Influence of Fines on the Compressibility of Surface Sands in Kuwait

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ABSTRACT

Influence of fines on the strength and compressibility of compacted fill soil is very important in determining its behavior under applied loads. In Kuwait, fill soil is usually backfilled from excavated surface soils that consists of windblown dune sand with fines content usually varying from 5% to 15% with an average of 10%. However, it exceeds the upper range at some sites. This sand is used as backfill in compacted layers around foundations and below ground slabs. This paper investigates the influence of fines on the compressibility of surface sands. Laboratory consolidation tests were carried out on two types of sand samples with different fines contents to determine the compressibility parameters that included the compression index (C_c), the swell index (C_s), and the coefficient of consolidation (C_v). The influence of relative compaction on the compressibility parameters of both sands was also examined. Results indicated that the compression index (C_c) values decreased from 0.082 to 0.016 for sands with 7.3%, and from 0.089 to 0.016 for sands with 14.6 % fines, when the relative compaction increased from 80 to 100%. The swell index Cs also decreased with increasing relative compaction for both sands. Moreover, with increasing fines, the compressibility increased as demonstrated by the larger values of Cc at all degrees of relative compaction except at 100% and that the coefficient of consolidation Cv decreased with increasing fines, which means that as the fines increase the time required to achieve a certain degree of consolidation will also increase.

Keywords: Compressibility; Fines; Compression index; Swell index; Coefficient of consolidation

1 INTRODUCTION

Generally, natural sands consists of fines and sands in different proportions. The fines content affects the engineering properties of sands. The soil profile in Kuwait consists of a surface layer of windblown dune sand underlain by cemented sands (Ismael, 1985). It varies in thickness from 0 to 7 m and consists of fine or fine to medium sands with some fines (Ismael et al., 1987). The fines are calcareous and softer in nature. The percent of fines usually varies from 5% to 15% with an average of 10%. However, it exceeds the upper range at some sites. This sand is used as backfill in compacted layers around foundations and below ground slabs. The influence of fines on the strength and compressibility of surface sands compacted to different relative compaction (Rc) is very important in determining its behavior under applied loads (Ismael, 2006). The fines may also affect the compressional characteristics of coarse-grained soils (Çabalar, 2008). Further, compressibility characteristics deliver essential information of soil behavior. There are only few studies that have reported on the behavior of granular sandy and/or clayey soil with different fines contents.

Kim et al. (2005) performed a series of triaxial compression tests on soil mixed with various silt contents, and the results showed that the critical state friction decreased with the increase in fine aggregate content. Phan et al. (2016) investigated the effects of fines content on the engineering properties of sand - fines mixtures based on laboratory tests. They reported that as the fines content increased, all parameters of deviator stress, volumetric strain, shear stress, internal friction angle, and cohesion increased. Moreover, as the fines content increased, soil type with constant void ratio also showed degradation in the cohesion, internal friction angle, and critical state in the consolidated undrained shear test.

In this study, laboratory consolidation tests were carried out on samples of sand with two different fines content to determine the compressibility parameters. These include the Compression Index (Cc), the Swell Index (Cs), and the Coefficient of Consolidation (Cv). Consolidation tests were performed on samples compacted to different relative compaction specified from the modified proctor compaction test. The influence of relative compaction on the compressibility parameters of both sands was also examined.

2 METHODOLOGY

The natural sand used in the tests was collected from the surface of a selected test site in AI-Rai area in Kuwait city, where the fines content is almost 15%. Bulk soil samples collected from excavated test pits were taken to the laboratory at Kuwait University for analysis and testing. The basic properties of the remolded soil sample were determined by conducting sieve analysis, consistency tests and compaction tests in the laboratory. Sieve analysis indicated that the percentage of fines in the soil was 14.63%, which is approximately the maximum value of fines usually encountered for surface sand in Kuwait city (Ismael et a1., 1986). The fines are calcareous and softer in nature. Another soil sample was prepared by washing some part of original soil through sieve # 200, and then adding the isolated fines based on weight calculations, so as to make the percentage of fines in the soil to be 7.3% (50% of 14.63). For example, for every 92.7 kg of soil particles that remain in sieve # 200, 7.3 kg of fines were added. Figure 1 shows the grain size distribution for sand with 14.63% fines and sand with 7.3% fines.

After the sieve analysis tests, samples from both sets of soils were tested to determine the Atterberg limits (liquid and plastic limit), specific gravity, optimum water content and maximum dry density. The liquid limit and plastic limit for the sand with 14.63% fines was found to be 23 and 18, respectively. The sand with 7.3% fines is considered as non-plastic. According to the Unified Soil Classification System (ASTM 0-2487), the soil with 14.63% fines is classified as silty clayey sand (SC-SM), and the soil with 7.3% fines is classified as poorly graded sand with silt (SP-SM). In addition, the specific gravity for the sand with 14.63% fines was 2.61 and for the sand with 7.3% fines was 2.645.

The Modified Proctor Compaction test (ASTM D-1557) was conducted on samples of both sets of soils to determine the max dry density ($\gamma_{d\ max}$) and optimum water content (w_{opt}). In order to determine the consolidation parameters, five one-dimensional consolidation tests were conducted on soil samples with different degrees of relative compaction, for each set of soils. The laboratory consolidation tests were carried out according to ASTM D-243, on the compacted soil samples with 14.63% fines at 80%, 85%, 90%, 95% and 100% relative compaction at moisture contents corresponding to the wet side of the optimum water content. These tests were repeated on samples with 7.3% fines.

3 RESULTS AND DISCUSSION

Figure 2 shows the compaction curves for sands with 14.63% and 7.3% fines. For the sand with 14.63% fines, the maximum dry unit weight was found to be 2033 kg/m^3 and the optimum water content was 9.4%. The corresponding values for the sand with 7.3% fines were 1954 kg/m^3 and 9.8%, respectively.

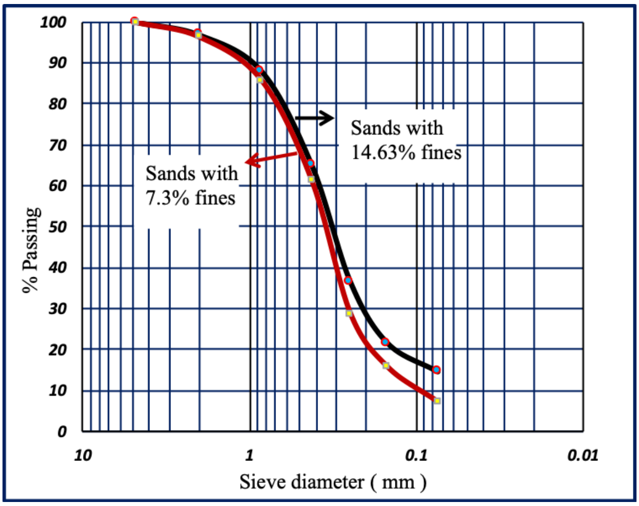

Figure 1: Grain Size Distribution curves for the test samples

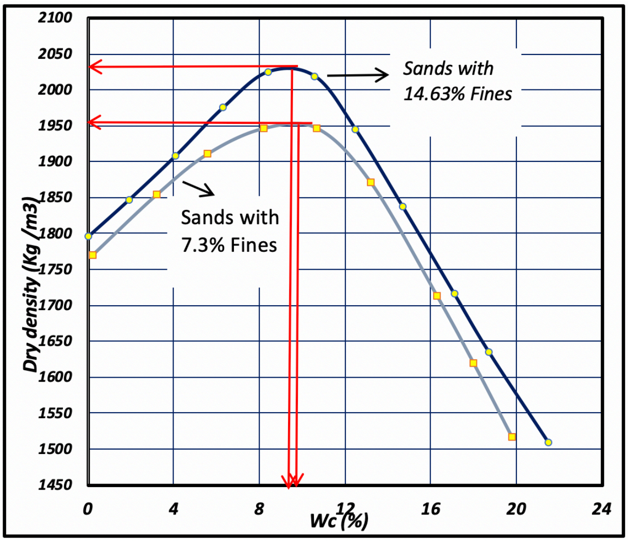

Figure 2: Compaction curves for the soil samples

Table 1 shows a summary of the consolidation test results and Table 2 shows the variation of the coefficient of consolidation with the applied pressure increment for the different relative compaction values. Figure 3 shows comparison between the Compression Index (C_C) and Swelling Index (C_S) with increasing relative compaction. The average Coefficient of Consolidation (C_v) values with respect to relative compaction for the soils with 7.3% and 14.6% fines, are plotted in Figure 4. Figures 5 and 6 show the e-log σ' curves at different relative compaction for sands with 7.3% fines and 14.6% fines, respectively.

Table 1: Summary of the consolidation test results

Relative Compaction (Rc %)	Water Content Wc (%)		Initial Void Ratio (e_0)		Dry Density $\gamma_{d\text{-}max}$ (kg/m^3)		Compression Index (Cc)		Swelling Index (Cs)		Avg . Cv (mm^2/ min)	
	Sands with 7.3% fines	**Sands with 14.6% fines**	**Sands with 7.3% fines**	**Sands with 14.6% fines**	**Sands with 7.3% fines**	**Sands with 14.6% fines**	**Sands with 7.3% fines**	**Sands with 14.6% fines**	**Sands with 7.3% fines**	**Sands with 14.6% fines**	**Sands with 7.3% fines**	**Sands with 14.6% fines**
80	19	18.85	0.702	0.642	1563.2	1626.4	0.082	0.089	0.008	0.009	670.0	667.3
85	17.3	16.75	0.601	0.545	1660.9	1728.1	0.043	0.068	0.009	0.008	679.6	672.5
90	15.4	14.8	0.513	0.459	1758.6	1829.7	0.023	0.035	0.008	0.008	689.8	674.6
95	13.5	12.75	0.433	0.383	1856.3	1931.4	0.018	0.023	0.007	0.007	692.0	690.5
100	9.8	9.4	0.361	0.313	1954.0	2033.0	0.016	0.016	0.007	0.006	694.6	695.1

Table 2: Variation of coefficient of consolidation with applied pressure

Rc %	**80%**		**85%**		**90%**		**95%**		**100%**	
Pressure **(kpa)**	Sands with 7.3% fines	Sands with 14.6% fines	Sands with 7.3% fines	Sands with 14.6% fines	Sands with 7.3% fines	Sands with 14.6% fines	Sands with 7.3% fines	Sands with 14.6% fines	Sands with 7.3% fines	Sands with 14.6% fines
6	700.4	700	699.4	700.5	701.6	688	701	546.5	702.44	703
12	697.3	695.6	695.5	696.6	699.4	686	699	688.2	701.5	702
25	690	682.8	689.5	689.1	696	683	696.4	731.2	699.4	700
50	678	661.6	682.3	678.9	690	678	652.8	737.4	696.2	697
100	662	640	673.9	665	686.9	671.5	732	687.3	692.3	693
200	644	656.7	664.5	648	680.6	663	684	680.5	687.8	688
400	623.4	634.6	652.2	629.7	674.4	652.5	678.5	762.7	682.7	683

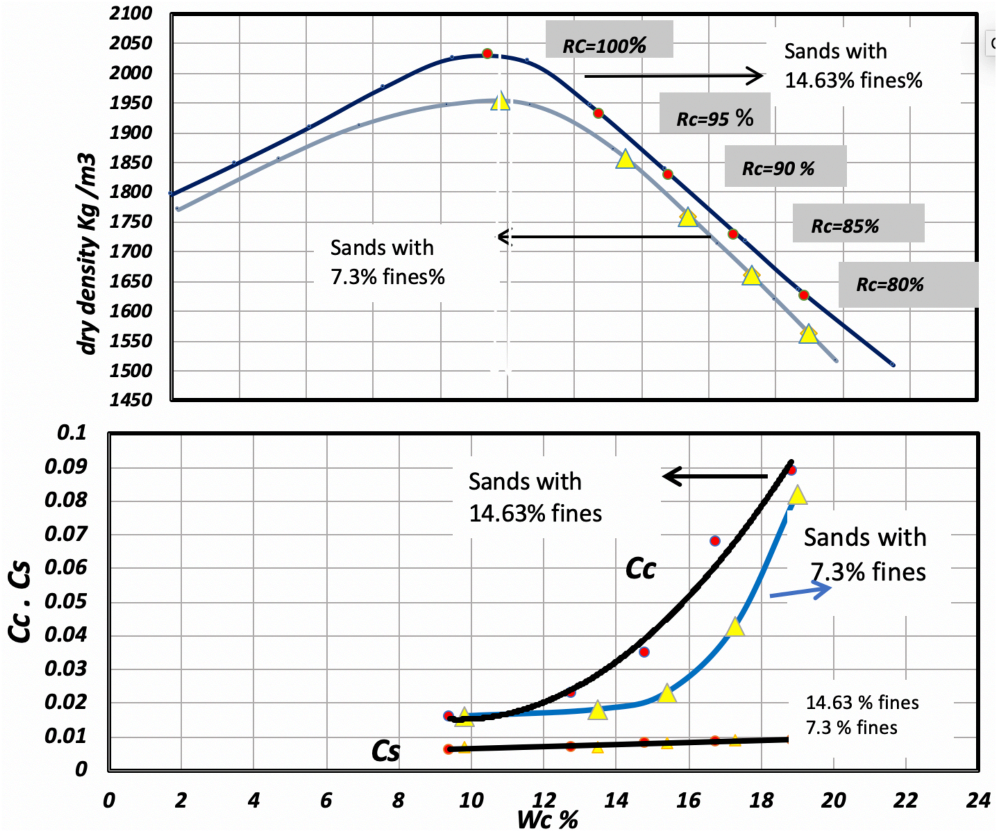

Figure 3: Comparison between the Compression Index (Cc) and Swelling Index (Cs) values

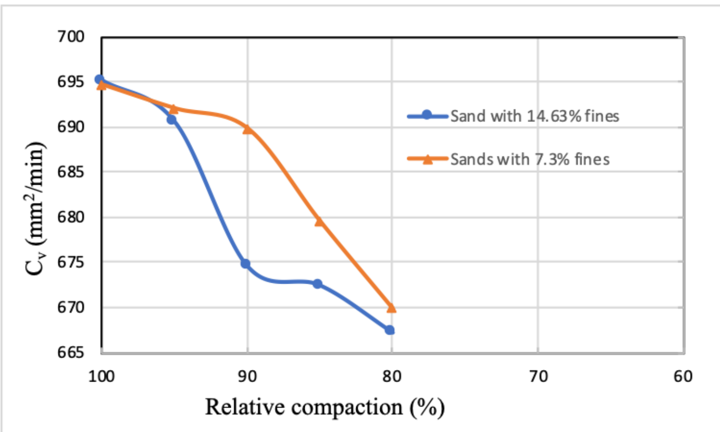

Figure 4: Variation of Coefficient of Consolidation (C_V) with the relative compaction

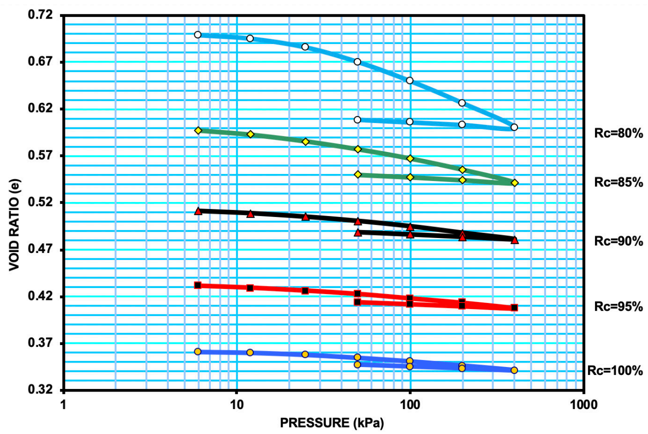

Figure 5: e-log σ' curves at different relative compaction for sand with 7.3 % fines

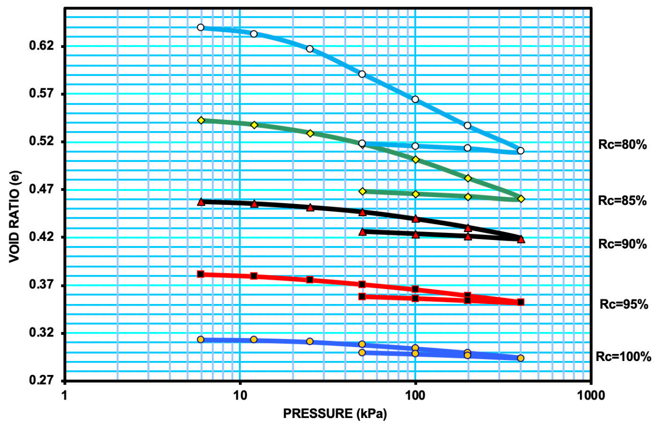

Figure 6: e-log σ' curves at different relative compaction for sand with 14.63 % fines

As represented in Table1, for both sets of soil samples (with 14.63% fines and 7.3% fines) the Compression Index (Cc) decreased sharply as the relative compaction increased from 80% to 90%, and decreased at a slower rate as the relative compaction increased from 90% to 100%. This decrease in compression index values indicates that the compressibility decreased and stiffness increased as the relative compaction increased. The ratio of C_c at 90% to Cc at 80% is 0.28 and the ratio of Cc at 100% to Cc at 90% is 0.69 for the test soil with 7.3% fines. Similar observations were made for the samples with 14.6% fines. The Swelling Index (Cs) decreased slightly as the relative compaction increased as shown in Table 1 and Figure 4.

A summary of the pre-consolidation pressure values σ_c as determined at different relative compaction values is given in Table 3. From Table 3 it is clear that σ_c remained nearly the same except at 80% relative compaction for the sand with 14.6% fines where a significant decrease occurred.

Table 3: Variation of pre-consolidation pressure with relative compaction

Relative Compaction (Rc %)	Pre-Consolidation Pressure, σ_c' (kPa)	
	Sands with 7.3% fines	**Sands with 14.6 % fines**
80%	40	27
85%	45	48
90%	42	50
95%	43	43
100%	38	45

The above results show the important effect of fines on compressibility. As the fines increase the compression index increases at all values of relative compaction except at the 100% value. A possible explanation is that the decrease with low void ratio makes the effect of increased fines within the range of this project insignificant. Increased compressibility leads to larger settlement under the applied loads as the settlement is directly proportional to C_c.

Looking at the coefficient of consolidation C_v, it is evident from Figure 5 that C_v is lower with increased fines content at all relative compaction except 100%. It is known that for a given degree of consolidation, the time is inversely proportional to the coefficient of consolidation. Thus, it is clear that with lower values of C_v with higher fines, the time required to achieve a given degree of consolidation will be longer due to the lower permeability and the plastic nature of the soil containing larger fines content. As indicated in Figures 6 & 7, the void ratio also decreased with increase in relative compaction.

4 CONCLUSION AND RECOMMENDATION

A laboratory-testing program consisting of compaction and consolidation tests was carried out on two sets of sands with fines content of 14.7% and 7.3%. The following conclusion were made based on the laboratory test results:

i. For both sands, compressibility decreased as the relative compaction increased from 80% to 100%. The Compression Index Cc and the Swell Index Cs decreased with increasing relative compaction.

ii. The Compression Index (Cc) values decreased from 0.082 to 0.016 for sands with 7.3%, and from 0.089 to 0.016 for sands with 14.6 % fines, when the relative compaction increased from 80 to 100%.

iii. The average Coefficient of Consolidation (Cv) increased from 670 to 695 mm^2/min for both types of sands with increasing Relative Compaction (Rc).

iv. With increasing fines, the compressibility increased as demonstrated by the larger values of C_c at all degrees of relative compaction except at 100%.

v. The Coefficient of Consolidation C_v decreased with increasing fines. This indicates that as the fines increase the time required to achieve a certain degree of consolidation will also increase.

It is recommended to carry out the same tests on soils with fines content up to 30% to confirm the findings of this study.

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