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FULL LENGTH ARTICLE

Effect of seawater on consistency, infiltration rate and swelling characteristics of montmorillonite clay

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Abstract This paper presents the results of an experimental investigation performed to quantify the effect of mixing clayey soils with saltwater on consistency and swelling characteristics of clays. Massive natural clay deposits and compacted clay backfills either exist or are used in certain important and sensitive applications such as dams, liners, barriers and buffers in waste disposal facilities. In many cases, the clay deposits in these applications are subjected to saltwater. However, in standard laboratory classification tests, distilled or potable water are usually used in mixing test samples. This may lead to faulty interpretation of the actual in-situ consistency and volume change behaviors. In this research, an attempt is made to quantify the changes in consistency and swelling of clay soils from various locations around the Nile valley and possessing a wide range of consistency, when mixed with natural seawater with different salt concentrations. The results showed that the increase of the salt concentration of the mixing water may result in major decrease in the liquid limit and swelling characteristics of high plasticity montmorillonite clays. The reduction in the swelling of the clay soils is also proportional to the rate of saltwater infiltration. In an attempt to correlate the swelling of clays to the rate of water infiltration, a new simplified laboratory apparatus is proposed where swelling and infiltration are measured in one simple test "the swelling infiltrometer".

Introduction

Swelling soil causes major geotechnical problems all over the world. Swelling soil deposits are found mainly in arid and semi arid areas. The regions around the Nile valley in Upper Egypt contains a great extent of swelling soil that contains montmorillonite or both montmorillonite and kaolinite minerals. Massive natural clay deposits and compacted clay backfills either exist or are used in certain important and sensitive applications such as dams, liners, barriers and buffers in waste

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disposal facilities. In many cases, the clay deposits in these applications are subjected to saltwater. However, in standard laboratory classification tests, distilled or potable water are usually used in mixing test samples. This may lead to faulty interpretation of the actual in-situ consistency and volume change behaviors Ajalloeian et al. [1].

Di Maio [2], Kaya and Fang [3], and Ören and Kaya [4] have published studies on the variations in behavior of clayey soils upon mixing with fluids other than distilled water. These studies reported saltwater causes major changes in the swelling characteristics of clays. Di Maio [2] concluded that the seawater effect on compressibility characteristics of clays is more pronounced for bentonites. Shirazi et al. [5] concluded from an experimental study, that the liquid limit of bentonite remarkably decreased from 497% to 112% when the mixing water changed from distilled water to 0.5 M of NaCl solution. Then it gradually decreases upon the NaCl concentration increasing from 0.5 to 4 M while plastic limit slightly increased upon the increasing salt concentration. Don et al. [6] reported major ground settlement upon intrusion of saline water Shiroishi lowland plain, southwestern Kyushu Island of Japan. Yukselen-Aksoy et al. [7] showed that seawater effect becomes more significant when liquid limit is greater than 110%. Beyond this limit, the individual soil index values decrease linearly on a logarithmic plot.

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 seawater environment.

Soil samples

In this study, several swelling clay samples, of different mineralogy, were mixed with distilled water and natural salty water from different sources. The soil samples used were collected from three different locations in Egypt as follows:

Soil Sample A	Toshka Shale (Toshka area in Upper Egypt).
Soil Sample B	Fayioum Clay (Baher Elgaraq in Middle Egypt).
Soil Sample C	Borg El-Arab factory Bentonite (industrialized).

The mineralogy of the three tested clays was analyzed using X-ray Diffraction technique to determine the percentage and composition of the clay minerals. The results are presented in Table 1.

Table 2 shows the chemical analysis of the soil–distilled-water-extract (D.W.) where soil C (Commercial Bentonite) has the highest total dissolved salts, while soil A (Toshka Shale) has the lowest total dissolved salts.

Mixing water

The mixing water used is distilled water (D.W.), soft clay area water (S.C.W.), Mediterranean Sea water (M.S.W) and Qarun lake water (Q.L.W). It is also clear from Table 3 that the total dissolved salts of the S.C.W. are the highest, followed by the M.S.W., followed by the Q.L.W.

The three soil samples were all mixed with the three saltwater samples. The chemical analyses of the soil saltwater extract of each case are presented in Table 4. Table 4 shows that mixing Commercial Bentonite (soil type C) with any of the saltwater types increases the total dissolved salts (TDS) in the water extract. The table also shows that soil type C mixed with S.C.W. results in TDS higher than that of soil type C after mixing it with M.S.W. and higher than that when mixed with Q.L.W.

Consistency limits

Standard consistency limit tests were performed on the clay samples after mixing with different water samples. The soil

Table 1 XRD results of the three clay samples.

	Soil A (Toshka Shale)	Soil B (Fayioum Clay)	Soil C (Commercial Bentonite)
Montmorillonite	66	72	95
Kaolinite	30	15	1
Illite	1	4	1

Table 2 Total dissolved salts in soil distilled-water-extract in (ppm).

Soil and mixing water	PH	T.D.S	Cl	$Ca(Hco_3)^2$	SO_3	Ca	Mg
Toshka Shale (A) and D.W.	7.4	2050	1250	221	250	45	15
Fayioum Clay (B) and D.W.	7.4	4166	417	300	1540	120	1256
C. Bentonite (C) and D.W.	8.5	8120	2077	2408	140	8	8

Table 3 Dissolved salts in mixing water (ppm).

Saltwater	PH	T.D.S	Cl	$Ca(Hco_3)^2$	SO_3	Ca	Mg
S.C.W.	8.5	106,852	85,492	677	5200	300	3370
M.S.W.	8.4	37,056	19,452	210	4979	64	916
Q.L.W.	8.4	29,050	9691	331	6700	120	446