

Expansive Behavior of Subgrade Soils in Arid Areas

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Crushed cemented sand from arid areas has been used as a road base material in highway construction in Kuwait owing to the lack of good granular soils. Following several problems of pavement heave and cracking and of ground floor slabs placed on those soils, an extensive laboratory testing program was carried out on samples from six sites to examine the causes of those problems and to focus on suitable remedial measures. The program consisted of classification tests, chemical and mineralogical analysis, swelling tests in the consolidation apparatus, and CBR tests. The tests were performed on crushed or remolded soils and on the fines and coarse fractions separately. Test results indicated that several environmental factors have contributed to the high swell potential: the low natural moisture content, large placement density, soil disturbance owing to the breaking of cementation bonds, and the presence of large amounts of fines in the soil matrix. Swelling increased sharply as the percent of fines exceeded 35 percent, although the clay minerals were rather scarce in the fines and the plasticity index was below 20 for all soils. Hydrated lime was found to be effective as an additive in reducing the swelling potential of the local soils and in increasing their bearing capacity.

With the rapid development of arid areas in recent years, many construction projects have been completed including major highways, housing projects, and office buildings. Following completion of those projects, several problems associated with the collapse of the local surface soils of Kuwait (1,2) or the swelling of the underlying cemented sands have been observed. Cracking and damage occurred in highway pavements at some locations owing to the swelling of subgrade soils. Moreover, heave and cracking of ground floor slabs of light buildings resting on compacted soils was observed. Because subgrade soils at many locations consist of calcareous silty sand with varying degrees of cementation (3), which is crushed prior to placement and compaction, it is surprising to observe swelling of those basically granular soils. Swelling of clays of high plasticity containing expansive clay minerals is known and has been examined in detail over the past 25 years. However, those soils differ in properties and basic characteristics from the subgrade soils in arid areas.

To examine the causes of swelling of those soils in Kuwait, an extensive laboratory testing program was performed over the past 2 years on samples recovered from six sites. The program consisted of tests for classification and physical properties, chemical and mineralogical composition, and oedometer and CBR tests. Several important environmental-related

factors have been investigated, including the very low natural moisture content of the subgrade soils; the effect of initial cementation and subsequent soil disturbance resulting from breaking cementation bonds during excavation, placement, and compaction; and the influence of the amount and characteristics of the fines. The potential use of hydrated lime as a possible treatment technique has been examined by laboratory testing.

This paper presents and analyzes the results of this laboratory testing program to assess the relative importance of the various factors contributing to the observed expansive behavior of cemented sands when used as a base material or foundation course in Kuwait. Practical remedial measures are also discussed in light of test results and previous work on similar soils.

SOIL PROPERTIES AT THE TEST SITES

The soil profile at the sampling sites consists of a thin layer of wind-blown fine dune sand to a depth of up to 0.5 m, underlain by an extensive cemented calcareous sand deposit that extends to a great depth over limestone bedrock. The excess of evaporation over rainfall and the hot temperatures over the summer months lead to the precipitation of carbonates and other salts in the soil matrix and the formation of crusts of cemented sands, known locally as "gatch." Blocks of cemented sand were recovered from existing excavation pits at a depth of 1 m below ground level. The samples for classification tests were prepared by breaking the block samples by mortaring with a rubber pestle. Atterberg limit tests were conducted on fractions passing the No. 40 U.S. sieve. A summary of the physical properties and classification test results is given in Table 1 and reveals that after crushing and breaking the cementation bonds the soils can be classified as silty sand or as clayey sand mixtures. The amount of fines varies within a large range from 17.7 to 58.4 percent, with the clay size nearly 50 percent of the fines. All the soils tested had plasticity indices less than 20. The activity of the soil given in Table 1 is defined by

$$\text{activity} = A = \frac{PI}{C} \quad (1)$$

where PI is the Plasticity Index and C is the percentage of clay (particles < 0.002 mm) by weight.

The compaction characteristics of the test soils were determined by using the Modified Proctor test. The corresponding optimum moisture content varied within a narrow range of 8 to 12 percent.

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TABLE 1 PHYSICAL PROPERTIES OF THE TEST SOILS

Property	Mirgab A	Dasmah B	Mishrif C	Shuwaikh D	Jabriya E	Andalus F
Sand %	81.2	66.4	54.6	82.3	73.3	41.6
Fines (Silt & Clay)%	18.8	33.6	45.4	17.7	26.7	58.4
Clay (<0.002 mm) %	8.5	13	20	11.4	14	30.9
Clay/Fines %	45.2	38.7	44	64.4	52.4	52.9
Liquid Limit - %	N.P	31	35	27	29	49
Plastic Limit - %	N.P	25	23	19	18	32
Plasticity Index - %	N.P	6	12	8	11	17
Shrinkage limit - %	-	-	19.6	18	17	17.3
Specific Gravity	2.69	2.72	2.74	2.66	2.7	2.63
Mean Diameter (mm)	0.18	0.15	0.10	0.33	0.26	0.07
Unified Soil Classification	SM	SM	SM-SC	SC	SM-SC	SM
AASHTO Classification	A-2-4	A-2-4	A-6	A-2-4	A-2-6	A-7-5
*Max Dry Unit Wt. (kN/m ³)	19.81	18.83	19.71	20.10	19.81	18.24
*Optimum Moisture Content %	9	10	12	8	10	12
*Max Dry Unit Wt. with 5% lime	18.83	18.34	18.93	-	-	-
*Optimum Moisture	11	12	13.5	-	-	-
Activity of Soil	N.P	0.46	0.60	0.70	0.78	0.55
**Free Swell - %	0.3	2.5	11.2	4.56	10.9	27.3
**Swell Pressure KPa	20	60	210	92	164	686
**Free Swell-Soil-Lime Mix	Nil	Nil	1.2	-	-	-
**Swell pressure kPa soil-lime mix	10	40	170	-	-	-

* Based on ASTM D 1557-78 using 4.5 kg Rammer

** Samples prepared at maximum Modified Proctor dry density and optimum moisture content and tested as per ASTM D 3877-80.

- Not measured

Chemical tests on selected samples from all sites and X ray mineralogical analysis of samples from four sites were carried out to gain a clear understanding of the factors affecting soil behavior. The results (summarized in Tables 2 and 3) reveal that the soils consist mainly of quartz with the clay minerals limited to a maximum of 10 percent of the soil composition at site F and a minimum of 2 percent at site E. Mineralogical analysis was not carried out for sites A and B. However, their clay mineral content, judging from the physical and chemical composition, is believed to be closer to the lower limit (2 percent) of the four tested soils.

It is clear that most of the clay size particles are not clay minerals when comparing the clay fraction from Table 1 with

the clay mineral content of Table 3. The clay mineral content is only 25 percent, on average, of the clay size particles and is composed of chlorite and illite minerals. The remaining clay size particles include carbonates, salts, and other minerals in very fine form.

ENVIRONMENTAL FACTORS

Low Moisture Content

The surface and near-surface soils are in a relatively dry condition with natural moisture content below 2 percent within

TABLE 2 CHEMICAL ANALYSIS OF THE SOIL SAMPLES

Component	% Composition					
	Mirgab A	Dasmah B	Mishrif C	Shuwaikh D	Jabriya E	Andalus F
SiO_2	80.5	80.0	87.47	91.74	76.4	82.51
Al_2O_3	3.5	7.4	5.23	2.71	2.25	7.6
Fe_2O_3	0.48	-	1.96	0.83	0.91	2.36
CaO	4.84	1.74	0.37	1.94	9.28	1.35
MgO	0.21	1.59	0.3	0.29	0.32	0.3
TiO_2	-	-	0.51	0.15	0.16	0.55
K_2O	-	-	1.64	1.14	0.82	1.58
Na_2O	-	-	1.20	0.55	0.12	1.06
SO_3	0.07	0.03	1.24	0.24	0.71	1.37

- Not measured

TABLE 3 SUMMARY OF MINERALOGICAL COMPOSITION OF THE TOTAL SAMPLES

Mishrif C	Mostly Quartz (~90%), very little feldspar Clay minerals: ~6% (chlorite, illite)
Shuwaikh D	Mostly Quartz (~90%), little feldspar, dolomite Clay minerals: ~3% (chlorite, illite)
Jabriya E	Mostly Quartz (~80%), dolomite (~12%) Clay minerals: ~2% (chlorite, illite)
Andalus F	Mostly Quartz (~90%), very little feldspar Clay minerals: ~10% (chlorite, illite)

the upper 1.5 m (I) for most of the year. The mean annual rainfall of about 100 mm occurs in several heavy showers during the winter season. The extremely hot weather during the summer months with temperatures exceeding 50°C and the lack of rain in the period from April to November leads to very low moisture content near ground level. To examine the effect of this low moisture content, samples from soils A, B, and C were compacted at different molding moisture contents to their maximum Modified Proctor dry density in a consolidation ring in accordance with ASTM D 3877-80. All specimens had a diameter of 73 mm and a thickness of 19 mm. Free swelling tests were performed after saturation under a seating pressure of 2.4 kPa for 48 hours. Identical tests were done on samples of the same soils mixed with 5 percent hydrated lime compacted to maximum modified dry density of the soil

lime mix and cured for 28 days in humid conditions. Test results (see Figure 1) indicate the remarkable effect of the initial moisture content on the free swell. The free swell occurring at the natural moisture content of ~2 percent is nearly four to five times the corresponding value at optimum moisture content of each soil. The addition of lime results in a significant reduction of the free swell at all moisture contents.

Following those tests just described, samples of soils A, B, and C were tested in the consolidation apparatus at their natural moisture content (~2 percent), optimum moisture content, and optimum moisture content of the soil lime mixes containing 5 percent lime. All samples were compacted to their maximum modified dry density, and two series of tests were performed: (a) loaded and expanded, where the unsoaked specimen is saturated with water, loaded to prevent uplift,

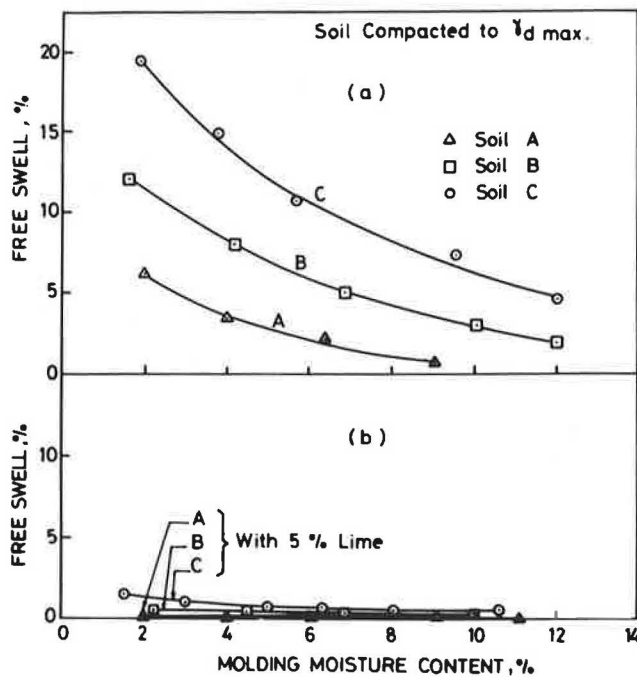


FIGURE 1 Free swell versus molding moisture content for compacted soils and soil-lime mixes.

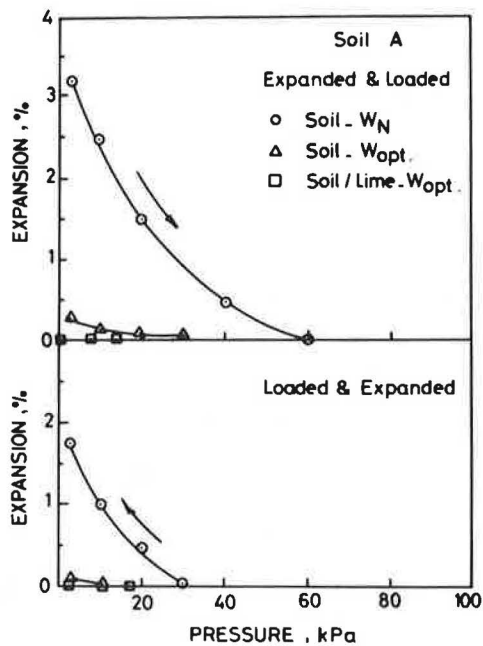


FIGURE 2 Load-expansion curves for soil A.

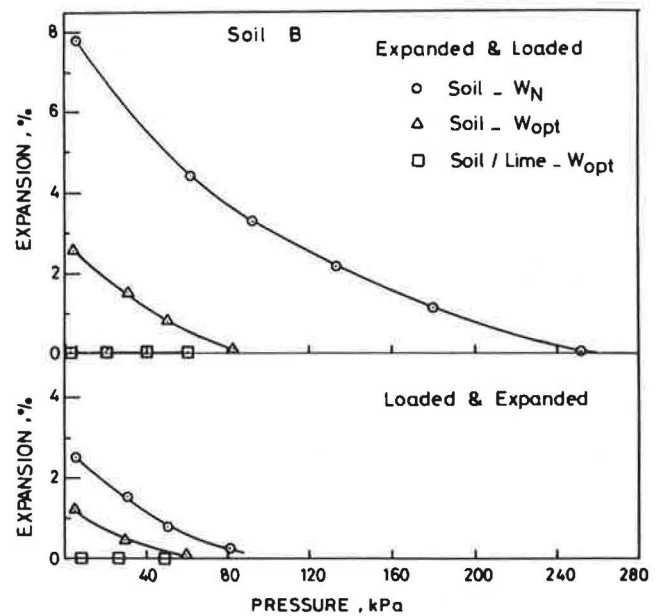


FIGURE 3 Load-expansion curves for soil B.

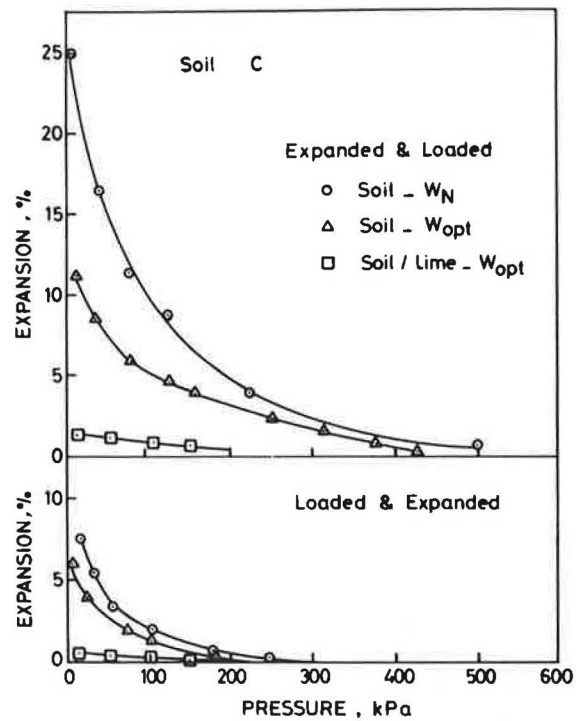


FIGURE 4 Load-expansion curves for soil C.

and then unloaded; and (b) expanded and loaded, where the specimen is saturated prior to loading under a seating load equal to a pressure of 2.4 kPa. The testing procedure for this and subsequent swelling tests followed ASTM Designation D 3877-80.

Test results are plotted in Figures 2-4 for soils A, B, and C, respectively. Expansion or swell is plotted against the applied

pressure for samples expanded and loaded and for samples loaded and then expanded. Three curves are shown on each plot. The top curve is for the samples prepared at natural moisture content. The center curve is for samples prepared at the optimum moisture content. The bottom curve is for samples treated with lime at optimum moisture content and cured for 28 days prior to testing. The curves show that the

free swell and swelling pressure increased several times when the moisture content decreased from the optimum to the natural values.

The preceding results can be explained by moisture deficiency and large suction potential of the local soils. The soil reaches minimum volume as the moisture content drops well below the shrinkage limit. The soil absorbs water when it becomes available and increases in volume as the water content increases above the shrinkage limit toward an equilibrium value that depends on the gradation characteristics and the amount and properties of the fines in the soil matrix.

A comparison between the expansion versus applied pressure curves for samples of three soils prepared at natural moisture content is presented in Figure 5. Because the dry unit weight and molding moisture content are nearly the same for the three soils (see Table 1), the large difference in behavior is attributed to differences in the percent of fines in the soil matrix. Soil C, for example, has 1.35 times the fines and 4.5 times the free swell of soil B. The characteristics of the fines will be examined later.

CBR tests were performed on specimens of the three soils prepared according to AASHTO Designation T 193-63 by using three energies. The samples, soaked for 96 hours before testing, were prepared at natural moisture content, optimum moisture content, and mixed with 5 percent lime and optimum moisture content. Figure 6 indicates that a significant increase in strength was achieved by the addition of 5 percent lime and by curing for 28 days. CBR values for samples prepared at optimum moisture content are somewhat larger than the corresponding values for samples prepared at the natural moisture content, and this reduction in strength corresponding to dry conditions should be considered in pavement design.

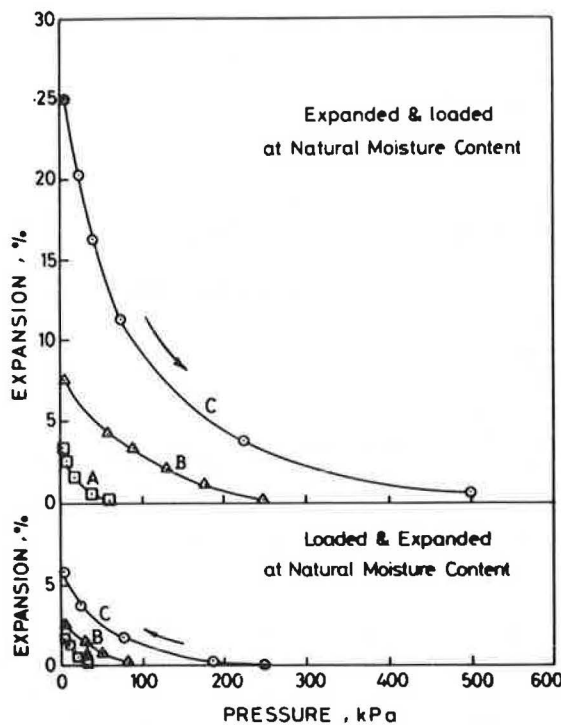


FIGURE 5 Comparison of the load expansion curves for specimens of soils A, B, and C molded at natural moisture content.

Loss of Cementation Bonds

Excavation of cemented sand leads to breaking the cementation bonds and disturbance of the soil fabric, and a new soil is formed on placement and compaction. Because of this disturbance, and of soil placement at high unit weight ($\gamma_d \text{ max} \approx 19.6 \text{ kN/m}^3$), additional swelling on saturation with water may happen. Undisturbed samples were trimmed from block samples taken from site E at a depth of 1.0 m to examine this factor. Both the expanded and loaded and the loaded and expanded tests were performed in the oedometer on undisturbed samples at in situ conditions and on samples remolded to the same moisture content and density. The results (plotted in Figure 7) reveal that the free swell and swell pressure are 6 percent and 50 kPa for undisturbed samples and 18 percent and 100 kPa for remolded samples. Thus, the free swell increased three times and the swell pressure increased twice owing to the crushing of cementation bonds and remolding. The moisture content increased from 1.6 percent at the beginning of the test to 20.7 at the end of the test for the undisturbed samples and to 26.7 percent for the remolded samples, thus reaching an equilibrium value above the plastic limit of 18 percent in both cases.

Although long-term monitoring of the moisture content with time following field compaction was not performed, it is possible to predict the direction of moisture changes throughout the year from the few measurements made so far. The moisture content drops from optimum (8 to 12 percent) to ~2 percent during the long summer season. Complete saturation and moisture content exceeding the optimum values are reached in the winter and following heavy rain. This, however, will last for short periods, and the preceding laboratory saturation of small samples is considered and is, therefore, severe when compared with field conditions. Thus, laboratory values will overestimate the actual swell under field conditions.

The results presented in Figure 7 point to the importance of soil disturbance as a factor aggravating or activating the expansive behavior of subgrade soils derived from cemented sands. Ratio of swelling of remolded to undisturbed cemented sand will depend on the degree of cementation and the type and amount of cementing agents present in the soil matrix. What caused the breaking of the cementation bonds to result in more swelling? It is evident that a large amount of fines is produced by breaking the cementation bonds (Table 1). The percent of fines is proportional to the degree of cementation (3), and most of the cementing agents break into fine sizes. Those fines that have a large surface area are moisture deficient. When densely packed, it has a high potential for absorbing water and for swelling freely when compared with the cemented sand matrix where the soft fine particles are welded to the larger size particles in a more stable soil fabric. Additional research is needed in this area that will involve testing soils of different degrees of cementation to assess the relative contribution of the different factors affecting this behavior.

Swell parameters determined from the preceding test methods may not be representative of many field conditions and should be considered as qualitative in nature. The lateral swell is not simulated, and swelling in the field depends on the availability of water while the specimen in the laboratory is inundated with distilled water. The chemical content of the

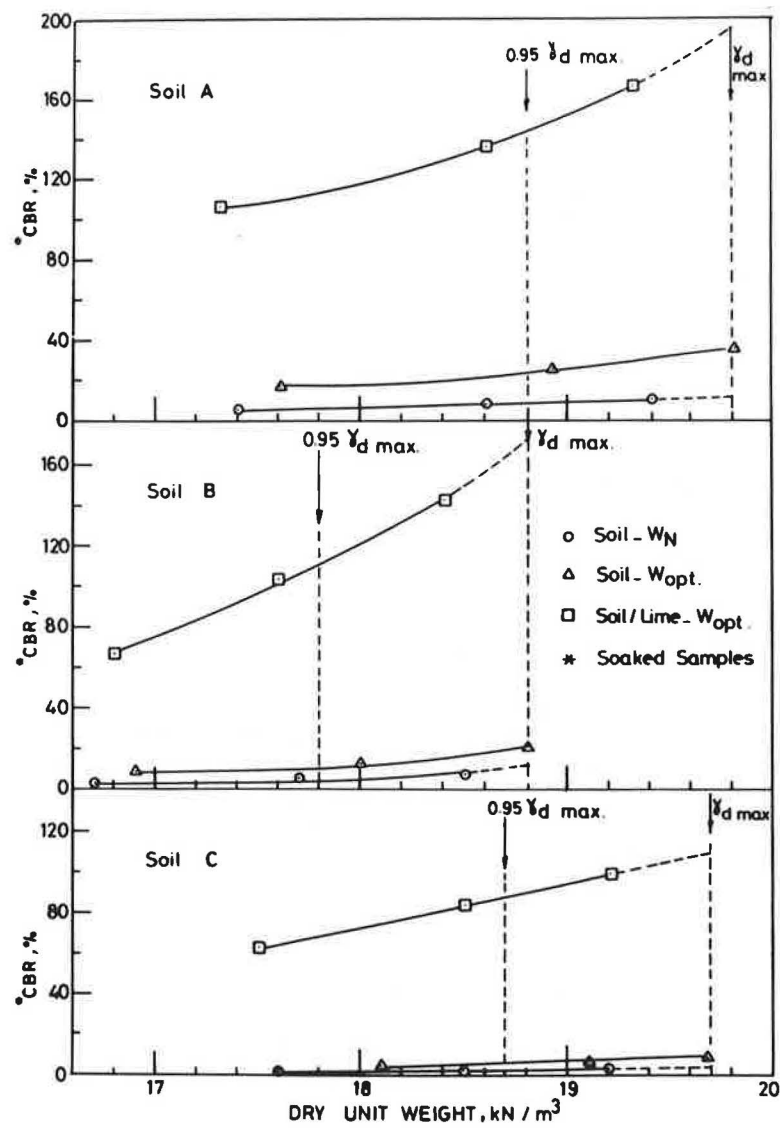


FIGURE 6 CBR versus dry unit weight for soils A, B, and C.

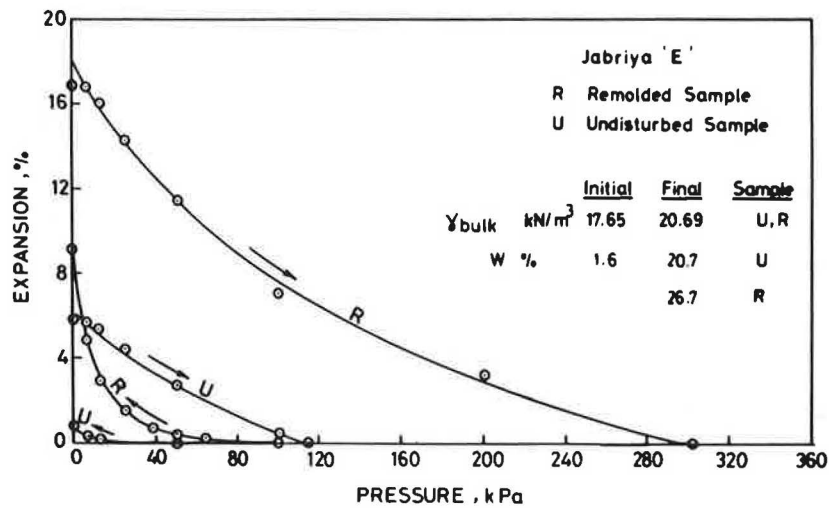


FIGURE 7 Load-expansion curves for undisturbed and remolded specimens from site E (depth = 1 m).

inundating water affects volume change and swell pressure in the field.

Characteristics of the Fines

Because of the important role of fines with respect to the swelling phenomenon, three samples were taken from sites D, E, and F and the fines fraction (< 0.075 mm) isolated from the coarse fraction. Free swelling tests were performed first on samples of the coarse fraction compacted to maximum dry density and optimum moisture content of the coarse fraction. Free swell was zero in all tests, indicating that swelling occurs entirely in the presence of fines. A summary of physical and engineering properties of the fines is presented in Table 4. Because of the limited number of fines available for testing, compaction tests on the fines were performed by using the Harvard Miniature Compactor apparatus, a proposed ASTM (1971) standard method of test.

Free swell and swell pressure values in Table 4 are for samples compacted to maximum dry density and optimum moisture content of the fines. Detailed chemical analysis of the fines is presented in Table 5 and indicates great similarity of the fines composition. Table 4 also confirms the similarity of the classification and compaction characteristics of the fines.

From Table 5 it can be seen that the fines contain approximately 30 percent of carbonates consisting of calcium and magnesium carbonates with a mineral hardness of 3 (compared with 7 for silica sand) (4). Because of its compressibility and soft structure, it is evident that it transforms to silt and clay size particles when breaking the cementation bonds and thus increases the amount of fines.

The results of the swelling tests are plotted in Figure 8. All samples were compacted to maximum dry density and optimum moisture content. Significant differences exist between the characteristics of the fines in the expanded and loaded tests and possibly is due to the disturbance caused by absorbing water at practically no restraint, which makes this particular test method unreliable for swelling or settlement calculation. However, the loaded and expanded tests indicate little difference in the behavior of the fines for the three soils (Figure 8).

Additional tests were conducted on the fines fraction only to determine the effect of molding moisture content on the expansive behavior of fines. Specimens for those tests were prepared at moisture contents of 15 to 35 percent with an interval of 5 percent to densities reflecting the compaction curves. The free swell in percent is plotted versus the molding moisture content in Figure 9, which also presents the compaction test results of the fines. The top and bottom envelopes of the data points indicate similar behavior of all fines especially considering the expected scatter of the test results. By examining Figure 9 one can see a significant reduction of the free swell when the moisture content is increased above the optimum values.

EXPANSIVE BEHAVIOR OF THE TEST SOILS

The expansive behavior for soils A, B, and C has been discussed in connection with the influence of the moisture content and the samples were prepared at natural moisture content and at optimum moisture content and maximum Modified Proctor dry density and were tested in the consolidation appa-

TABLE 4 PHYSICAL AND ENGINEERING PROPERTIES OF THE FINES

Property	Shuwaikh D	Jabriya E	Andalus F
Liquid Limit - %	59.5	72.8	65.0
Plastic Limit - %	32.2	36.7	35.8
Plasticity Index - %	27.3	36.1	29.2
Shrinkage Limit - %	13.6	19.0	15.2
Shrinkage Index - %	18.6	17.7	20.6
Specific Gravity	2.7	2.65	2.68
Unified Classification	MH	MII	MH
AASHTO Classification	A-7-5	A-7-5	A-7-5
*Maximum Dry Unit Wt. kN/m ³	14.91	13.73	14.32
*Optimum Moisture Content %	22.5	29.8	27.5
Free Swell %	20.1	12.9	17.9
Swell Pressure - kPa	320	220	295

* Specimens were prepared in five layers and ten tamps per layer using Harvard Miniature Compaction Apparatus.

TABLE 5 SUMMARY OF THE CHEMICAL ANALYSIS OF THE FINES

Component Oxides	% Composition		
	Shuwaikh D	Jabriya E	Andalus F
SiO ₂	43.46	45.40	43.1
AL ₂ O ₃	14.18	15.08	13.92
Fe ₂ O ₃	1.48	2.16	2.96
CaO	7.82	5.16	6.82
MgO	9.70	8.29	8.65
CO ₂	16.7	14.88	13.75
CL ⁻	0.09	0.03	0.06
SO ₃	0.71	0.75	2.91
Organic matter	4.95	6.43	7.18

Compounds	% Composition		
CaCO ₃	13.96	9.21	12.18
MgCO ₃	20.19	17.41	16.03
Total Carbonates	34.15	26.62	28.21
pH value	7.81	7.70	7.75

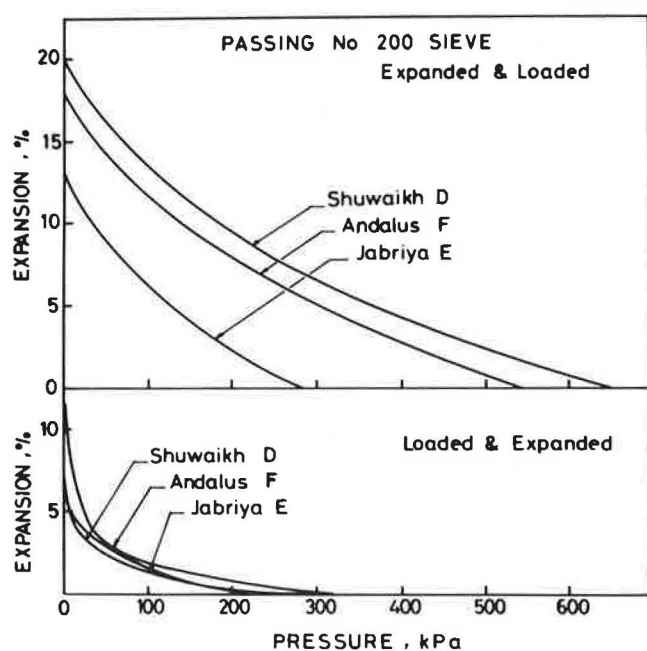


FIGURE 8 Load-expansion curves for the fines fraction of soils D, E, and F.

ratus. For soils D, E, and F, only samples compacted to maximum Modified Proctor dry density were tested. The results are depicted in Figure 10, and swell parameters are presented in Table 1. The significant influence of the presence of fines can be seen from the curves of soil F. Here, the free swell and swell pressure are 27.3 percent and 686 kPa, in comparison with soil D where the corresponding values were 4.56 percent and 92 kPa. Considering that the percent of fines in soil F is over three times greater than that of soil D, it is possible to relate this large difference in swell potential directly to the difference in the percent of fines in the two soils.

The relationships between the percent of fines, free swell, and swell pressure for the test soils are shown in Figure 11. When the percent fines exceeded about 35 percent, both the free swell and swell pressure increased rapidly to unacceptably large values. This means it is necessary to limit the amount of fines in those soils to a maximum of 35 percent if heave, cracking, and possible damage owing to expansive subgrade soils is to be avoided. This would place suitable local subgrade soils with respect to expansive behavior within the granular materials defined by the AASHTO soil classification system.

The preceding test results explain clearly the swelling behavior of subgrade soils in Kuwait. Swelling occurs in the presence of fines and increases as the percent of fines increases in the soil matrix. The characteristics of the fines are nearly the same

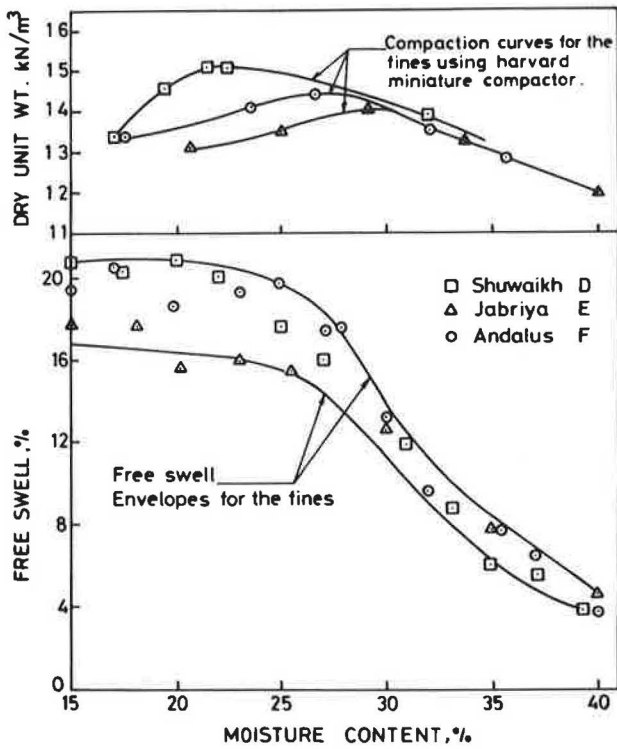


FIGURE 9 Free swell and dry unit weight versus molding moisture content for the fines of soils D, E, and F.

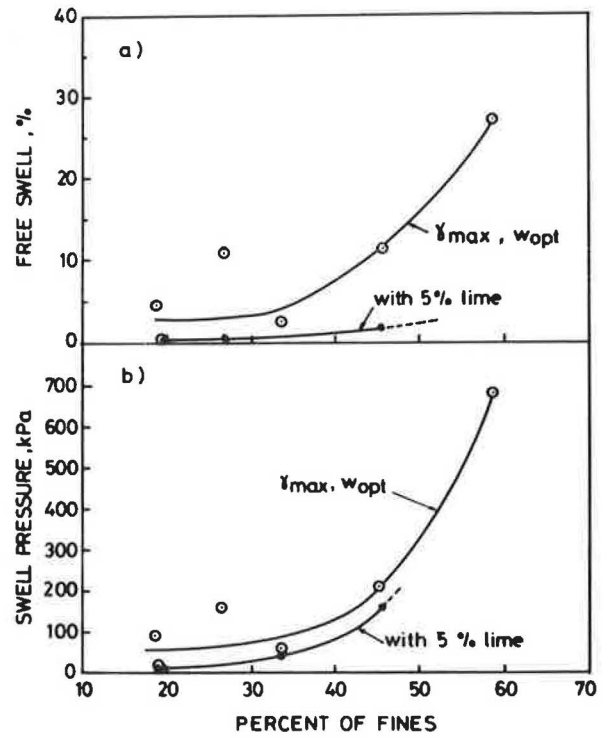


FIGURE 11 Free swell and swell pressure versus percent of fines for the test soils.

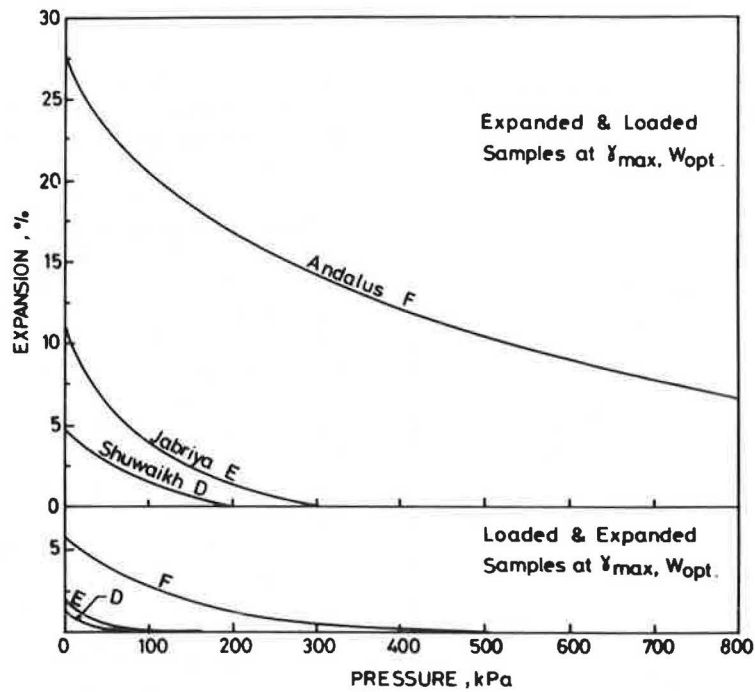


FIGURE 10 Load-expansion curves for soils D, E, and F.

at the test locations with the clay size nearly 50 percent of the fines. Approximately one-fourth of the clay size particles consist of clay minerals not considered highly expansive.

The presence of a large percentage of fines and the high placement density are aided by several environmental or climatic factors to cause unexpectedly intolerable swell and include the very low natural moisture content of the soil, which is well below the shrinkage limit and thus creates high soil suction. The presence of cementation bonds and the breaking of those bonds during excavation and compaction lead to disturbance of the soil fabric and high swelling. The precipitation of carbonates in the soil matrix during evaporation leads to an increase in the fines content as the cementation bonds are broken and causes more swell on saturation. Those factors combined lead to high potential for swell contrary to other soils with similar liquid limit and plasticity. On the basis of classification charts for swelling potential of cohesive soils that employ Atterberg limits (5,6), all the six test soils with liquid limit less than 50 and plasticity index below 20 will be classified as having low swell potential with the expected swell limited to 1 percent. However, problems of heave and cracking occurred in pavements and ground slabs that required costly maintenance and repair. Therefore, it is recommended to assess the swelling potential of the local soils in the oedometer by using an applied pressure equal to the overburden pressure plus the expected foundation pressure.

TREATMENT METHODS

Lime Stabilization

Because good granular materials are in short supply in Kuwait, it is necessary to use crushed cemented sand (gatch) as a road base material. If the percent of fines is excessive or if it is desired to limit volume changes to nearly zero, then the use of 5 percent hydrated lime as an additive appears to be an attractive option. Figures 1–4 and 6 present the effect of lime use on the swelling and bearing capacity of compacted gatch specimens. Because clay minerals are rather scarce in gatch [as shown here and in other studies (7)], gatch may not be suited for lime stabilization. However, with the present test results and the low cost of lime locally, lime is highly recommended because it reduces drastically the plasticity index and volume changes and improves the bearing capacity of compacted gatch soils.

Cement Stabilization

The use of ordinary portland cement as an additive has proven successful for local soils. The characteristics of the surface dune sand (8) and the underlying cemented sands can be improved significantly with the use of cement. Riedel and Simon (7) recommended for practical applications not less than 3 percent cement should be added to the gatch. However, cement is more costly than lime but will lead to higher strength.

Limiting the Percent of Fines

Because the amount of fines in the crushed cemented sand is a critical indicator of the possible swelling, limit the fines to a maximum of 30 to 35 percent of the composition of the fill. In many locations the local gatch will satisfy this requirement. However, if more fines are found, then isolate some of the fines by sieving to arrive at an acceptable ratio. This method may not be practical if a large amount of fill is employed.

Other Methods

Compaction to lower unit weight on the high side of optimum moisture content (3 to 4 percent above the optimum moisture content) is a method that may be applicable to local conditions (9). Compaction at moisture content above optimum leads to significant reduction of the free swell of the local soils and their fines (see Figure 1, soil B, and Figure 9). Prewetting may be used to achieve most of the heave before construction. After ponding, 5 percent of hydrated lime may be added to the top layer of soil to reduce its plasticity and swell potential (10). With time, moisture will be removed by gravity and evaporation. However, the presence of lime will restrain upward swell in case of sudden saturation by rain, broken pipes, or irrigation.

CONCLUSIONS AND RECOMMENDATIONS

An extensive laboratory testing program was performed on cemented sand samples obtained from six sites in Kuwait to examine the factors affecting the swelling potential of those soils and the practical treatment measures. On the basis of test results, the following conclusions and recommendations are reached:

1. Several environmental factors contribute to the swelling problem and include the very low moisture content of the near-surface soils and the high suction potential, loss of cementation bonds, and the presence of clay and silt size carbonates.
2. Swelling occurs owing to the presence of a large percent of fines in the soil matrix. The fines content should be limited to a maximum of 35 percent to avoid objectional swelling and heave.
3. Characteristics of the fines are nearly the same at the different test locations. Comparison of the physical and chemical composition of the fines and the free swell at different molding moisture content leads to this conclusion.
4. Clay fraction is nearly 50 percent of the fines for all soils. However, clay minerals are only one-fourth the clay fraction and consist of illite and chlorite.
5. Owing to its unique characteristics, and to the influence of environmental factors, the swelling of crushed cemented sands cannot be predicted by the charts employed for cohesive soils, which present low swelling potential in variance with reality. Laboratory and field swelling tests are recommended.

6. Compaction at moisture contents on the wet side of optimum leads to significant reduction of the free swell of the local subgrade soils and their fines.

7. The use of 5 percent of hydrated lime has proven effective in reducing or eliminating the swelling potential and in improving the bearing capacity of local soils.

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