Treatment of Expansive Soils: A Laboratory Study

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ABSTRACT

Excessive heave and settlements that are associated with the volume changes of expansive soils can cause considerable distress to civil engineering structures. Even structures such as highway embankments and roadways that are generally insensitive to small vertical movements are subject to high maintenance costs if constructed on expansive soils. It has been reported that a small amount of settlement or heave over a short length of road is intolerable for high-speed highways (1-5). A laboratory investigation to reduce the swelling properties of the expansive soils found in Nasr City, a satellite community of Cairo, Egypt, is reported in this paper. Three techniques to reduce the amount of swelling and the associated swelling pressures were studied: (a) complete saturation of the expansive soil specimens after they had been compacted at various initial water contents, (b) mixing of the expansive soil with various proportions of sand to study the effect of grain size distribution on the swelling potential, and (c) use of various salt concentrations of the pore fluid to show its effectiveness in reducing the overall swelling property. All three techniques were found to be effective in reducing the swelling behavior of soils to various degrees as discussed in this paper.

Volume changes of clayey soils due to change in their water content represent one of the most serious problems in the field of foundation engineering because of unpredictable upward movement of structures that are founded on such soils. Many researchers investigated the effect of initial water content on the amount of swelling and swelling pressures (6-11). They noticed that swelling and swelling pressures were inversely proportional to the initial water content for disturbed and undisturbed specimens of clay. They also observed that there was a certain initial water content for a particular expansive soil at which no swelling occurred.

Other investigators (9,12-14) showed that the swelling phenomenon was dependent, to a certain degree, on the salt concentration of the pore fluid. Their results indicated that the percentage of swelling was inversely proportional to the concentration of salt in the solution. Grim found that lime acted as a stabilizing agent and greatly improved the soil subgrade containing high percentages of expansive clays (15). In addition, this also reduced the plasticity index and increased the bearing capacity of these soils.

The purpose of this study was to investigate in the laboratory three different techniques that can be used to reduce the swelling behavior of the soil found in Nasr City, a satellite community of Cairo, Egypt. The first technique consisted of completely saturating the expansive soil specimens after they had been compacted at various initial water contents. In the second technique the expansive soil was mixed with various amounts of sand. In the third technique various salt concentrations of the pore fluid were used.

TEST APPARATUS AND TECHNIQUE

The test apparatus and the technique that were used throughout this study are described in detail by Mowafy and thus are only summarized here (16).

The mold of the oedometer used in the swelling tests had an internal diameter of 63 mm and a height of 25 mm. After preparation of the specimen, the mold containing the soil was put into the loading apparatus. An initial load was applied and the reading of the dial gauge was recorded. After a normal pressure application, the specimen was submerged in distilled water. The dial readings were recorded at intervals of 1/4, 1/2, 1, 2, 4, 8, 24, 48, 72, and 96 hr. The test was continued until the deformation of the specimen ceased.

Swelling pressure is defined as the external pressure required to consolidate a preswelled sample to its initial void ratio. To decrease the frictional stresses between the specimen and the oedometer ring, either a filter paper or a rubber membrane was placed around the wall of the compaction mold. The results of this investigation have been discussed elsewhere in this Record. It is therefore recommended that to investigate the swelling potential of soils in an oedometer, side friction effects should be minimized.

To study the effect of initial water and sand contents on swelling percent and swelling pressure, the clay was mixed with the following percentages of sand: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 percent. For each subgroup, four specimens each of initial water contents 5, 10, 15, and 20 percent were tested.

To study the effect of salt concentration on the swelling properties, the soil was permitted to swell by wetting it with different concentrations (20, 30 and 60 g/L) of a sodium chloride solution.

SOIL PROPERTIES

Physical Properties

The natural moisture content of the soil was 18.9 percent; the specific gravity was 2.7; the unit weight was 16.8 KN/m^3; and the dry unit weight was 14.5 KN/m^3. The soil had a liquid limit of 86 percent, a plastic limit of 43 percent, and a plasticity index of 43 percent. It also had a free swell of 90 percent. A grain-size distribution curve of

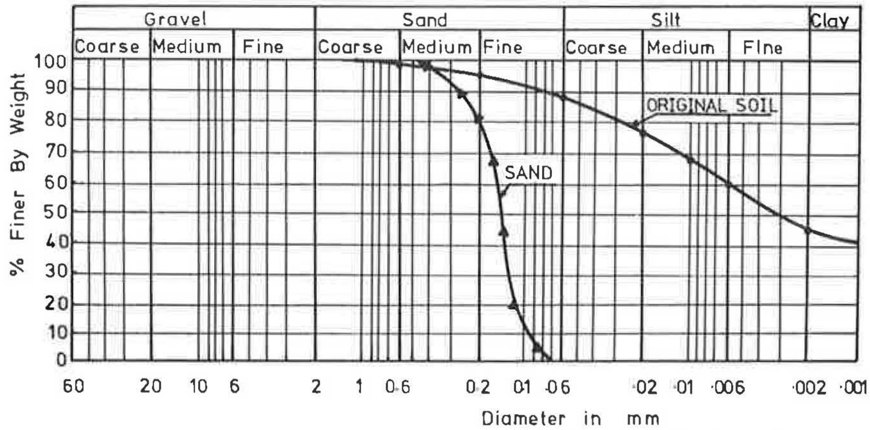

FIGURE 1 Grain size distribution curve for original soil and sand used in the testing program.

TABLE 1 Summary of Soil Properties

Physical Property	Value
Depth of sampling	3.00 m
Natural moisture content (w_n), %	18.9
Specific gravity (G_s)	2.7
Unit weight (γ)	16.8 KN/m^3
Voids ratio (e)	0.61
Liquid limit (w_L), %	86
Plastic limit (w_p), %	43
Plasticity index (PI), %	43
Shrinkage limit (w_s), %	14
Sand percentage	
Coarse (2 - 600 micron), %	1
Medium (600 - 212 micron), %	3
Fine (212 – 75 micron), %	6
Silt percentage (% > 2 micron), %	44
Clay percentage (% < 2 micron), %	46
Liquid limit of particles < 2 micron, %	128
Plastic limit of particles < 2 micron, %	50
Plasticity index of particles < 2 micron, %	78
Activity of clay mineral (A)	0.93
Dry unit weight (γ_d), %	14.5 KN/m^3
Free swell, %	90

the original soil is shown in Figure 1. Table 1 gives a summary of the soil properties.

Mineralogical Composition

The mineralogical composition of the tested soil was found by x-ray, and the results are given in Table 2.

TABLE 2 Mineralogical Composition

Mineral	Percentage
Percentages of non-clay minerals	
Alpha quartz (α si 0_2)	13.6
Orthoclase (KAl si 30_8)	32.6
Calcite [ca Mg $(co_3)_2$]	11.3
Dolomite [ca Mg $(co_3)_2$]	4.7
Anhydrite (ca so_4)	7.9
Geothite [Fe (oH)]	10.2
Ilmenite (Fe Tio_3)	2.7
Magnetite (Fe_3 0_4)	6.8
Alpha manganese (α Mn)	3.4
Beta manganese (β Mn)	6.6
Clay minerals	
Ca(montmorillonite, vermiculite) mixed layer (46%)	
Montmorillonite: $[(0H)_4\ Al_4\ Si_8\ 0_{20}\ nH_{20}]$	
Vermiculite: $[(0H)_4(Mg{\cdot}Ca)\ (Si_{8-X}\ Al_X)\ (Mg{\cdot}Fe_X\ 0_{20}\ Y\ H_20)]$	
where X = 1.0 to 1.1 and Y = 8	

The grain-size distribution curve for the sand that was used in mixing with the clay is also shown in Figure 1. The uniformity coefficient for the sand was 1.7 and its specific gravity was found to be 2.71.

PRESENTATION AND ANALYSIS OF RESULTS

The most pertinent information that resulted from this investigation is shown in Figures 2-10.

EFFECT OF INITIAL WATER CONTENT ON SWELLING VALUES

Figures 2-5 show the relationship between the swelling percent and the clay content at initial water

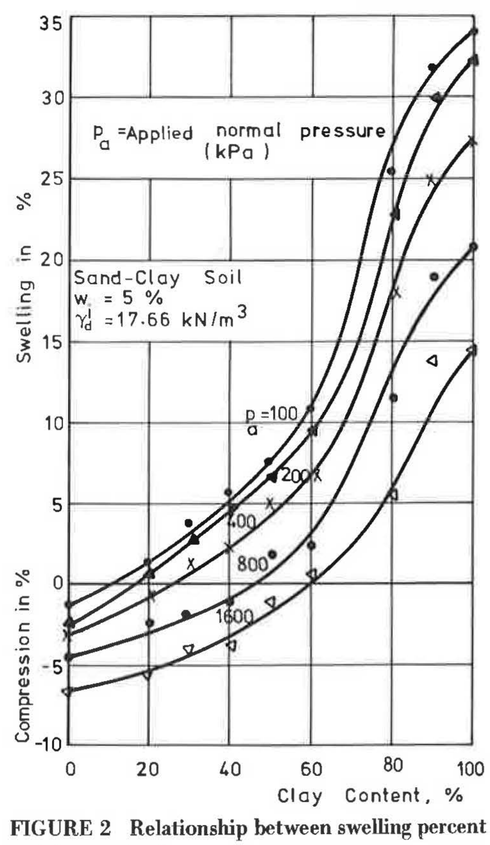

FIGURE 2 Relationship between swelling percent and clay content.

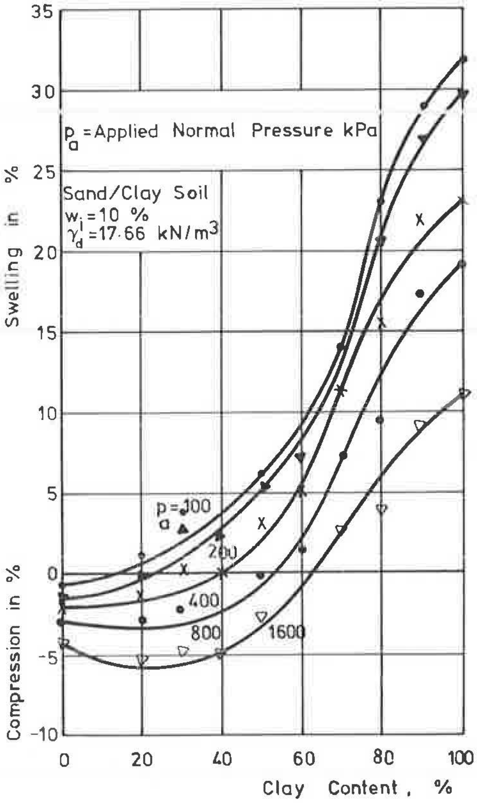

FIGURE 3 Relationship between swelling percent and clay content.

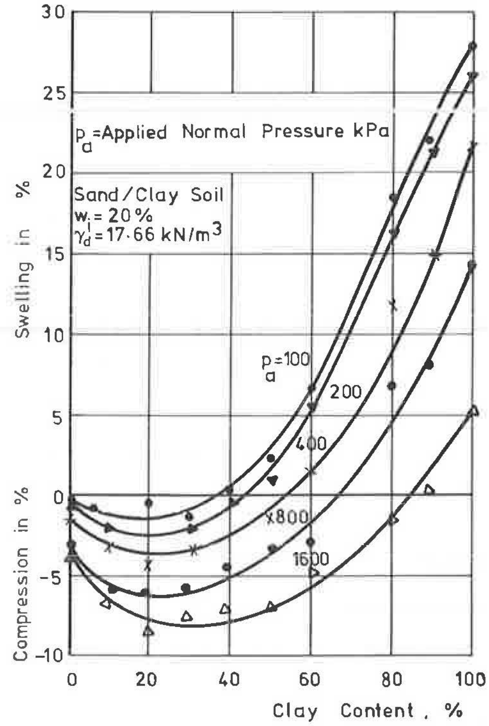

FIGURE 5 Relationship between swelling percent and clay content.

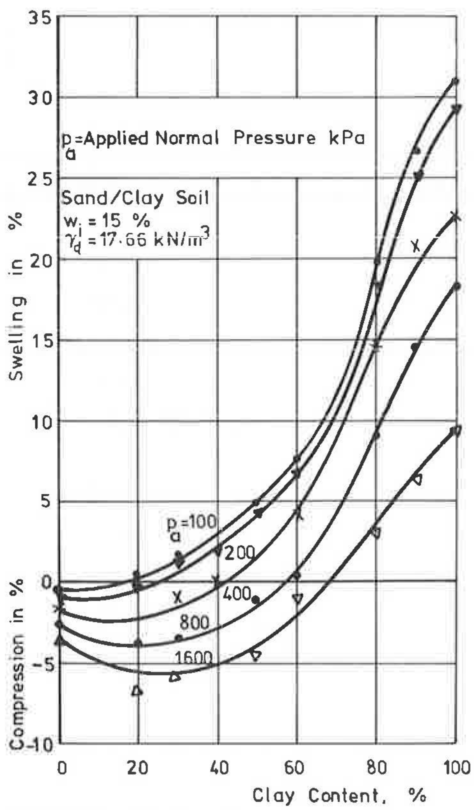

FIGURE 4 Relationship between swelling percent and clay content.

contents of 5, 10, 15, and 20 percent, respectively. The normal pressure varied from 100 to 1600 kPa. From the four figures it can be observed that the amount of swell decreased with increasing initial water content. For a low initial normal pressure of 100 kPa and a clay content of 100 percent, the swelling percent decreased by 15 percent if the initial water content was increased from 5 to 20 percent. For a high normal pressure of 1600 kPa, the amount of swell decreased by 64 percent as the initial water content was increased from 5 to 20 percent for 100 percent clay content.

Figure 6 shows the amount of swelling pressure to clay content. Curves for 5, 10, 15, and 20 percent initial water content are given. The amount of swelling pressure is clearly influenced by the initial water content of the soil. For example, the swelling pressure decreased by 50 percent when the initial water content was increased from 5 to 20 percent at a clay content of 100 percent.

EFFECT OF THE AMOUNT OF SAND ON SWELLING PROPERTIES

The effect of the amount of sand on swelling percent and swelling pressure is shown in Figures 2-6. From these figures the following observations can be made:

1. Clay content has a great influence on the magnitude of swell (swelling percent) of the soil.
2. For a given initial water content and normal pressure, there is a "critical" clay content at which the amount of swell is zero. Below that critical value the soil will compress, and above that the soil is susceptible to swelling.
3. Swelling potential is increased considerably as the clay content is increased. For example, at an initial water content of 5 percent, a normal pressure of 100 kPa, and a clay content of 20 percent,

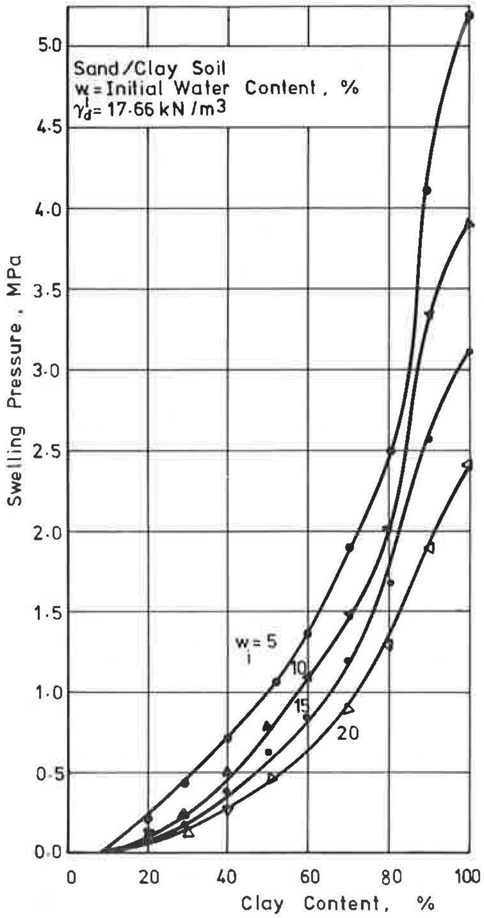

FIGURE 6 Relationship between swelling percent and clay content.

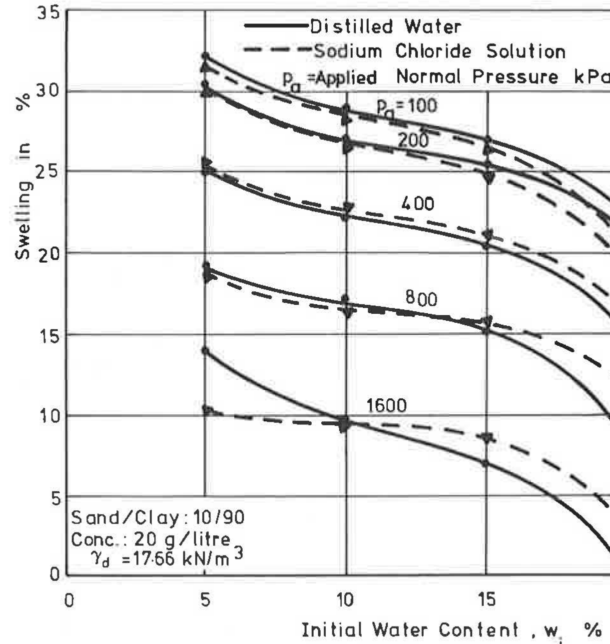

FIGURE 7 Relationship between swelling percent and initial water content.

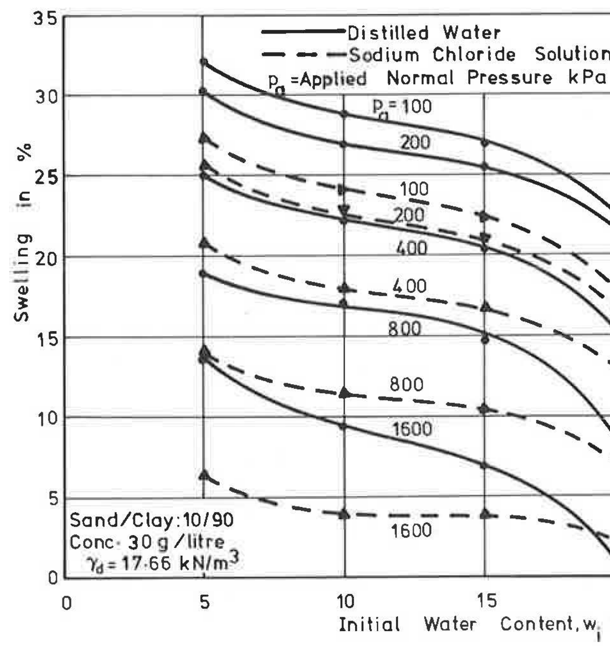

FIGURE 8 Relationship between swelling percent and initial water content.

the amount of swell is 1.2 percent. As the clay content is increased to 60 percent, keeping all other conditions the same, the amount of swell increases to 11.5 percent.

4. Swelling pressure increases dramatically as the clay content is increased at the same initial water content (Figure 6). At a clay content of 10 percent (critical clay content), the swelling pressure is zero regardless of the initial water content. As the clay content is increased to 60 percent, the swelling pressure increases to 1.4 MPa for 5 percent initial water content and to 52 MPa at a clay content of 100 percent.

5. A higher proportion of sand content, and corresponding lower clay content, will reduce the tendency of the clay to swell due to the larger capillary canals in the soil pores and the corresponding reduction in soil suction.

6. The addition of sand to the swell-susceptible clay increased the rate of deformation considerably due to the corresponding increase of soil permeability.

EFFECT OF SALT CONCENTRATION IN THE PORE FLUID ON SWELLING BEHAVIOR

The effect of salt concentration of pore fluid on swelling percent and swelling pressure are shown in Figures 7-10. Figures 7-9 show the relationship between the swelling percent and the initial water content. All specimens had a sand-to-clay ratio of 10 to 90. The normal pressures varied from 100 to 1600 kPa. The salt concentration varied from 20 to 60 g/L. A study of these figures reveals that as the concentration of sodium chloride increases, the swelling percent decreases for the same conditions of initial water content, initial normal pressure, and clay content. At a concentration of 20 g/L, for a high applied initial normal pressure and a high initial water content, the swelling percent due to wetting by sodium chloride solution is greater than that due to wetting by distilled water. For concentrations greater than 20 g/L, the swelling per-

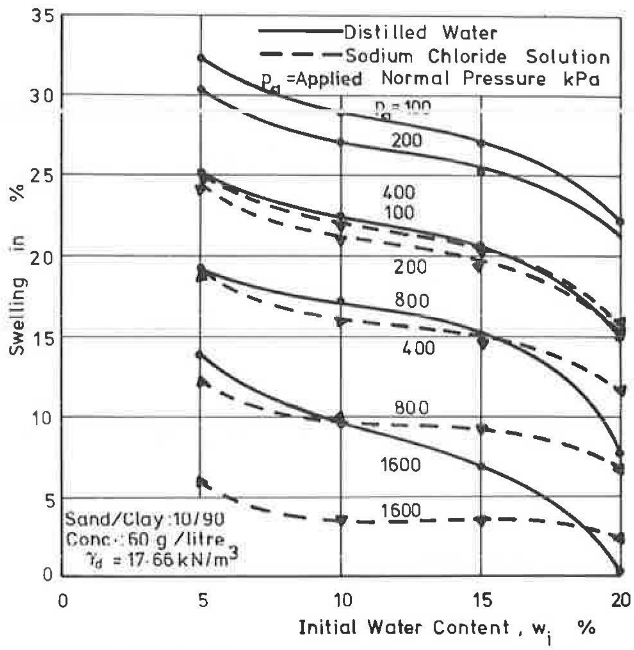

FIGURE 9 Relationship between swelling percent and initial water content.

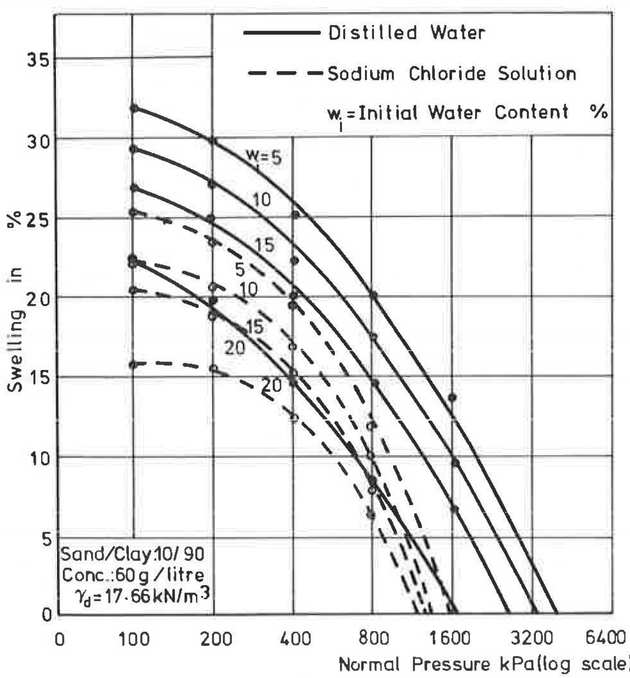

FIGURE 10 Relationship between swelling percent and normal pressure.

cent for sodium chloride solution is lower than the value obtained with distilled water. However, the increase in the swelling percent decreases with the increase of the initial water content.

Figure 10 shows the relationship between the initial normal pressure and the swelling percent. All specimens had a sand-to-clay ratio of 10 to 90 by weight. Curves for 5, 10, 15, and 20 percent initial water contents are given. As shown in Figure 10, when a sodium chloride solution is used, the swelling pressure is lower than the corresponding value for distilled water. Such a decrease in swelling pressure is more pronounced at higher concentrations of sodium chloride. As the initial water content is increased, the addition of sodium chloride has a minor effect on reducing the swelling properties of the soil. This phenomenon can be explained as follows:

1. The charges on the surface of the particles of the clay play an important role in the stability of colloids that require the presence of small concentrations of electrolytes. The addition of sodium chloride produces a large amount of electrolytes that precipitate in the colloids with the effect of rapidly flocculating the colloids (17). The increase in the size of particles leads to a decrease in the total surface area and hence, the amount of absorbed water will decrease and in turn the swelling will diminish.
2. The sodium chloride in solution is ionized into Na^+ and Cl^-. Cation exchange occurs between the Na^+ and Ca^{++} ions of the calcium montmorillonite, while the chloride ions are absorbed between the sheets of the montmorillonite to form calcium chloride between the sheets. The calcium chloride prevents water from entering and thus decreases the swelling ability of the montmorillonite.
3. Owing to the high osmotic pressure of the sodium chloride solution, dehydration of soil particles occurs and thereby decreases the amount of retained water and the swelling potential.

CONCLUSIONS

The investigation of swelling properties of Nasr City soils warrants the following conclusions:

1. All of the three techniques, that is, variation of initial water content, increasing the proportion of sand content, and using different salt concentrations of the pore fluid, were found to be effective in reducing the swelling behavior of expansive soil to various degrees.
2. The amount of swell and swelling pressure increases with the amount of clay content of the soil.
3. An increase in initial water content will cause a reduction in the magnitude of swell and in the swelling pressure. Therefore, in order to reduce both these properties, compaction of these soils in the field should occur at high moisture contents.
4. A reduction of swelling potential can also be achieved by decreasing the clay content. This can be accomplished in the field by mixing coarse fractions of granular material with swell-susceptible soils.
5. In general, the presence of sodium chloride in the pore fluid caused a decrease in swelling and swelling pressure. Therefore, the injection of a salt solution into swell-susceptible soils could be a possible method of overcoming this problem, if the soil permeability is sufficiently high.
6. It may be more convenient to use more than one technique in order to reduce the swelling potential of the expansive soil.

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