSI), %	66.65
Swelling heave (mm)	5.61
Activity (A_c), %	94.8

Also, Chemical Composition of Expansive Soil Samples was carried out. The mineralogical composition of the tested soil was found by x-ray, and the results are given in **table 2**.

Table 2: XRF analysis of natural fine-grained soil

Oxide	Content Value
SiO_2	52.9
AL2O3	17.7
Fe2O3	10.6
CaO	2.09
MgO	1.5
Na2O	0.91
K2O	1.95
SO3	1.38
TiO2	1.53
P2O5	0.22
MNO	-
ZrO2	0.08
SrO	0.05
ZnO	0.04
Cr2O3	0.04
BaO	0.04
CL	0.55
L.O.L	8.41
Total	99.99

X-ray diffraction and Differential Thermal Analysis tests for clay soil samples were carried out to investigate different types of clay and non-clay minerals.

Salt water which is obtained from mixing of distilled water and sodium chloride at various concentrations as an effective chemical stabilizer in expansive soils.

2.2. TESTING PROGRAM

The overall testing program was conducted in three stages: **In the first stage**, a set of experiments were performed to examine the properties of the natural soil extracted from field before being stabilized with Nacl solution. Tests under this section include: chemical analysis, natural water content, unit weight, specific gravity, optimum moisture content and maximum dry density, Atterberg limits, free swell, and swelling heave. **In the second stage**, the virgin soil is mixed with Nacl solution prepared at concentrations of (5, 10, 20, 30, 50 and 60%) and examined as described in the first stage to recognize the effect of salt solution in changing the soil properties and swelling behavior, and to determine the optimum salt concentration at which the sample used in the third stage. **In the last stage** and Based on the obtained results, the optimum concentration of NaCl as an effective chemical stabilizer for treatment of the expansive soil was 20% which shows better improvement with swelling characteristics. A large-scale model was used to modeled untreated and treated expansive soil with the optimum salt concentration at different test procedures and according to loading conditions and specification described in the next section.

2.2.1 Acrylic Glass Tank

An acrylic glass tank (Poly Methyl Methacrylate) with inner dimensions of 400 mm long, 400 mm wide and 400 mm deep was constructed and is perforated with four holes at each side of the tank for fresh water feed distribution system and other hole on the bottom of the tank for water disposal. The wall thickness is 15 mm. Dimensions are selected so that the effect of the tank boundaries on the applied stress and the measured displacement is minimized. Also, acrylic glass tank is selected as a manufacturing material to allow for direct observation of soil behavior during testing as shown in **figure 2.**

Figure 2: Acrylic Glass Model Tank

2.2.2 Steel Footing

The square footing model used for the test is made of steel plate with dimensions of 100 mm long, 100 mm wide and 25 mm thick as shown in **figure 3**. The footing was centered in the tank and attached to the loading rod to ensure that no extraneous moment is applied to the model footing and allow the foundation to rotate freely as it approaches failure.

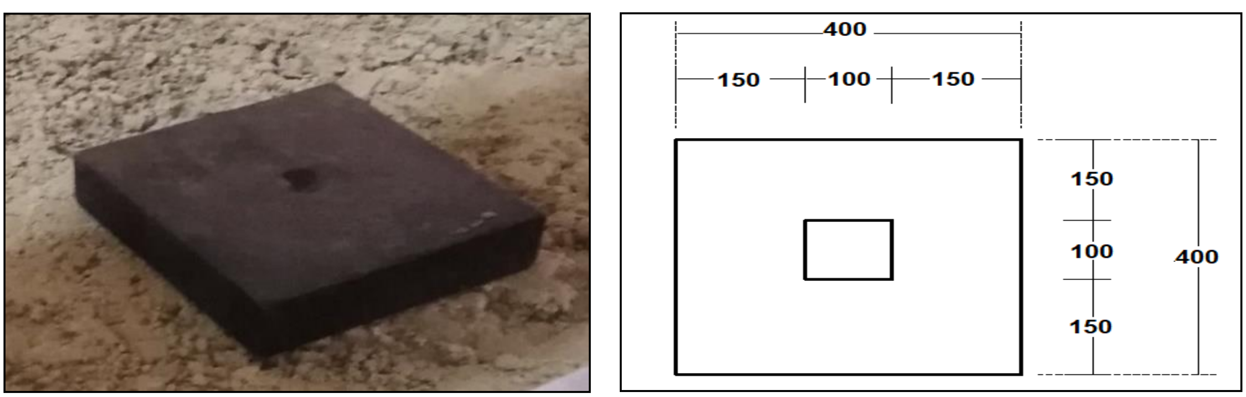

Figure 3: Steel Plate Footing

2.2.3 The Loading System

The loading system was designed to be rigid and capable of sustaining the loading stress without any deflection. A concentrated light load of 0.7 KN is applied to the center of the steel footing through the loading system. One dial gauge was adjusted to the loading system.

2.2.4 The surface Displacement Measuring Devices

Four dial gauges with sensitivity of 0.01 mm and a maximum travel of 50 mm were used to measure the soil displacement. Two gauges are mounted to measure the displacement occurred all around the soil sample and two gauges are adjusted at the top of steel footing.

2.2.5 Fresh Water Feed Distribution System

An UPVC pipe of diameter 20 mm connected to the source of flow is surrounding the glass tank from outside. The pipe is connected through hoses 10 mm diameter fixed to the water tank so that four holes connected to flexible tubes can allow for the flow entrance to the tank at each side. This arrangement is used to ensure uniform distribution of water through the tested soil samples as shown in **figure 4**.

2.2.6 Salt Water Feed Distribution System

Salty water is added directly from top of the model at first, then a group of eight copper pipes arranged around the steel plate were used for salt water injection to ensure a uniform distribution of salty water through the tested soil. Each pipe has a length of 40 cm, with a perforated section at the middle 20 cm. pipes are closed at bottom to prevent soil infiltration onto the pipes. A kind of fabric is used as a filter to cover the perforated part to prevent soil particles to infiltrate and block the openings. Pipes are connected to the source of 20% NaCl solution tank through flexible eight hoses as shown in **figure 5**.

Figure 4: Fresh Water Feed Distribution System

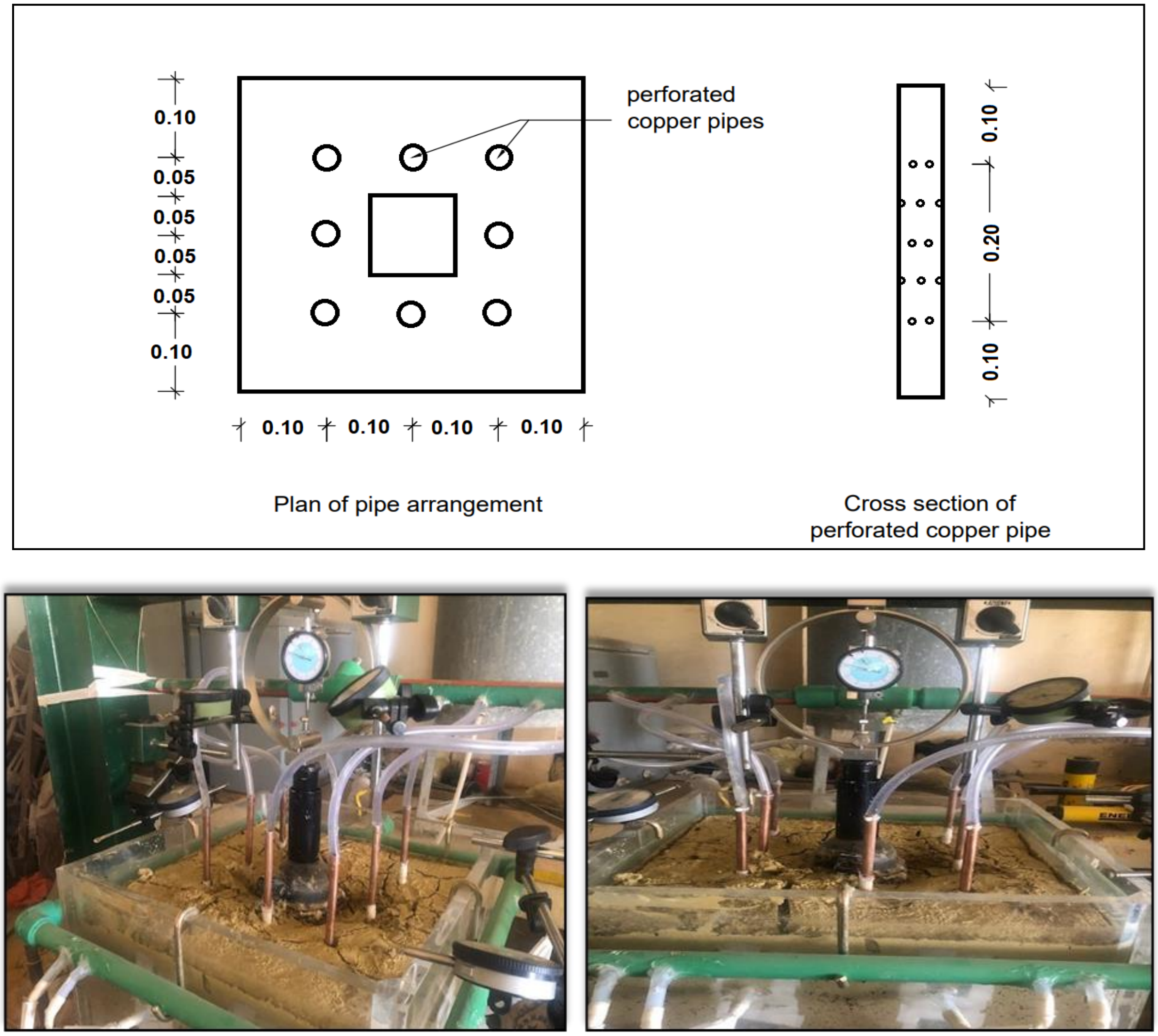

Figure 5: Salt Water Distribution System

2.2.7 Preparation of Experimental Model

Selected samples were oven dried and pulverized to be in powder form. The dry samples were prepared by compacting soil powder to reach a density of about 20.2 kN/m3. Obtained clay sample was placed and compacted in the model tank in four layers each layer was 50 mm to reach a full depth of 200 mm with sand layer 100 mm and was pressed by a metallic plate to avoid air voids and to reach the required density. Top surface of each layer was scratched so that clay layer interlocks with the next layer. Each layer was compacted in the model tank using the moist tamping hammer to reach the required maximum dry density 17.83 KN/m3. Lubricated material was used for inner sides of model tank to ensure a good contact between the compacted layers. After reaching full height which is marked on the side of the tank, the surface was scraped by a wooden plate in order to provide a horizontal surface and the soil was then covered with thin plastic cover. Footing model with required dimensions is centered placed on the soil sample then the light load on the footing is applied. Using the surface displacement device and surface of soil sample in the model tank was surveyed. Displacement is monitored through the dial gauge and recorded every 0.25, 0.5, 1, 2, 4, 8, 15, 30 minutes, then at 1, 2,4,8,16,24 hours, then at the end of each following day until completing model days readings. **Figure 6** illustrates preparation of experimental model.

Figure 6: Preparation of Experimental Model

2.2.8 Experimental Model Setup

After preparation of the soil sample, the steel footing and final adjustment of dial gauges as mentioned in the previous section, the average values of measured settlement and swelling were recorded as shown in **figure 7**. Test is performed for soil prepared at optimum water content and mixed with both tape and salty water of optimum concentration percentage 20% resulted from experimental laboratory test stage.

The average values of measured settlement and swelling were recorded at different test procedures to evaluate the heave of the prepared soil samples in the following conditions:

- Soil Sample was immersed in fresh water without any treatment for 77 days under light load of about 70.0 kN/m2 with continues inundation to maintain the water level constant throughout the test period.
- Removal of fresh water gradually drying of the submerged samples and directly soil sample was treated, immersed in salt water solution with the optimum NaCL concentration of 20 % (obtained from the previous stage) for one month. The measured swelling heave were recorded till reaching constant readings.
- Removal of salt water till reach drying condition.
- Finally, soil sample was re-submersed in fresh water.

Graphs are then plotted between time increment and recorded swelling heave at each test stages are presented next section.

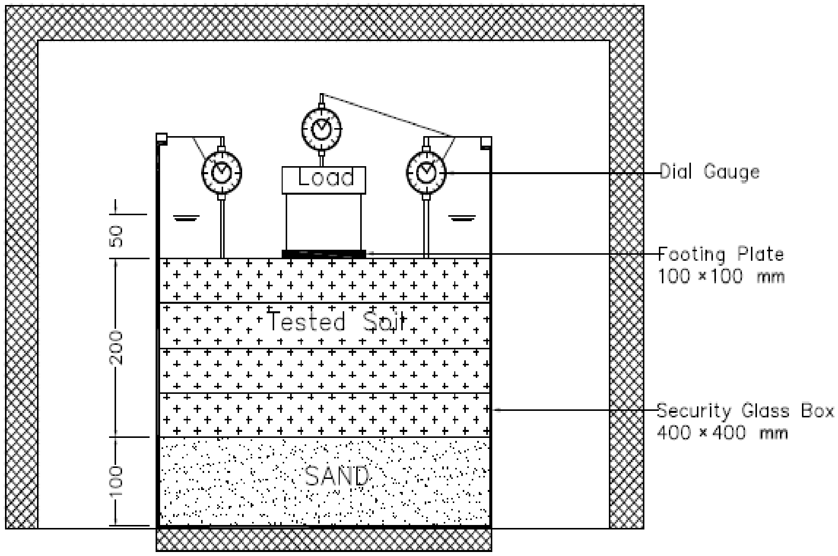

Figure 7: Experimental Model Setup

3. RESULTS AND ANALYSIS

Laboratory test results of expansive soil samples were carried out and presented in the previous research [7] and the optimum salt concentration at which the sample used in the experimental model was 20%.

3.1 Results of experimental model

To simulate field conditions, an experimental model was constructed to evaluate the effect of the optimum salt concentration at different test procedures on the behavioral parameters of fine-grained soil at four stages (233 days) as follows:

3.1.1 Phase 1 :Swelling Heave of soil sample submerged in Fresh Water (Untreated Soil Sample - Reference)

In this phase soil sample was immersed in fresh water without any treatment under light load of about 70.0 kN/m2 with continuous inundation to maintain the water level constant for 78 days as follow:

- Firstly, fresh water was added from the top surface for 10 days.
- Then, feeding starts from 16 holes distributed at four sides of the boundary walls of the tank, and lasts for 68 days.

The purpose of this stage is to measure the heave in soil before treatment is applied. The measured heave is plotted versus time beneath steel plate and at the top of soil sample as shown in **figures 8 and 9**. The observed heave shows an average value of 1.525 mm with an axial free swell of 9.5% beneath the steel plate, and 32.58 mm at top of soil with an axial free swell of 16.3 %. For untreated experimental soil sample, the recorded swelling heave value at top of soil reached about 75% of the total heave value at the first 10 days.

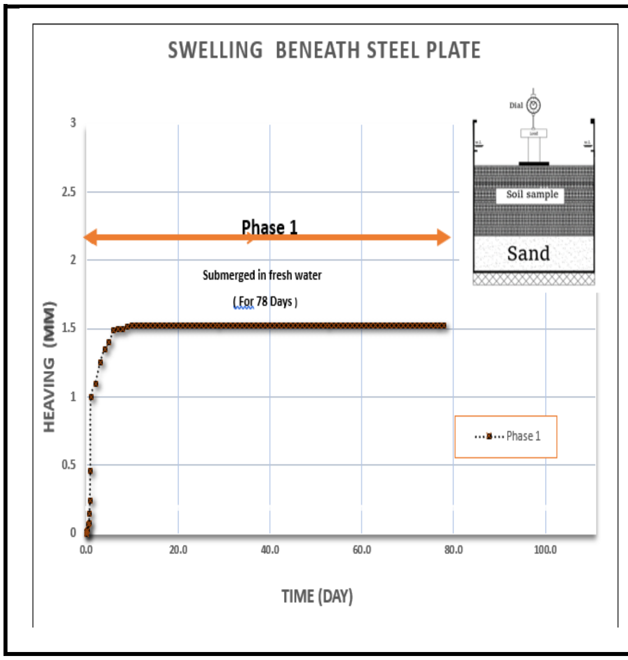

Figure 8: Swelling Heave – Time Relationship beneath Steel Plate for Experimental Model (Phase1 - Reference)

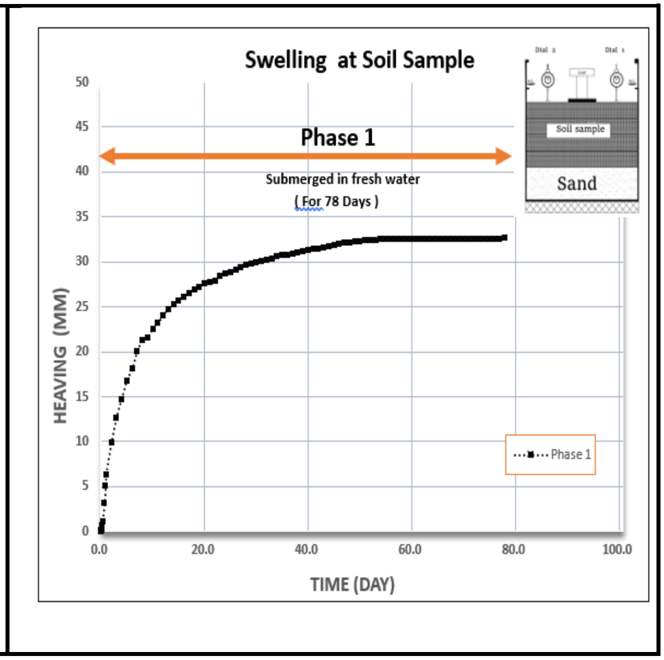

Figure 9: Swelling Heave – Time Relationship at soil sample For Experimental Model

(Phase 1 - Reference)

3.1.2 Phase 2: Swelling Heave of soil sample on drying condition and directly Treated with optimum percent of Salt Water

When readings continue to show a constant value, water disposal is allowed and directly soil sample was treated with salt water 20% salt concentration with continuous inundation of salt water for 31 days as follow:

- Adding salty water starts from the top surface for 19 days.
- Injection of salty water was allowed form eight perforated copper pipes for another 12 days. Heave values decrease gradually until reach constant values.

The measured heave is plotted versus time beneath steel plate and at the top of soil sample as shown in **figures 10 and 11**. The measured swelling heave shows gradual decrease that reached an average value of 1.355 and 28.3 at steel plate and top of soil respectively, with a reduction of 11% under the steel plate and 13% at top of soil compared to original sample before treatment. Obtained result agrees with the finding of

[9]. This reduction is mainly attributed to the fact that at higher salt content, cation concentration increases which resulted in depressed double layer thickness due to cation exchange reaction.

3.1.3 Phase 3: Swelling Heave on drying condition of treated soil samples

This stage lasts for 46 days to remove salt water gradually from submerged samples, and the measured swelling heave was recorded. The measured heave is plotted versus time beneath steel plate and at the top of soil sample beneath steel plate and at the top of soil sample as shown in **figure 12 and 13**. The measured heave recorded at the end of this stage shows a decrease in heave values to reach 0.68 mm at steel plate with a reduction of 55%, while the recorded value at top of soil was decreased to 18.39 mm at top of soil, with a reduction of 43% compared to reference phase.

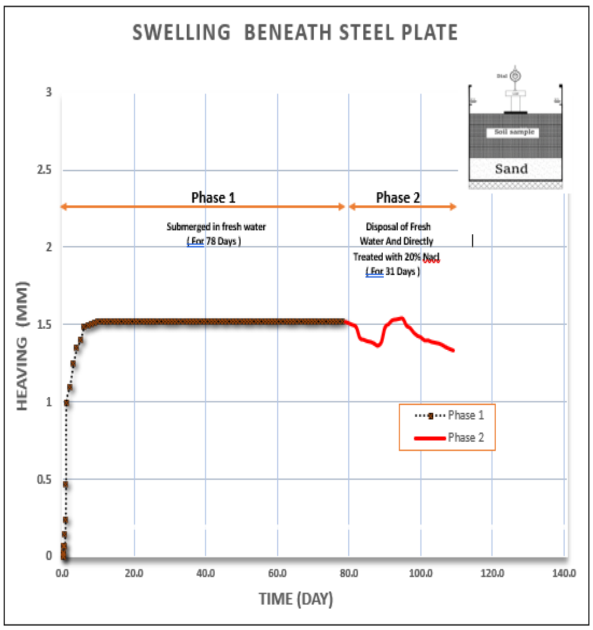

Figure 10: Swelling Heave – Time Relationship beneath Steel Plate for Experimental Model

(Phases 1&2)

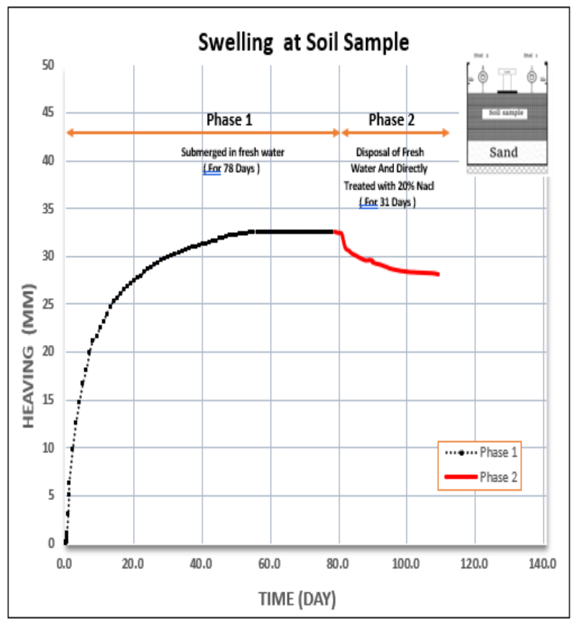

Figure 11: Swelling Heave – Time Relationship at soil sample For Experimental Model

(Phases 1 &2)

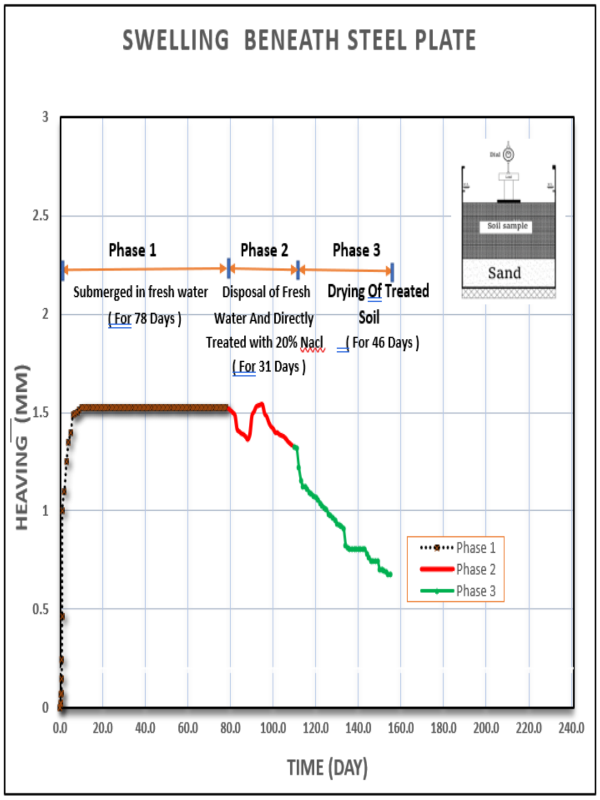

Figure 12: Swelling Heave – Time Relationship beneath Steel Plate for Experimental Model

(Phases 1&2&3)

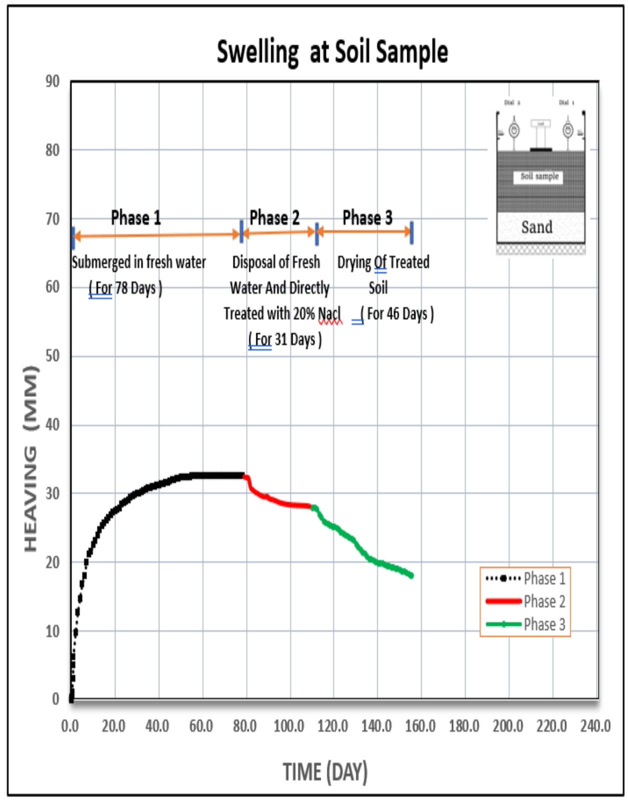

Figure 13: Swelling Heave – Time Relationship at soil sample For Experimental Model

(Phases 1&2&3)

3.1.4 Phase 4: Swelling Heave on treated soil samples re-subjected to fresh water

In this stage soil sample was re-immersed in fresh water for 78 days without continuous inundation, and with allowing of water disposal through 10 mm bottom hole. This stage simulates what can happen if under certain conditions the concentration of salty water diminished or completely vanish. This occurs in field when the level of ground water table increases, or, for example, a defect in a water pipeline causes a stream of fresh water to infiltrate treated soil and reduce the salt concentration. The measured heave with time is plotted beneath steel plate and at the top of soil sample till reach constant values by the end of this phase as shown in **figure 14 and 15**. Swelling heave value was1.33 mm beneath the steel plate, and 79.7 mm at top of soil. compared to reference phase, a reduction of 12.5%, and an increase of 144% for readings at steel plate and top of soil respectively. Results show that immersion again in fresh water led the sample to yield and a great increase in heave to reach about 80 mm at top of soil, which represents 2.5 times the record value at the first stage (32.58 mm), that is in agreement with the findings results by **[8]**.

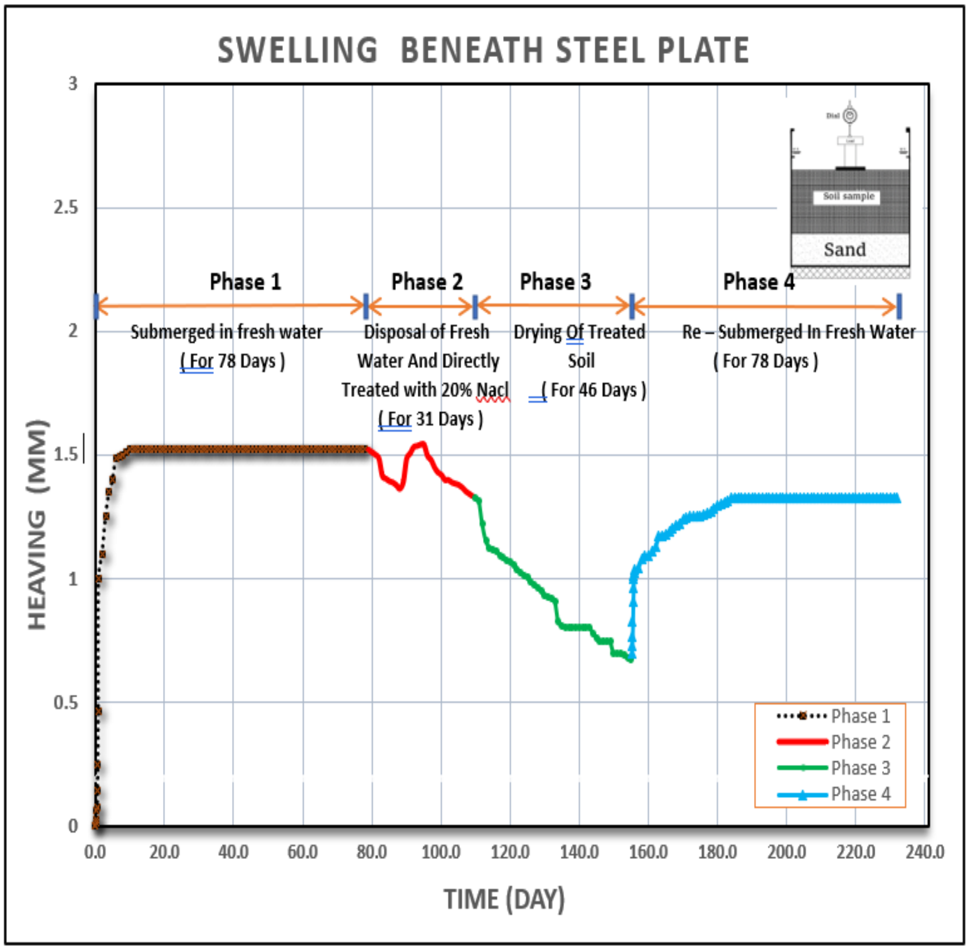

Figure 14: Swelling Heave – Time Relationship beneath Steel Plate

For Experimental Model Phases

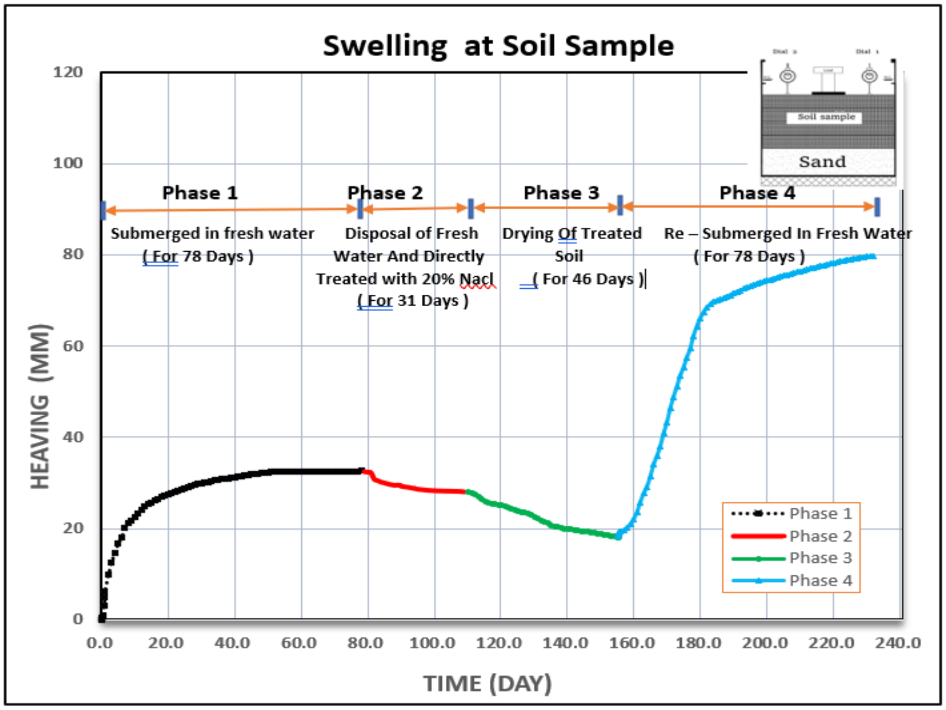

Figure 15: Swelling Heave – Time Relationship at soil sample

For Experimental Model Phases

3.2 Comparison of Swelling Heave Values from Odometer Test and Experimental Model

Table 3 and **figure 16** showed the swelling heave values of Oedometer test compared to results of experimental model. Results showed that recorded swelling heave values of soil sample in Oedometer test represents about four times the recorded values at experimental large-scale model.

Table 3: Heave values from Odometer test in comparison to values obtained from model testing

	Heave in Odometer Test (mm)	**Heave in Model testing (mm) (Beneath the steel plate)**
Original Sample (0% salt concentration)	5.61	1.525
Treated sample (20% salt concentration)	4.33	1.355

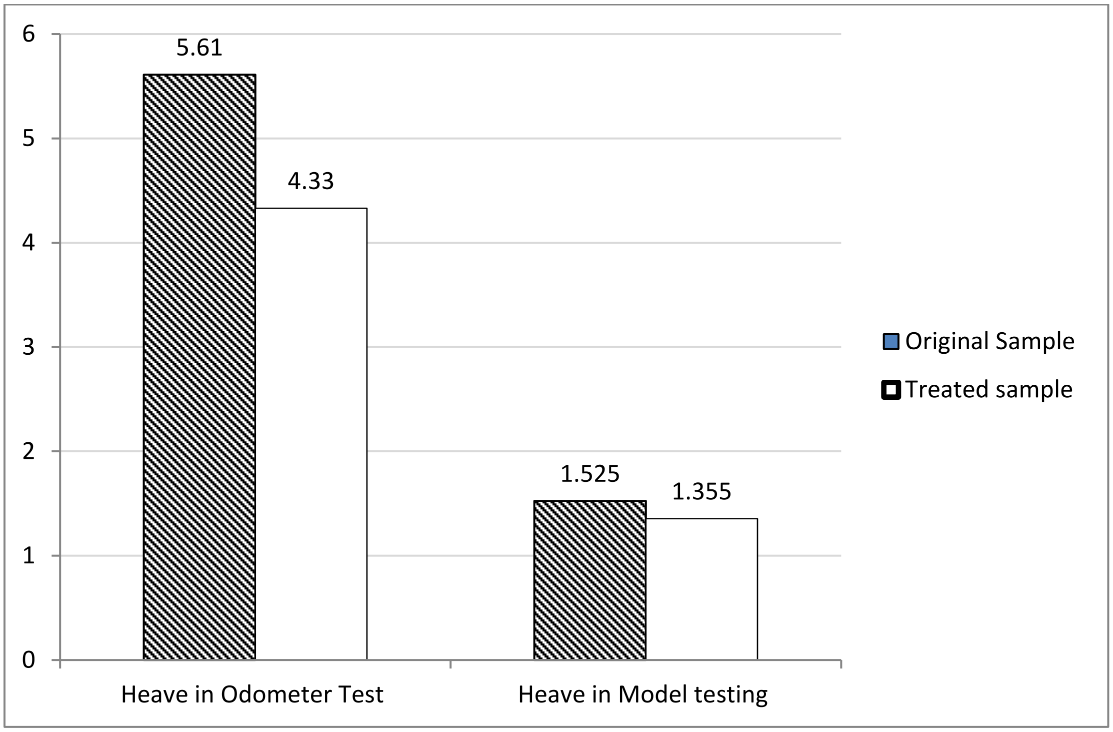

Figure 16: Swelling Heave Values – Bar Chart

3.3 Water Content – Depth Relationship for Model Soil Sample

The distribution of water content through the depth of the model soil sample was investigated throughout the experimental model phases.Test Results showed that water content decreases as the depth increases as shown in **table 4 and figure 17**. Absorbtion water molecules in the diffuse double layer of clay particles reduce the pore space and leading to clogging the water path to the below layers, **[21].**

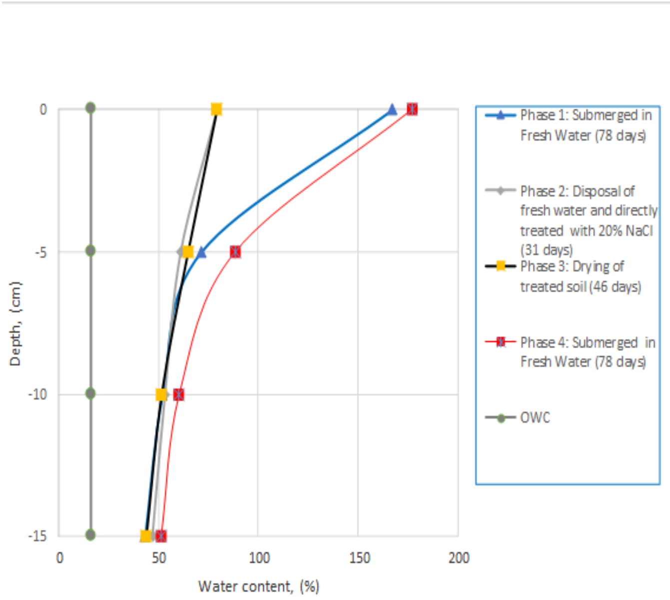

Figure 17: Water Content – Depth Relationship for Experimental Model Soil Sample

Table 4: Water Content-Depth Relationship for model Soil Sample

Depth (mm)	**Water Content (Wc) %**			
	Phase 1 {Ref.) Time 78 days	**Phase 2 Time 31 days**	**Phase 3 Time 46 days**	**Phase 4 Time 78days**
0 mm	166.98	79.13	79.13	177.11
50 mm	71.35	61.12	64.66	88.39
100 mm	51.95	53.34	51.44	60.24
150 mm	43.18	47.11	43.85	51.10

3.4 Effect of Salt Water on Steel Corrosion

It was observed during 77 days of phase (2) and (3), (when salty water is added to the soil sample then treated soil is allowed to dry), that a considerable amount of corrosion appeared in the loading plate. as shown in **figures 18**. This can predict a possible corrosion to happen in the steel bars of the reinforced footings having this treated soil at their foundation level due to chloride attack.

Figure 18: Effect of Salt Water in Experimental Model Steel Footing

4. CONCLUSION

Finally, from the above discussion, the following conclusions can be drawn:

- The swelling heave of untreated soil sample shows an average value of 1.525 mm with an axial free swell of 9.5% beneath the steel plate and 32.58 mm at top of soil with an axial free swell of 16.3 %.
- The recorded swelling heave value of untreated soil sample reached about 75% of the total heave value at the first 10 days.
- The measured swelling heave of treated soil sample shows gradual decrease that reached an average value of 1.355 mm with a reduction of 11% under the steel plate and 28.3 mm at top of soil with a reduction of 13% at top of soil compared to original sample before treatment.
- The measured heave recorded at the end of drying condition of treated soil sample shows a decrease in heave values to reach 0.68 mm at steel plate with a reduction of 55%, while the recorded value at top of soil was decreased to 18.39 mm at top of soil, with a reduction of 43% compared to reference phase.
- When salt concentration decreased with time as soil was re-subjected to fresh water, a great increase in swelling heave was recorded to reach about 80 mm at top of soil, which represents 2.5 times the record value of untreated soil sample (32.58 mm).
- The recorded swelling heave values of soil sample in Oedometer test represents about four times the recorded values at experimental large-scale model.
- Water content decreases with the increase of depth as absorbtion water molecules in the diffuse double layer of clay particles reduces the pore space and leading to clogging the water path to the below layers.
- Salty water in clayey soil causes corrosion in the steel plate of the testing model, and so similar defects are expected to happen in reinforced footings rested on salty treated soil in field.

5. FUTURE STUDIES

Special attention should be paid on expected negative effect of using salt water as a chemical stabilizer on reinforced concrete foundations resting on expansive soil.

6. ACKNOWLEDGEMENTS

The experimental work of this study was carried out at the Soil Mechanics Laboratory of civil Eng. Department, Al-Azhar University, thanks for the laboratory staff and technicians, and also for the help of material lab technicians.

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