Effect of Different Water Types on Expansive Soil Behavior

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Abstract: The main expansive clay soil behavior to be considered is swelling properties and surface heave. Therefore, determination of swelling properties by means of swell percent and estimation of surface heave is very important in the investigation of such soils. In order to obtain the swelling parameters of clayey soils, experimental laboratory tests are carried out. Distilled water is usually used during these experimental tests; however, the soil *in situ* interacts with different types of water. Therefore, the swelling behavior of expansive soils tested with using distilled water would naturally be different from the behavior of expansive soils tested with using different water types. For this reason, the effect of different water types on various properties of expansive clay soil was studied and compared. Four water types were used, distilled water, flat water, treated waste water and sea water. Tests results showed that there are significant effects of different water types on the behavior of expansive soil. The main result of this research was that the anticipated clay swell percentages and heaves for different used types of water were lower than for the distilled water routinely used in the experimental laboratory tests.

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1. Introduction

Expansive soils are clay soils with high shrink-swell potential. The clayey soils have the property to sensitively modify their volume when moisture changes. As moisture increases, the volume of clay soils increase and shrink when moisture reduces [1]. These soils have long been recognized as important problem soils in geotechnical engineering. The swelling increases the rate of deterioration of the buildings causing expensive damages. Numerous reports of expansive soil problems and related damage have been documented in different countries. The focus on this paper is on the behavior of swelling and heave characteristics of clay in presence of distilled water, tap water, treated waste water and sea water. The studies in the professional literature reported that seawater had a strong impact on the engineering behavior of expansive clay soils, especially on the montmorillonitic clay[2,3,4]. According to this study, the influence of fourwater types on swelling, Atterberg's limits, linear shrinkage, free swell index, compaction and unconfined compressive strength was studied for expansive clay soil.

2. Methodology

The methodology comprises of collection of soil and water samples from the desired locations. The distilled water was obtained from Faculty of Agriculture, Sohag university and was used as a control water sample, tap water was obtained from soil mechanics laboratory, treated waste water was obtained from waste treatment station at El-Kola village, Akhmim city, Sohag governorate, Egypt and sea water was obtained from the Red Sea at Safaga city, Red Sea governorate, Egypt.

Fig.1: Location of new Sohag city, Sohag governorate, Egypt.

The soil sample was obtained from new Sohagcity, Sohag governorate, Egypt. The site is located at the south east Sohag city. It lies at latitude 26º 26′ 23.24" and longitude 31º 40′ 20.03″, and 12 km from Sohag city, as shown in Fig.1. The region experience shows that there is a lot of deferential ground movement under structures footings and many structures have been destroyed due to existing of this soil under foundation. Disturbed soil sample was obtained from a test pit at a depth of two meters below ground surface. The collected soil sample and water were subjected to laboratory investigations to find their physical and mechanical properties.

2.1.Soil

The basic properties of the soil sample were determined according to the Egyptian Code[5] and are summarized in Table 1.

Table 1: Properties of expansive clay used in this study

Property	Results
Natural moisture content (%)	6.5
Specific gravity	2.63
% of gravel	0
% of sand	2
% of silt	22
% of clay	76
Liquid limit (%)	70
Plastic limit (%)	43.46
PH	7.95
In-situ density	20.5t/m^3

Table 2: Results of XRD analysis for used expansive clay soil

Oxide	Composition (%)	Mineral	Composition (%)
MgO	1.1503%	Mg	0.9742 %
Al_2O_3	9.6280 %	Al	7.2943
SiO_2	36.6254	Si	25.3006
K_2O	1.0432	K	1.3882
CaO	14.6339	Ca	17.1566
TiO_2	3.2636	Ti	3.3952
MnO	1.0233	Mn	1.4609
Fe_2O_3	32.6323	Fe	43.0300

2.2.Water

The salt species for different water types are found out through laboratory investigations and the results are shown in Table 3.

Table 3: Various salt species present in used water

Salt species	Distilled water (mg/L)	Tap water (mg/L)	Treated waste water (mg/L)	Sea water (mg/L)
TDS	Traces	496	2390	31100
CL		73.5	783	19992
SO_4		176	159	898
HCO_3		287	498	634
CO_3		.0.0	0.0	0.0
PH		7.2	8.2	7.8

3. Experimentalprogram

The experimental study involves studying the effect of different water types, distilled water, tap water, treated waste water and sea water on the various properties of expansive soil namely, swelling, Atterberg limits(liquid and plastic limits), linear shrinkage, compaction and unconfined compression strength. All tests were carried out according to Egyptian code of soil mechanics and foundation design and construction [5,6].

4. Results and discussion

4.1.Effect of water types on vertical swell

The values of vertical swell of tested samples were determined using two devices, large scale circular mold (modified Proctor cylinder with 152mm diameter and 116mm height) as well as a standard one dimensional consolidomiter device (oedometer ring, 63.5 mm diameter and 19.8 height) under no overburden pressure. In order to prepare soil samples at maximum dry density(1.79t/m^3)and optimum moisture content (18.5%) as obtained from modified proctor test, soil sample with weight 5kg was crushed and dried in oven with 105^{0}c for 24 hours and the required amount of distilled water equals to the optimum moisture content was mixed together carefully. The mixed soil was kept in the air- tight container for 24 hours to allow for uniform distribution of moisture. The height of modified proctor cylinder was divided into five layers and the required amount of mixed soil for each layer was weighted and placed in the cylinder and compacted by hammer 4.5kg until reached the required level. This method was repeated for each layer until the cylinder was filled completely. After that, the collar was erected on the cylinder. Filter paper was placed on the top surface of specimen and circular steel plate with 3mm thickness and 150mm diameter with holes 2mm diameter was placed on the filter paper. A dial gauge with sensitivity 0.01mm was fixed to measure the heave of specimen. After that, water was added and the sample was allowed to swell. Readings of swell deformation due to addition of water were taken at time intervals 0.5,1,2,4,8, 16,30,60 minutes and 2,4,8,16,24,48 hours until the heave is become nearly constant. The same procedure was followed for each type of water, tap water, treated waste water and sea water. Also, the same procedure was followed with using one dimensional consolidmeter device. (oedometer ring). Two replicate tests were performed to ensure repeatability of test results. The variations of vertical swell percent [(vertical swell /initial height of specimen)×100%] with time for different water types and using large scale mold and conventional oedometer device are shown in figure 2and figure 3, respectively. From these figures it can be seen that the vertical swell-time curves are represented by rectangular hyperbola which are in a good agreement with that obtained by Dakshanamurthy [7]. Also, it is seen that 400 minutes is enough to reach the ultimate swell in case of using large mold and 200 minutes in case of conventional oedometer device. This means that the time required to reach the maximum heave is a function of tested sample volume. The swell potential was calculated as the ratio of the maximum swell height of the specimendue to adding water to the initial height of the specimen. In case of large scale mold, the swell potential was found to be 32.5%, 22.16%, 19.51% and 15.08% for distilled water, tap water, treated waste water and sea water, respectively. In case of conventional oedometer device, the swell potential was found to be 30.44%, 26.24%, 22.8% and 17.45% for distilled water, tap water, treated waste water and sea water, respectively. This means that there is no significant effect of expansive clay sample volume on the results of swell potential. Also, this emphasizes that the conventional oedometer device is a good tool for swell potential tests.

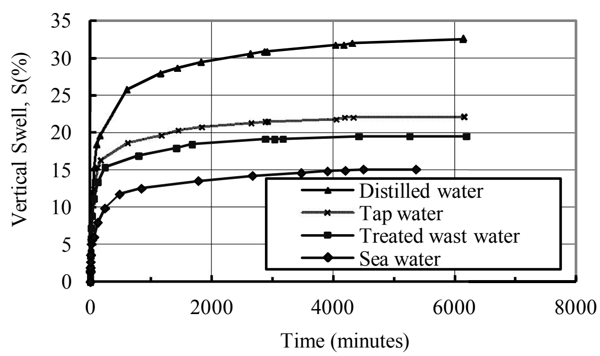

Fig.2: Vertical swell percent versus time for different water types(Using Proctor cylinder)

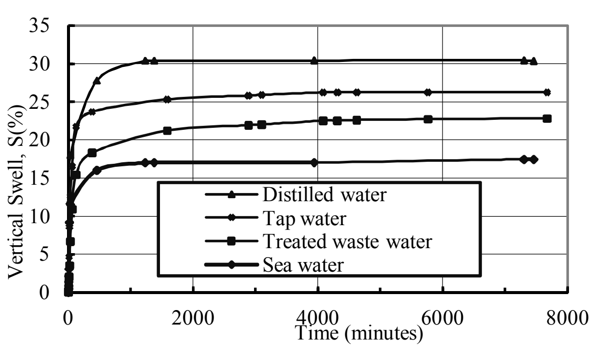

Fig.3:Vertical swell percentversus time for different water types(Using Oedometer ring)

4.1.1 Relationship between time/vertical swell percent and time

The time/vertical swell percent versus time is shown in figures4 and 5 for large scale mold and conventional oedometer device, respectively. From these figures, it can be seen that these relationships are straight lines. The slope of straight-lines can be used to predict maximum swell. Dakshanamurthy [7] proposed a relationship for free swell,

$$\% \text{ Swell} = \frac{t}{m \times t + c} \quad (1)$$

where, m is the slope of straight-line part of time/free swell vs. time, c is a constant and t is the time at which swell is required. For maximum swell percent, time goes to infinity, then:-

$$\% \text{ maximum swell} = \lim_{t\to\infty} \frac{t}{m \times t + c} = \lim_{t\to\infty} \frac{1}{m + c/t} = \frac{1}{m} \quad (2)$$

According to this equation, the reciprocal of the slope of each straight line gives the maximum vertical swell.

Also, it can be concluded that there is a small effect of tested sample volume on the value of the constant, m. Where its value increases slightly with the increase of tested sample volume.

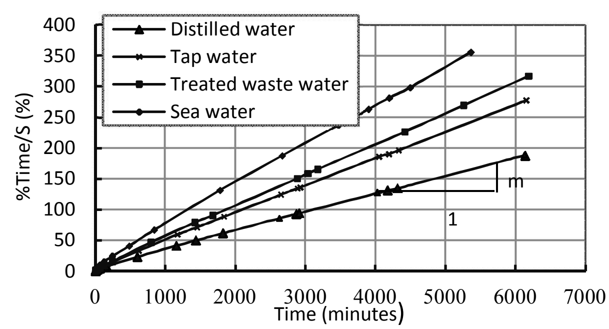

Fig.4: Time/S ratio versus time for different water types (Using Proctor cylinder)

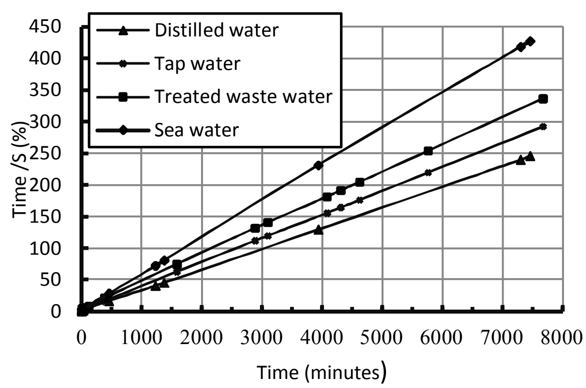

Fig.5: Time/S ratio versustime for different water types (Using Oedometer ring)

4.2.Effect of water types on free swell index

The determination of free swell index which is also known as differential free swell(DFS) of soil that helps to identify the potential of a soil to swell which might need further detailed investigation regarding swelling and swelling pressures under different field conditions. In this method 10 grams of oven-dried soil sample passing through 425 Micron sieve were poured in two graduated cylinders of 100 ml capacity. One cylinder was filled with kerosene and the other with distilled water up to the 100 ml mark. After removal of entrapped air by stirring with glass rod, the soils in both cylinders were allowed to settle. Sufficient time (not less than 24 hours) was allowed for the soil sample to attain equilibrium state of volume.

Free swell index (FSI) or differential free swell (DFS) = $[(V_d - V_k)/V_k] \times 100$ (3)

Where V_d and V_k are the final volumes of soil sample in water and kerosene, respectively.

The degree of expansivity and possible damage to lightly loaded structures may be qualitatively assessed from Table 4. In areas where the soil has high or very high FSI values, conventional shallow foundations may not be adequate.

Table 4: Degree of expansiveness and differential free swell (DFS) (After Mohan and Goel) [8]

Degree of expansivity	FSI(%)
Low	<20
Moderate	20-35
High	35-50
Very high	>50

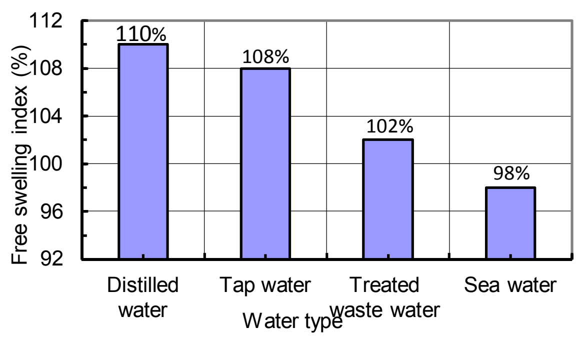

Fig.6: Effect of water types on free swelling index

The influence of water types on the values of free swell index is shown in figure 6. Soil sample with distilled water has FSI value of nearly 110% which shows that the potential of soil for free swell is very high and the soil can be classified as highly expansive. Using other water types, it is observed that there is a considerable reduction in the FSI values. The reduction in the value of FSI when using tap water, treated waste water and sea water is 2%, 8% and 12%, respectively. This means that the maximum reduction in swelling occurs by using sea water.

4.3. Effect of water types on Atterberg's limits

Four expansive clay soil samples each of about 100g was mixed with both distilled water, tap water, treated waste water and sea water separately to form paste [5], with the object of determining the effect of different water types on the Atterberg's limits of the expansive soil. The results show a clear change in the liquid and plastic limits after using different water types in mixing with expansive clay soils. All tests showed that there is a tendency to stiffen and drop in the Atterberg's limits when using treated waste water or sea water, the results are shown in table 5 and figure 7. From this figure, it can be seen that there is a significant change in the liquid and plastic limits due to using different water types. Liquid limit decreases from 70% by using distilled water to 68%, 61% and 55% when using tap water, treated waste water and sea water, respectively. Also, plastic limit decreases from 43.36% when using distilled water to 41.8%, 39.3% and 35.78% when using tap water, treated waste water and sea water, respectively. This result is in a good agreement with that obtained by Mahasneh[3], where he studied the effect of using dead sea water as an improvement for clay soil. He found that the liquid limit decreases from 38% to 28% and plastic limit decreases from 25% to 23%, when using tap and dead sea water, respectively. Also, the result is in an agreement with that obtained by Ivasue[9], where he studied the effect of both distilled water, tap water and sea water on the liquid limit and found that the liquid limit is 62.14%, 62.061% and 58.33% when using distilled water, tap water and sea water, respectively. Otoko[4] found that the liquid limit equals to39% and 29% when using tap water, Atlantic Ocean salty water, respectively. Arumairaj[2], found that the liquid limit decreased from 56.9% to 37.8% when using tap water and sea water, respectively. Also, the plastic limit decreased from 24.03% to 8.85% when using tap water and sea water, respectively. He explained the reasons for this as follow:-

When sea water is added to the clay soil, the free ions such as Al^{3+}, Na^{+}, Mg^{2+} and K^{+} present in the sea water replace the cations of the hydrous layer surrounding the clay particles and reduce the net electrical charge. This allows the sheets to come closer forming flocs. As clay particles flocculates, transforms natural plate like clays particles into needle like interlocking metalline structures, making the clay soils drier and less susceptible to water content changes. The flocs behave as silt particles which is less plastic. That is why a reduction in plastic limit is occurred.

Table 5: Effect of water types on Atterberg's limits

Atterberg's limits	Distilled water	Tap water	Treated waste water	Sea water
L.L (%)	70	68	61	55
P.L (%)	43.46	41.8	39.3	35.78
P.I (%)	26.54	26.2	21.7	19.22

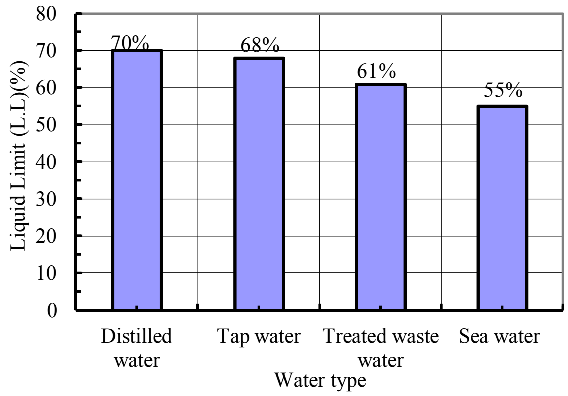

Fig.7: Effect of water types on liquid limit

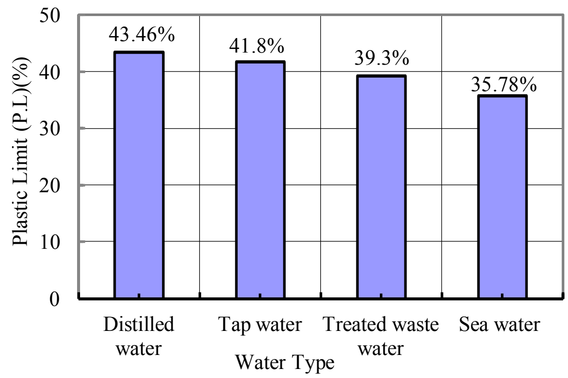

Fig.8: Effect of water types on plastic limit

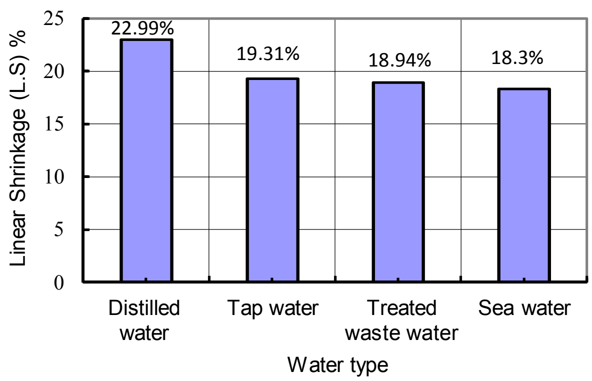

Fig.9: Effect of water types on linear shrinkage

4.4.Effect of water types on linear shrinkage

Fourexpansive clay soil samples each of about 150gm weremixed with different water types, distilled water, tap water, treated waste water and sea water. The amount of water equals to the liquid limit was weighted. The soil and water for each sample were thoroughly mixed together and the soil paste was put in the linear shrinkage mold. The test was carried out according to the Egyptian Code, [5]. The result of the tests are shown in figure 9. From this figure, it can be seen that the maximum and minimum linear shrinkage were obtained when using distilled water and sea water, respectively.

4.5.Effect of water types on modified Proctor compaction test

Modified proctor tests were carried out according to Egyptian Code[5]. Four soil samples with weight 5kg for each sample were prepared. They mixed with different amount of water and compacted into modified proctor cylinder. The moisture content versus the dry density was plotted as shown in figure 10. The maximum dry density and the optimum moisture content was determined and tabulated in table 6. From this table it can be seen that the maximum dry density for studied clay soil was found to be 1.81, 1.79, 1.68and 1.63t/m^{3}at optimum moisture content equals to 14.8%, 18.5%,11.8% and 11.5% for using distilled water, tap water, treated waste water and sea water, respectively. This means that there is a significant decrease in both maximum dry density and optimum moisture content when using treated waste water or sea water with clay soil. This result is in a good agreement with that obtained by Mahasneh[3], where he found that by using dead sea water with clay the maximum dry density decreased from 2.04t/m^3 to 1.75t/m^3 and optimum moisture content decreased from 20.8% to 11%. Also, Arumairaj[2] found that the maximum dry density according to standard Proctor test was equal to 1.83 and 1.74 t/m^3 and optimum moisture content14.25% and 16.5% when using tap water and sea water, respectively. The decrease in the maximum dry density could be obtained by the existence of repulsive force between the salts molecules and the clay intermolecular structures causing an increase in the inter molecular distances and an increase in the void ratio [1,10]. In addition, some of the salt ions have attracted some of the clay particles, which leads to forming coagulation phenomenon that affects the fragility of the clay compaction test,[12,13].

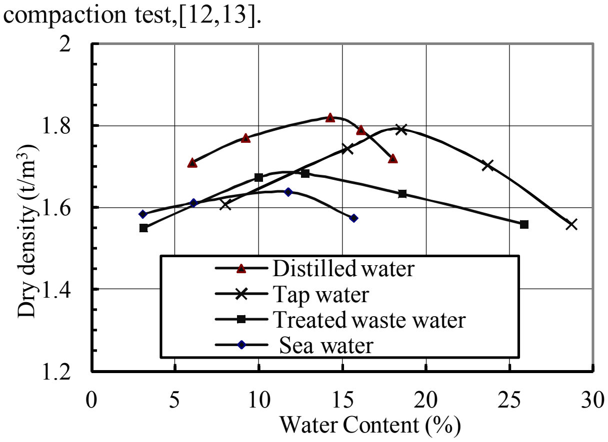

Fig.10: Compaction curves for expansive clayey soil using different water types

Table 6: Results of modified Proctor Tests

Water Type	Maximum dry density (γdmax) (t/m^3)	Optimum moisture content (OMC) (%)
Distilled water	1.81	14.8
Tap water	1.79	18.5
Treated waste water	1.68	11. 8
Sea water	1.63	11.5

4.6. Effect of water types on unconfined compressive strength

The unconfined compression tests were carried out on remolded soil samples compacted to maximum dry density and optimum moisture content according to the modified Proctor test. They are molded to cylindrical shape of dimensions 76.0 mm height and 38 mm diameter. The results obtained are shown in figure 11. From this figure, it can be seen that the unconfined compressive strength is remained almost the same for all water types, this can be due to the time is not enough for reaction of water with expansive clay soil, where all samples were left only one day to allow uniform distribution of moisture in specimen. This is because of the absence of very small pozzalonic reaction. The pozzolonic reaction usually occurs in lime stabilization due to presence of calcium and is responsible for the strength improvement in that case. Sea water contains very meager amount of Ca^{2+} which is insufficient for the pozzolonic reaction to take place,[2].

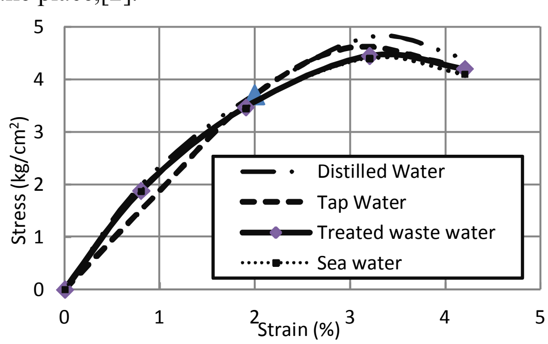

Fig. 11: Results of unconfined compressive strength for expansive clay sample mixed with different water types.

5. Conclusion

The following conclusions can be drawn from the results of this study:-

1) Addition of sea water to expansive soil has a great improvement in its swelling potential, Atterberg limits, linear shrinkage, compaction characteristics and unconfined compressive strength. This improvement is better with using sea water rather than using the other types of water in laboratory tests.

2) Sea water could be a great stabilizing agent particularly in such cases where the constructions are located along the cost of Red Sea. For sites that are located away from such type of sea water, treated waste water can be used as alternative for sea water.

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