Study of Silts Moisture Susceptibility Using the Tube Suction Test

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ABSTRACT

Moisture susceptibility is an important factor that affects the mechanical properties of pavements and subgrade materials. The Tube Suction Test (TST) monitors the capillary rise of moisture within a 150 mm. diameter by 200 mm. high cylinder of compacted soil, assessing the materials moisture susceptibility. The dielectric constant at the surface of the sample is measured with a probe, providing an estimation of the free or unbound water within the soil specimen. This unbound water is directly related to the materials strength and long term performance. The poorest performing materials exhibit high dielectric values, in excess of 16, which is considered a maximum permissible dielectric constant.

This paper presents a study regarding moisture susceptibility of three silts. A lean clay and a silty sand are also considered in order to compare the results. The effect of Portland cement on silts moisture susceptibility is addressed noticing a decrease of final dielectric values in the range of 6 to 12.

Also, different conditions for conducting TST are evaluated, such as tubes diameter, the effect of compaction energy and size of clods. The results from the tests conducted using smaller tubes diameters are similar with those provided from tests using "classic" tubes. In the range of compaction energies used, the final dielectric values were similar for samples compacted at the Proctor optimum moisture content. Also, the variation of clods size used in the laboratory tests produced almost the same final dielectric values.

The results demonstrate the relevance of TST for the evaluation of silts as subgrade materials.

INTRODUCTION

Soils with high silt contents, low strengths, and minimal bearing capacity can exhibit both construction and performance problems, especially when they become wet and are located under pavement subgrades or within pavement embankments. A pumping phenomenon can occur during construction, when the passage of equipment over a compacted section of the road induces deformation or "weaving" of the soil in front of the wheels. Long-term performance problems can develop due to a loss of strength of the silts in the pavement subgrade caused by a rising level of water table and cycling loads induced by traffic(*1*).

Moisture susceptibility is related to the notion of soil suction considered as the attraction that the soil exerts on the water (*2*). The total suction of a soil consists of two components: the capillary or matric suction and osmotic suction (*3*). Terzaghi defines the matric suction as the difference between the pore – air and pore – water pressure. Osmotic suction is given by "the difference in concentration of the cations in the electrical double layer surrounding the particles and in the free water farther from the particles generates an osmotic suction." (*3*).

Moisture susceptibility is an important factor that affects the mechanical properties of pavements and subgrade materials. The magnitude of these effects depends on the materials physical and chemical properties, moisture content and even the saturation history (*4*).

Water in soils occurs as 1) adsorption water or hygroscopic water, 2) viscous water or capillary water and (3) free water. The water molecules adsorbed by a soils particle from the air by means of surfaces forces form hygroscopic water. This water layer is influenced by factors such as the airs relative humidity, temperature and pressure. Viscous water or capillary water is not bound to mineral grains as hygroscopic water and the amount of it is influenced by the soil texture and structure, organic material and gravity. Free water is attracted to the soil particles so loosely that it may respond to the pull of gravity (*5*).

Water is attracted to soil particles and can develop a surface tension. In this manner, capillary menisci form between particles in a partially saturated soil mass. This curved air-water interface is a result of the pore water tension, which generates an effective compressive stress between particles. Capillary stresses are usually considered responsible for an apparent and temporary cohesion in soils (*6*).

The Tube Suction Test (TST) was developed by the Finnish National Road Administration and the Texas Transportation Institute for evaluating the moisture susceptibility of granular base materials (*4*). In this test the evolution of the moisture conditions is evaluated with a dielectric probe. A graph of surface dielectric values versus time provides the basis for performance classification. The poorest-performing materials exhibit final dielectric values higher than 16, which is considered to be a threshold value. Scullion and Saarenketo suggested this value as a maximum permissible dielectric constant for granular materials, based on research study, using electrical properties to classify the strength properties of base course aggregates (*7*).

The water rising due to capillarity transforms the soil's dielectric values, which is measured by the probe. Adsorbed water molecules are arranged in layers around soil particles. The electrical attraction diminishes with the increasing distance from the soil particle. The water molecules beyond the electrical capture are considered unbound and depending on the suction characteristics and permeability of the soil can migrate further.

The dielectric value is a measure of the unbound water within the soil sample. The strength of the material and its ability to resist repeated freeze-thaw cycling are considered to be directly influenced by the unbound water (*8*). The test reveals the state of bonding of the water within soil particles and should not be considered as a simple measure of the moisture content.

OBJECTIVES

The objectives of this study are:

1. To demonstrate the relevance of TST for studying the silts moisture susceptibility.
2. To evaluate the silts moisture susceptibility after stabilization with Portland cement.
3. To evaluate new conditions for conducting TST with respect to the tube's dimensions, the effect of compaction energy and size of soils clods on final results for TST in laboratory tests.

TESTING PROGRAM

The study is focused on a set of three silt soils, typical of many subgrades encountered in Louisiana and identified as: 1) Deridder White, 2) K1-1 and 3) HW 171. This research is part of a more extensive investigation regarding the identification and stabilization of problematic silts. In addition to gradation and plastic characters, the study reviews the variation of moisture content as another decisive factor influencing the performance of silts in road subgrades (*1*).

Classification

The soils considered were classified in group A-4 as silty soils, according to the AASHTO classification system (ASTM D 3282) and in group ML as silt, according to Unified

Classification System (ASTM D 2487) (*9*). The silt percentages were determined as 74% for Deridder White, 77 % for K1-1 and 73% for HW 171. Gradation curves are presented in Figure 1. Plasticity Indices were very low for these soils, approximately 1.5. In addition to this set of three silts, a lean clay CL (Chase Brown) and a silty sand ML (Alf) were considered for comparison purposes.

Mineralogy

A mineralogy study of the three silts was conducted by the University of New Orleans' Geology laboratory to determine the occurrence and frequency of the clay minerals, quartz and feldspar minerals, and metal oxides. Two methods were used in the mineralogic study of the natural soil. The first employed an AMRAY 1820 digital scanning electron microscope to digitize the images of the soil particles and to collect the energy dispersive spectra. A software page "Iridium," (IXRF Systems, Inc.) was used. In the second method, pulverized samples were scanned with a SINTAG XDS 2000 X-ray diffractometer. Scans were plotted and compared with ICDD patterns of the common minerals as well as potential reaction products. The results for the natural soils are presented in Table 1.

Compaction

Laboratory compaction curves, optimum moisture content (OMC), and the maximum dry density of the soils were established using the standard Proctor compaction method (DOTD TR 418 Method (ASTM D698 and AASHTO T99, 12,375 ft-lbf/ft^3 or 590 kN-m/m^3). A family of curves and a comparison of the individual soil's compaction character with different compaction efforts were also conducted. This included the modified effort (AASHTO T180 and ASTM 1557, 56,000 ft-lbf/ft^3 or 2,700 kN-m/m^3), a modified plus effort (78,750 ft-lbf/ft^3 or 3,750 kN-m/m^3), and a reduced standard effort (7,425 ft-lbf/ft^3 or 350 kN-m/m^3). The data are presented in Table 2. An example of typical compaction curves is illustrated in Figure 2 for K1-1.

Tube Suction Test

For all the tests described as follows, the soils were compacted at optimum moisture content corresponding to standard Proctor compaction energy. Chase Brown, a lean clay (CL), and Alf, a silty sand (ML), were also used to compare the moisture susceptibility of these soils and the silts considered. The TST soil samples were compacted at their optimum moisture content in a 305 mm by 152 mm diameter plastic tube. The compaction energy was the same as in Standard Proctor compaction test (12,375 ft-lbf/ft^3 or 590 kN-m/m^3).

For a sample height of 180 mm and using 35 blows /layer, compacting the soils in seven layers duplicates the standard compaction effort. The bottom of the tube was cut and replaced with aluminum foil pierced with a 1.5 mm nail, to form 3 concentric circles and with a distance between holes approximate 4 cm. The weight of each sample was recorded then placed in the oven at 50^0 C until no more significant changes are observed in their weight. After oven drying, the samples are allowed to cool down at room temperature. When their temperature has stabilized, the samples are placed in a dish containing approx. 20 mm of deionized water. The first measurements of the dielectric and electrical conductivity values are taken before placing the tube samples into the water. Once in the water, four measurements are taken. The highest and the lowest reading are disregarded. From the second day on, one measurement is taken daily, until the weight of the samples and the dielectric values become constant. The weight of the tube samples is measured in connection with every dielectric value measurement. The tests were conducted until the value of dielectric constant did not change.

In order to evaluate the effect of Portland cement on final dielectric values, the silts were mixed with cement, 3.5 percent by weight, and compacted at optimum moisture content in smaller tubes. A curing period of 28 days in the humidity room was used in order to allow the formation of cementitious products. After 48 hours in the oven at 50^0 C the samples were subjected to Tube Suction Tests.

The effects of the tube size on the final dielectric values were considered for the next stage of the study. A set of TST was conducted for soil samples compacted at the Proctor optimum moisture content and using the same 180 mm height in smaller tubes, 101.6 mm in diameter.

The effect of compaction energy on the final dielectric values was also evaluated. Using the smaller tubes, soils samples were compacted at optimum moisture content in 7 layers and 35 blows/layer (26670 ft.-lbf. / ft^3 or 1271 kN-m/m^3) which is identical with the compaction energy used in other investigations for standard tubes (*4*) and (*8*). It is interesting to note the combination of 7 layers and 35 blows/layer provides 12375 ft.-lbf. / ft^3 or 590 kN-m/m^3 for standard tubes (152 mm diameter) and 26670 ft.-lbf. / ft^3 (1271 kN-m/m^3) for the smaller tubes (101.6 mm diameter). The results were compared with those obtained from TST, smaller tubes, using standard Proctor compaction energy.

The effect of clods on final dielectric values was also studied. Two different samples of the same silt were compacted at optimum moisture content, using standard Proctor compaction energy. For the first sample the size of the clods were between 4.75 mm. and 0.5 mm. (i.e. passing through Sieve # 4 and retained on Sieve # 35). The clods for the second sample were smaller than 0.425 mm. (i.e. passing through Sieve # 40). The final dielectric values were very close for both samples, suggesting no influence from the clods size.

TEST RESULTS AND ANALYSIS

The comparative results for Tube Suction Tests for the three silts and the two additional soils considered are presented in Figure 3. The final dielectric values for the silts considered in this study are in the range of 16.5 – 21, i.e. higher than 16, which is considered to be a maximum permissible dielectric constant for subbase materials (*4*). These results demonstrate the silts considered are highly moisture susceptible, in contrast with the clay, which exhibits final dielectric values in the range of 12. The silty sand is also highly moisture susceptible, with final dielectric values in the range of 25. The high moisture susceptibility identified in these tests relates to the unbound water and makes the silts prone to pump under dynamic loads and to freeze-thaw problems.

At the completion of the TST, the moisture content at different levels of the soil sample was determined. The water front due to capillarity is distributed within the soil sample revealing differences up to 3 percent between the top and the bottom's moisture for the raw soils. The variation of test specimen's average moisture and dielectric values with time is illustrated in Figure 4 for HW 171. The TST is complete when the dielectric values reach a constant value over time. This corresponds to a constant or final value of moisture content for the test specimen. It can be noted that in the HW 171 specimen, the final moisture content was 3 percent above optimum moisture content (which is 12 percent for this silt). The moisture sensitivity of silts and their tendency to pump at moisture contents that exceeds optimum by small percentages was noted by McManis et al. (*1*). The tests demonstrate the silts ability to attract additional moisture through capillarity. This additional moisture can lead to post compaction problems for an unstable silt subbase or subgrade.

The improving effect of Portland cement on silts moisture susceptibility is illustrated on Figure 5. Portland cement has a dramatic effect on final dielectric values, by reducing it from 16-21 to 5-12. A significant reduction in permeability is also the likely cause of the reduction in dielectric values observed for cement-treated silts specimens compared to the untreated silt. The cementitious products formed by adding Portland cement will increase the radius of influence of electrical attraction between soil particles and water molecules. The zone of electrical capture will enlarge, more water dipoles will be bonded to the mineral particles and less unbound water affecting final dielectric values will be encountered within the soil. The results of laboratory tests demonstrate the silts mixed with adequate percentages of Portland cement exhibit a much lower level of moisture susceptibility, considered in an acceptable range (final dielectric values less than 16). This positive aspect is maintained during time as the formation of cementitious products is occurring in a long term period of time and it will consume a considerable part of the water from future capillary ascension, reducing in this way the amount of free water within the soil (*10*) and (*11*). Silts stabilized with Portland cement became more reliable for subgrade roads from the moisture susceptibility point of view.

The results of TST using tubes with different diameters are illustrated in Figure 6. The results from tests conducted with standard tubes (152 mm diameter) are similar with the results from smaller tubes (101.6 mm), for the same height of the sample (180 mm.), with a ratio $\text{Vol.}_{\text{classic}} / \text{Vol.}_{\text{small}} = 2.1$ for the tubes volumes. The dimension of the tube's diameter appears to have no influence.

The two compaction energy levels used in this study have no effect on final dielectric values as long as the samples are compacted at optimum moisture content. Figure 2 illustrates the fact that a higher compaction effort than Proctor standard will generate approximately the same dry unit weight for the soil considered (around 110 lb./cu.ft. corresponding to 15 percent moisture content). This leads to the conclusion that almost the same porous space structure is encountered in these samples. The capillarity would have the same effect so TST would reveal the same final dielectric values. The typical results are illustrated in Figure 7 for HW171.

The influence of the clods size in the laboratory samples may also be of interest. The compaction effort at optimum moisture content or on the wet side can transform silts with bigger clod sizes into a more uniformly compacted soil. Benson et al. demonstrated in their study regarding the influence of clods on hydraulic conductivity that relatively high moisture contents made clods soft and compressible and their size had no influence on hydraulic conductivity after compaction (*12*). The typical results for the range of clods size (4.75 mm. – 0.5 mm. and smaller than 0.425 mm.) used in this investigation are presented in Figure 8 for K1-1 with very close final dielectric values for the cases considered.

CONCLUSIONS AND DISCUSSIONS

Changes in moisture content can significantly alter the engineering properties of silty soils due to their high moisture susceptibility and has a major impact on their field performance.

The Tube Suction Test provides valuable information that indicates the soil sensitivity to moisture variations with implications to its performances during construction and post construction support. It can be used for fine-grained soils demonstrating the role of the free water versus the bond water within the soil. It also provides a means for measuring the reduction in moisture susceptibility provided by stabilization efforts. This study illustrates the significant decrease, below critical level, of the final dielectric values for a set of highly moisture susceptible silts when stabilized with 3.5 percent Portland cement.

One drawback in using the TST in a testing program of fine-grained soils involves the long test period requested for the soils to reach a constant level of readings.

The variations in the test's results when a reduced specimen size was used did not significantly differ from those values obtained when the standard size was used.

For the range of the soils clods sizes used in these tests, no significant differences in the dielectric readings were noted.

Samples compacted at OMC ensured no differences on final dielectric values with respect to compaction energy, clods size or tube diameter used in these laboratory tests.

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List of tables and figures:

TABLE 1 Mineralogy Analysis

	K1-1	Deridder White	HW171
Components	%	%	%
Quartz	67	72	82
K - feldspar	5	11	2
Na - plagioclase	7	10	2
muscovite/illite	4	<1	3
biotite/chlorite	7	5	4
montmorillonite	5		
kaolinite	<1	1	
other clay minerals	<1	1	6
ilmenite	<1		
hematite or Fe oxide	1		1
zircon	<1	<1	<1
titanium dioxide	<1		<1
calcite/dolomite	1	1	

TABLE 2 Compaction effort

	Reduced Compaction	**Standard Proctor Compaction**	**Modified Compaction**	**Modified + Compaction**
Hammer Wt. (lb)	**5.5**	**5.5**	**10**	**10**
Drop Height (in.)	**12**	**12**	**18**	**18**
Number of Blows	**15**	**25**	**25**	**35**
Number of Layers	**3**	**3**	**5**	**5**

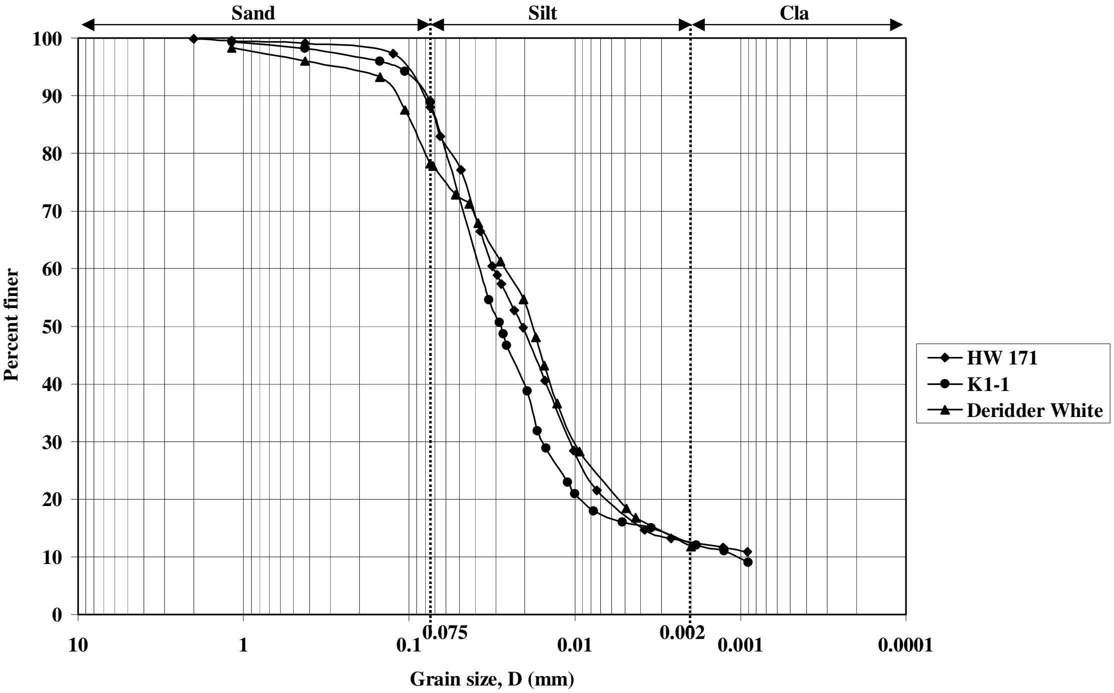

FIGURE 1 Gradation Curves.

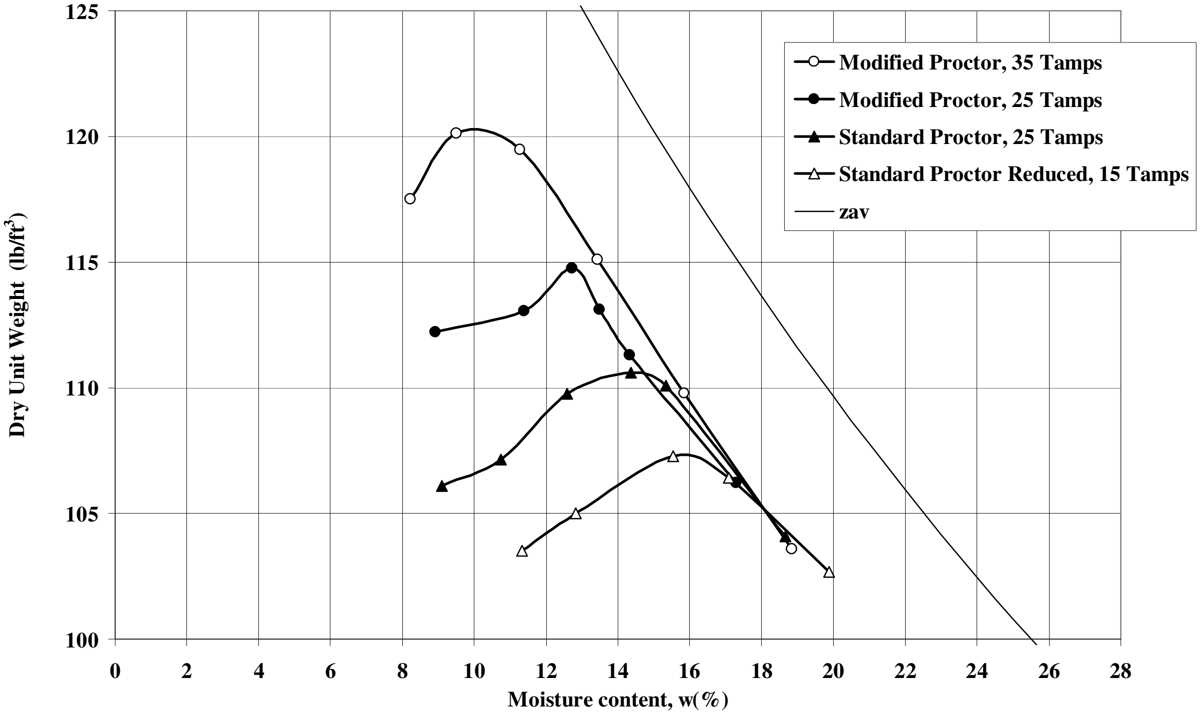

FIGURE 2 Multiple Levels of Energy, K1-1

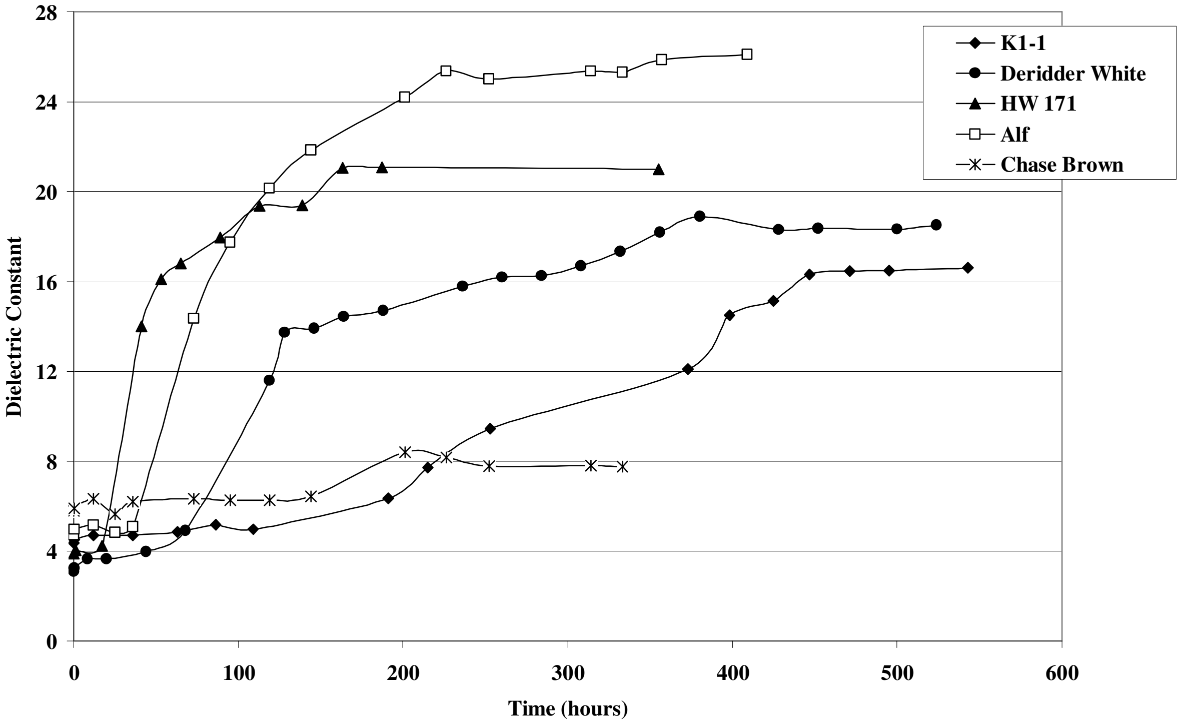

FIGURE 3 Tube Suction Test Results

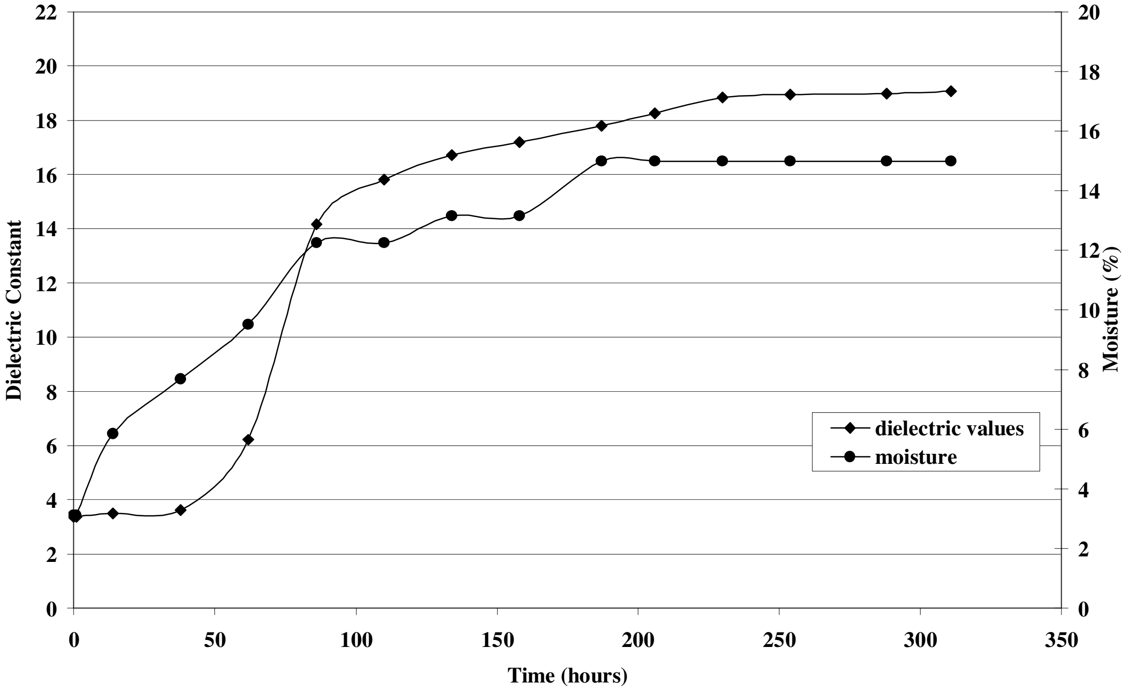

FIGURE 4 Variation of Moisture and Dielectric values with Time for HW 171

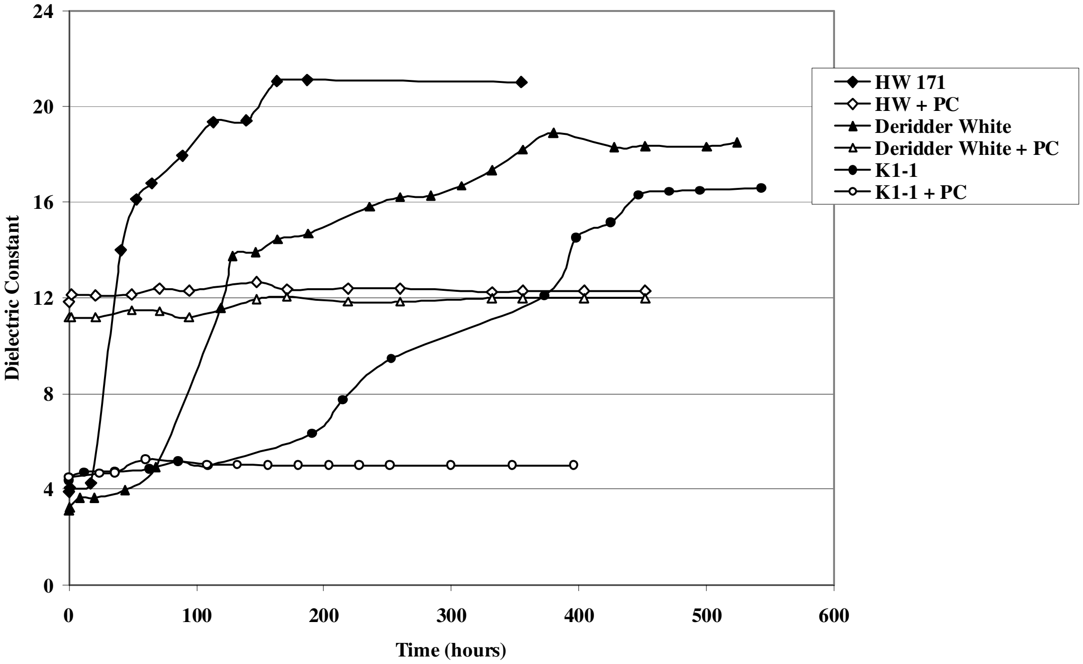

FIGURE 5 Comparative TST Results for Silts and Stabilized Silts

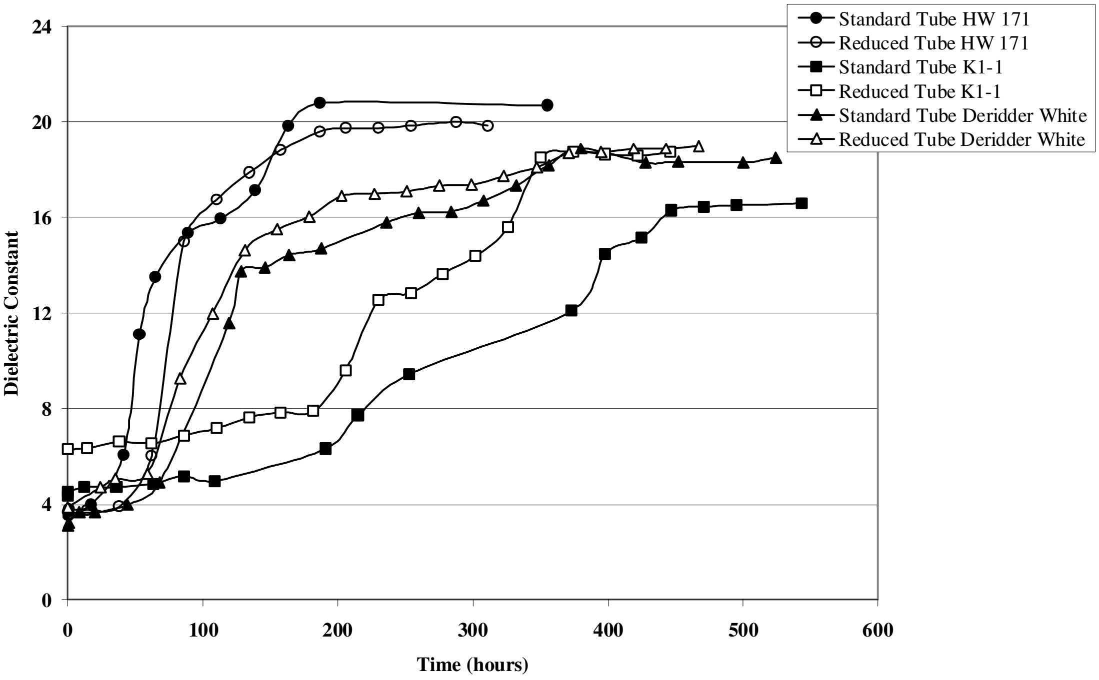

FIGURE 6 Tube Suction Test Results for Different Tube's Diameters

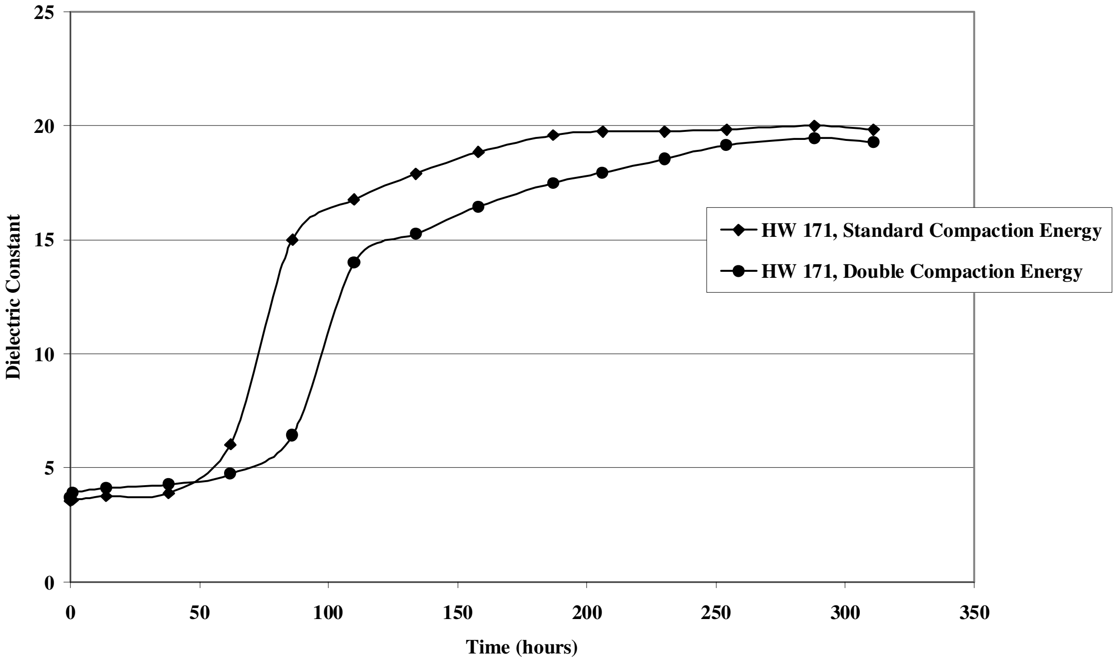

FIGURE 7 Tube Suction Test Results HW 171, Different Compaction Energies

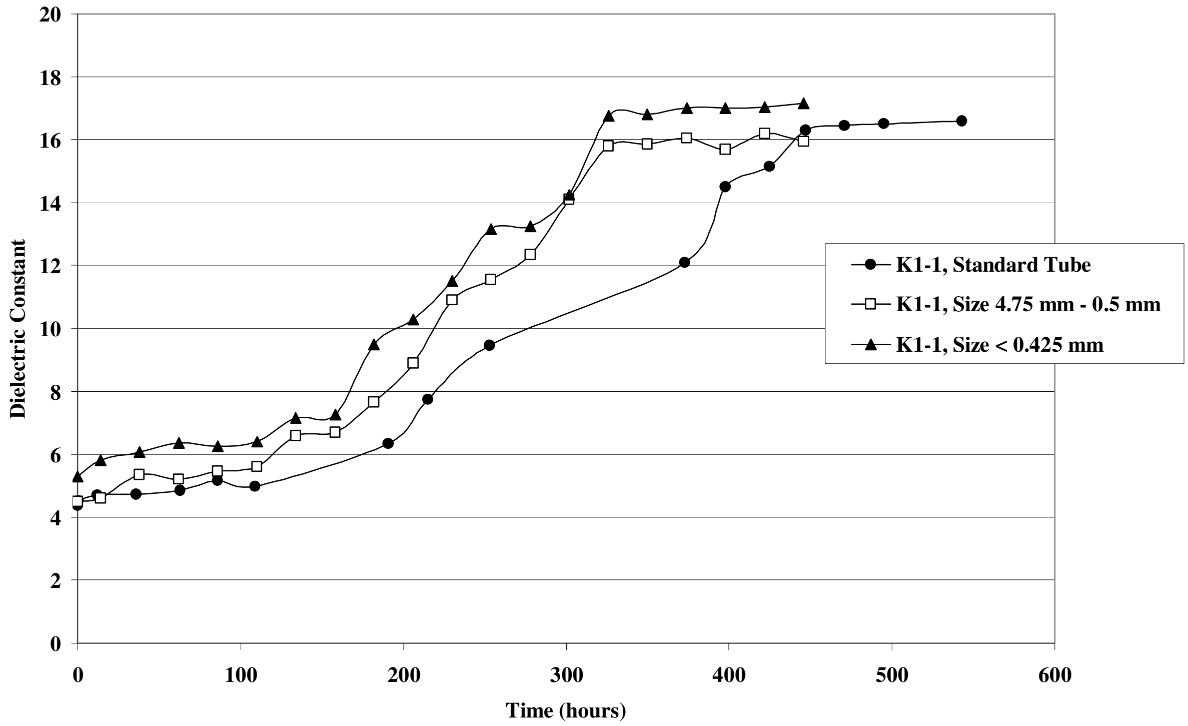

FIGURE 8 Tube Suction Test Results K1-1, Different Clods Size