Improved Shrinkage and Bulkage Factors for Cohesionless Soils

by

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1999 Transportation Research Board Annual Meeting
Washington, D.C.

ABSTRACT

A methodology for estimating shrinkage and bulkage factors for granular soils is described in this paper, based upon the changes in the unit weight of the soil as it is excavated, transported, and compacted. Soil unit weights are determined from several borrow pits in the Central Florida area. Laboratory testing, such as grain size distribution analyses, unit volume box tests and standard Proctor tests, and field testing using drive sleeve tests, nuclear density tests, cone penetration tests, and dilatometer tests, has been used to determine the unit weights of the soil at the three stages of earthwork construction.

A method has been developed to correlate the results of the cone penetration testing (CPT) to in-situ dry unit weight of sandy soils using maximum and minimum unit weights estimated using the uniformity coefficient obtained from the grain size distribution analysis. Dilatometer test results were also utilized to estimate the dry unit weight of the soil but were found to over-predict the values in most cases. A unit volume box test was used to simulate the unit weight of a soil while in a loose state simulating a truck. Lastly, the compacted unit weight values were obtained from the field logs or using standard Proctor tests in the laboratory. Based upon the results of all the tests, average values of shrinkage and bulkage factors are computed. For AASHTO Type A-3 granular soils, shrinkage factors of 10 to 15% and a bulkage factor of 25% are recommended for general use based on the current research. The recommended shrinkage adjustment values take into account other undetermined factors that may also influence the earthwork estimation.

KEYWORDS

shrinkage and bulkage factors, borrow soils, cone penetration test, earthwork estimation.

INTRODUCTION

The use of shrinkage and bulkage factors in earthwork applications is a common practice in most construction. The shrinkage factor indicates the reduction in volume of soil from the borrow pit stage to the final compacted stage, while the bulkage factor accounts for the increase in volume of the soil between the borrow pit and the loose state during transportation in the truck. The current practice adopts arbitrary factors, based only on engineering experience, to account for adjustment of fill as it is excavated, transported, placed at a construction site, and compacted. For example, shrinkage values for the Florida Department of Transportation (FDOT) range from 30 to 35% while a bulkage factor of 25% is adopted for most construction projects. The NAVFAC Design Manual (1982) recommends a shrinkage factor of 10 - 15%, and the British Columbia Forestry Service (1995) suggests shrinkage factors of 5 - 10% and bulkage factors of 10 - 30% based on soil type. In addition, the Caterpillar Performance Handbook (1995) offers insightful definitions for shrinkage and bulkage and the proper calculations of these factors. It is pointed out in these publications that the shrinkage properties will vary with compaction method, moisture content, grain size, and in-situ unit weight.

However, adopting factors, without extensive knowledge of the local soils, has proven to be costly and over- or under-predicted shrinkage and bulkage factors have caused significant losses to the FDOT along with significant variations in the nature of the construction work. A study similar to the present research was conducted by the Georgia DOT (Scruggs, 1990), which stated that the actual shrinkage factors exceed the published values resulting in cost overruns on numerous projects. This report also presents more accurate means of predicting these shrinkage and bulkage factors for each district in Georgia. Others such as Helton (1992), Lewis (1983) and Neil (1982) have also provided guidelines for proper calculation of shrinkage and bulkage factors. Lastly, a study by Leary and Woodward (1973) describes the applicability of relative density of a granular soil as a valid construction control criterion.

It is apparent that the shrinkage and bulkage factors selected for earthwork calculations have a direct relationship to the accuracy of the planned quantity estimated for the purpose of budgeting. This paper deals with the estimation of shrinkage and bulkage factors from field studies conducted in the Central Florida area. Further studies are planned in the near future for other areas of the state to determine suitable factors based on various types of soils encountered.

EXCAVATION CLASSIFICATION

The scope of this study deals primarily with roadway and borrow excavations based on the definitions of the FDOT (1991). Roadway excavation refers to the net volume of the material excavated at the site between the original ground surface and the bottom of the roadway template. Borrow excavation is the net volume of material that the earthwork contractor must furnish from areas generally outside the project boundaries. If available, borrow materials may also be obtained from within the right of way of the project. Borrow excavation is measured using two methods - Pit Measure or Truck Measure. In each case, the designer has to apply correction factors to the net total fill volume calculated from the roadwork plans to account for reduction in soil volume or losses due to handling from one stage to another.

Earthwork volumes occupy three different stages consisting of:

(1) In-place state or pit measure,

(2) Loose state, as in a truck (truck measure, borrow excavation only),

(3) Design Fill or Compacted State.

Currently, the practice of computing these factors in Florida is based on the Roadways Plans Preparation Manual of the FDOT (1989) where typical values are assigned based upon the recommendations of the district offices.

DEFINITION OF SHRINKAGE AND BULKAGE FACTORS

As described previously, shrinkage is used to define the reduction in volume of the quantity of soil when it is obtained from a cut and is placed and compacted to form an embankment or fill. Based upon the net volumes of the design fill and the borrow materials from the excavation, a theoretical shrinkage factor (SF) is defined as

$$SF = \frac{V_E - V_C}{V_E} \tag{1}$$

where V_E is the volume of the excavated soil and V_C is the volume of the compacted soil. The shrinkage factor can also be expressed in terms of the dry unit weight of the two states of soil as follows:

$$SF = 1 - \frac{(\gamma_d)_E}{(\gamma_d)_C} \tag{2}$$

where $\left(\gamma_d\right)_E$ is the dry unit weight of the in-place excavated soil and $\left(\gamma_d\right)_C$ is the dry unit weight of the compacted soil at the specified percent compaction. The compacted dry unit weight at 100-103% of the standard Proctor compaction is usually greater than the dry unit weight of in-place material and the soil has a positive shrinkage factor.

The bulkage factor (BF) is used to account for the additional volume that the soil occupies when it is in a loose state, as in the case of being in a truck. It is defined as the difference in volume between the loose volume in the truck and the excavated volume from the borrow pit, expressed as a percentage of the excavated volume. The bulkage factor can be expressed as,

$$BF = \frac{V_T - V_E}{V_E} \tag{3}$$

where V_T is the volume of the loose borrow soil in the truck. In terms of the soil dry unit weight in the loose state in the truck and the dry unit weight of the borrow material in the pit before placement, the bulkage factor can be expressed as:

$$BF = \frac{\left(\gamma_d\right)_E}{\left(\gamma_d\right)_T} - 1 \tag{4}$$

The adjustments applied to the computed earthwork quantities based on the two factors may be summarized in the following relation:

$$V_T = \left[\frac{V_C}{(1 - SF)} - V_{roadway} \right](1 + BF) \tag{5}$$

where V_T is the amount of borrow material needed, V_C is the design fill, and $V_{roadway}$ is the volume of roadway excavation obtained from the right-of-way of the construction project. It must be noted that several parameters influence the quantity of earthwork including grain size, moisture content, and losses during each stage.

SOIL UNIT WEIGHT TRACKING PROGRAM

A soil unit weight tracking program was established to study the volumetric changes of the soil as it moved from the borrow pit to the project site. Figure 1 depicts the three stages of this program wherein the theoretical volume of soil is tracked from its in-place location to its final compacted state. Assuming no significant volumetric losses of soil occur during transport, dry unit weights of the soil are determined from the field and laboratory tests, and are used in calculating the shrinkage and bulkage factors.

Three field projects, in the Central Florida area, were selected to monitor the volumetric changes and to conduct field tests. These were:

(a) Expansion of Interstate 4 in Seminole County (4.4 miles),

(b) Lane expansions of State Road 44 in Sumter County (4 miles), and

(c) State Road 5 (Nova Road) in Volusia County.

All the projects were located within District Five of the FDOT, and of the fifteen available borrow pits at the sites, five were selected for detailed site investigations. Those borrow pits consisted of retention ponds “A”, “F”, and “J” at the I-4 project, retention area #4 at the SR 44 project site, and pond #1 at the SR5 project site. These ponds averaged 8,000 m^2 in size with a total cut volume exceeding 40,000 m^3.

Field and Laboratory Methods for Estimating Soil Unit Weights

Methods for determining soil unit weights at the three stages of earthwork described above are discussed here. The objective is to describe the tests performed and relate each test to the unit weight of the particular excavation classification. This provides the basis for the ultimate calculation of the theoretical shrinkage and bulkage factors.

Field Tests

The nuclear density gauge is one of the most accurate methods for measuring soil unit weight and moisture content on relatively undisturbed areas conducted in accordance with ASTM D2922-71. This device was used to obtain the unit weight of in-situ soils in the excavation borrow pits (retention ponds), in haul trucks loaded with the same soil at the point of loading, and at the site where the soil was compacted.

Field tests, such as the cone penetration test (CPT) and the dilatometer, have been used mainly for identifying the stratification of soils and estimating pile load capacities. These tests do not directly determine the unit weight of the soil. In this study, indirect relationships were developed for obtaining in-situ soil unit weights from these tests. Previous research (Schmertmann, 1976 and Vesic, 1977) has found that the cone penetration resistance, Q_c, can be related to the relative density, D_r, of soils. More recently, Baldi *et al*. (1986) elaborated on this correlation through the use of the vertical effective stress, σ'_{vo}. The present research makes use of this relationship and the definition for relative density through maximum and minimum unit weights to estimate the in situ pit density. The equation proposed by Baldi *et al.* (1986) is as follows:

$$D_r = \frac{1}{C_2}\left[\frac{Q_c/K_q}{C_0\left(\sigma'_{vo}\right)^{C_1}}\right] \tag{6}$$

where, for most sands, C_0 = 157, C_1 = 0.55, C_2 = 2.41, Q_c and σ'_{vo} are expressed in kPa, and K_q is a calibration chamber correction factor for field data suggested by Parkin and Lunne (1984) and may be expressed as,

$$K_q = 1 + \frac{\left(D_r - 30\right)}{60} \tag{7}$$

The dependence on laboratory maximum and minimum unit weights initially made the use of this correlation questionable. However, an additional correlation through the use of the uniformity coefficient of the soil obtained from grain size distribution analysis, provides a more reliable substitute for the determination of maximum and minimum unit weights from the laboratory.

Johnston (1973) found that an empirical relationship exists between the coefficient of uniformity of a soil and its corresponding maximum and minimum dry unit weights. This relationship is based on (a) the assumption that the unit weight of cohesionless soil is a function of the grain-size distribution and specific gravity and (b) test results on sub-angular to rounded granular soils having all material retained on the U.S. Standard 200 sieve and specific gravity from 2.65 to 2.89. Figure 2 represents the empirical relationship of C_u on a logarithmic scale versus the maximum and minimum dry unit weights on an arithmetic scale, with a normalized specific gravity of 2.65. These curves can be used to estimate the maximum and minimum dry unit weight if the grain-shape and specific gravity of the soil are known. The coefficient of uniformity has also been related to maximum dry unit weight of the soil by Lacroix and Horn (1973), Leary and Woodward (1973), and Poulos and Hed (1973).

The equations of the maximum dry unit weight and minimum dry unit weight are estimated from Figure 2 as:

$$\tilde{\gamma}_{d(\max)} = 31.5 \log\left(C_u\right) + 92.5 \tag{8a}$$

$$\tilde{\gamma}_{d(\min)} = 31.5 \log\left(C_u\right) + 70.5 \tag{8b}$$

The maximum and minimum dry unit weights obtained from these relationships are then corrected for the normalized specific gravity.

This correlation allows for the estimation of the in-situ relative density and is used within an iterative method to obtain the in-situ dry unit weight. The iterative procedure is summarized in several steps as follows:

- The first step is the assumption of an arbitrary initial in-situ unit weight, usually the minimum dry unit weight, for a specified value of corrected cone tip resistance and depth. Based on this in-situ unit weight, the relative density is calculated from the following relationship:

$$D_r = \left[\frac{\gamma_d - \gamma_{d(\min)}}{\gamma_{d(\max)} - \gamma_{d(\min)}}\right]\left[\frac{\gamma_{d(\max)}}{\gamma_d}\right] \tag{9}$$

where $\gamma_{d(max)}$ and $\gamma_{d(min)}$ represent the dry unit weight of the soil in the densest and loosest condition obtained using maximum/minimum unit weight tests in the laboratory or from correlation with the coefficient of uniformity from sieve analyses.

- The second step is to calculate the vertical effective stress at known moisture content, ω, based the penetration depth. A soil is considered completely saturated if submerged under the groundwater table and unsaturated if above the ground water table. For the completely saturated condition, the vertical effective stress can be expressed as,

$$\sigma'_{vo} = \frac{\gamma_d z(G_s - 1)}{G_s} \tag{10}$$

where G_s is the specific gravity of the soil determined from the laboratory test and z is the current depth of penetration of the cone. For the unsaturated condition, the vertical effective stress is a function of the moisture content and may be expressed as:

$$\sigma'_{vo} = \gamma_d (1 + \omega) z \tag{11}$$

- The third step uses the relationship between relative density and vertical effective stress. The relative density from the first step is used to calculate the cone tip resistance factor, K_q, from Equation (7). Equation (6) is then used to calculate the in-situ relative density.
- In the final step, the relative density computed from the above step is compared with the value computed in the first step. This iterative process is continued until the two values converge to within a small tolerance. The converged value is considered to be the best estimate for the in-situ dry unit weight of the soil under the constraints of known cone tip resistance, depth, uniformity coefficient, minimum and maximum unit weight.

A sensitivity analysis confirmed that the moisture content has little effect on the determination of the in-situ dry unit weight, showing less than a 1% difference when the moisture content was changed from 3% to 33%, the normal range of moisture content for most borrow soils.

The third field test used for determining the in-situ unit weight is the dilatometer test. Dry unit weights are determined based on the chart provided by Marchetti and Crapps (1981) which relates the soil unit weight and dilatometer modulus.

Laboratory Tests

The soils from each project site were subjected to a battery of tests to determine soil properties used in determining the dry unit weight of the soil. The laboratory tests performed were the maximum and minimum unit weight tests, standard Proctor test, and grain size distribution and specific gravity tests.

The theoretical maximum and minimum unit weights of a soil were obtained in accordance with test procedures from ASTM D2049-69 and were used in this research as a reference for the range of maximum possible shrinkage or bulkage of the soil. It is important to note, the validity of these tests has been under continual scrutiny. Therefore, the gradation of the soil will be an important soil characteristic for this research. The uniformity coefficient will be used in this research to estimate the maximum and minimum unit weights of untested soils.

A unit volume box was used to determine the unit weight of soil under loose conditions as it was transported in a truck from the in-situ state to the compacted state. During the field work, the assumption was made that the actual moisture content obtained using the calcium carbide gas pressure moisture tests, also called Speedy moisture test (FM 5-507), was a sufficient indicator of the moisture in the soil.

RESULTS OF FIELD TESTS

Soil types encountered at each of the borrow pits are summarized in Table 1 along with the corresponding percentage passing the 200 sieve. All soils may be classified as AASHTO type A-3 soils and were used as the compacted fill layers at all the construction sites.

In-Situ (Pit) Unit Weight Results

Nuclear density and drive sleeve tests were conducted at the borrow pits (earmarked for use as retention ponds) and the results are presented in Table 2. The values obtained from these two testing methods are quite often very near each other, and it should be noted that the drive sleeve testing performed at Pond “J” was conducted after the completion of grading, where the unit weight of the soil was higher than normal in-situ values.

CPT and dilatometer soundings conducted at the borrow pits ranged in depths of penetration from 3 m to 6.5 m. The iterative program described in the previous section, is used to determine the in-situ unit weight based upon CPT cone resistance values obtained from the retention ponds. A table of the weighted average in-situ dry unit weights calculated, along with the moisture content, for the maximum/minimum unit weight based correlation and those obtained based on the uniformity coefficient, C_u, are presented in Table 3. Further details for the computation of these values may be found in Negron (1997). It should be noted that the uniformity coefficient for the soil samples from SR5 project was much higher in magnitude than all other cases. This resulted in very high values of minimum and maximum unit weights from C_u correlation and significantly different in-situ dry unit weights for this pond.

In-situ dry unit weights were also estimated from dilatometer soundings at each pond. Table 4 shows a comparison of dry unit weight values obtained from the dilatometer soundings and the dry unit weights obtained from nuclear density test. In all but one case, the in-situ unit weight found using the dilatometer substantially over-estimated the values.

Truck Unit Weight Results

Nuclear density tests were performed on the soils in trucks hauling soil from Pond “J”, Pond #4 and the SR5 pond to obtain the loose unit weight. However, these values are considerably higher due to localized densification beneath the nuclear device. Instead, unit volume box tests were performed at each pond to simulate the unit weight in the truck. The results of the unit box tests are displayed in Table 5.

Compacted Unit Weight Results

Compacted unit weights were obtained in the field for Ponds “A”, “J”, and #4 using the nuclear density and Speedy moisture tests (FM 5-507), and checked against values obtained from the standard Proctor tests. The results of these tests are shown in Figure 3, with average values of 16.4 kN/m^3 for Pond “A”, 16.1 kN/m^3 for Pond “J”, 17.9 kN/m^3 for Pond #4, and 17.5 kN/m^3 for the SR5 pond. Due to the lack of excavation at Pond “F”, compacted values for this pond were not available, and the maximum unit weight of 15.9 kN/m^3 obtained using only the standard Proctor test was used to as the compacted unit weight.

Discussion of Results

Table 6 summarizes the dry unit weights obtained at each stage of earthwork from each field and laboratory test conducted. From the data, it is evident that the field compacted unit weights are within 100-103% of the standard Proctor values as specified by FDOT compaction requirements.

Test results obtained from the drive sleeve test and cone penetration test were compared with results obtained from the nuclear density test at similar depths. These comparisons are shown in Figures 4 and 5. The unit weight values from the drive sleeve test compared well with the corresponding values from the nuclear density test. In addition, the dry unit weight values obtained from the cone penetration test based on the uniformity coefficient compared well with the nuclear test results. In contrast, the cone penetration test based on the maximum/minimum test results from the laboratory showed a consistent underestimation of the dry unit weights obtained from the nuclear device. The results from C_u - based correlation are recommended for the computation of these adjustment factors.

Ultimately, the dry unit weights from each stage of excavation were used to calculate the shrinkage and bulkage factors for each borrow pit and the results are shown in Table 7. The average shrinkage factor for the five ponds is 6 %, while the average bulkage factor is 26 %. Keeping in mind that there are several other undetermined factors such as wastage and errors in cross-sections that may influence these earthwork factors, a shrinkage factor of 10-15% and a bulkage factor of 25% are recommended to be used for AASHTO type A-3 soils that were investigated in this research. The shrinkage factors are found to be significantly lower than the shrinkage factors currently used by the FDOT (30 - 35%) while the bulkage factor seemed to agree well with FDOT recommended bulkage factor of 25%.

CONCLUSIONS

This paper describes a procedure for estimating shrinkage and bulkage factors based on volumetric changes of soils. The volumetric changes of the soil was tracked from the in-situ state, to a bulked state during transport, and in a compacted state using the direct and indirect methods for estimating dry unit weights. Based on field monitoring of changes in unit weight and taking into account other factors that may influence volumetric changes, shrinkage factors of 10 to 15% and a bulkage factor of 25% were recommended for type A-3 sandy soils.

One of the most noteworthy contributions is an iterative procedure for estimating in-situ dry unit weights of soils from CPT values based on soil properties that can be determined from grain size distribution analyses.

ACKNOWLEDGMENTS

The first two authors would like to acknowledge the financial support of the Florida Department of Transportation which funded this project through a grant (number: WPI 0510796). The valuable advice and guidance of the project manager, Dr. Robert K.H. Ho, P.E., is gratefully recognized.

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LIST OF FIGURES

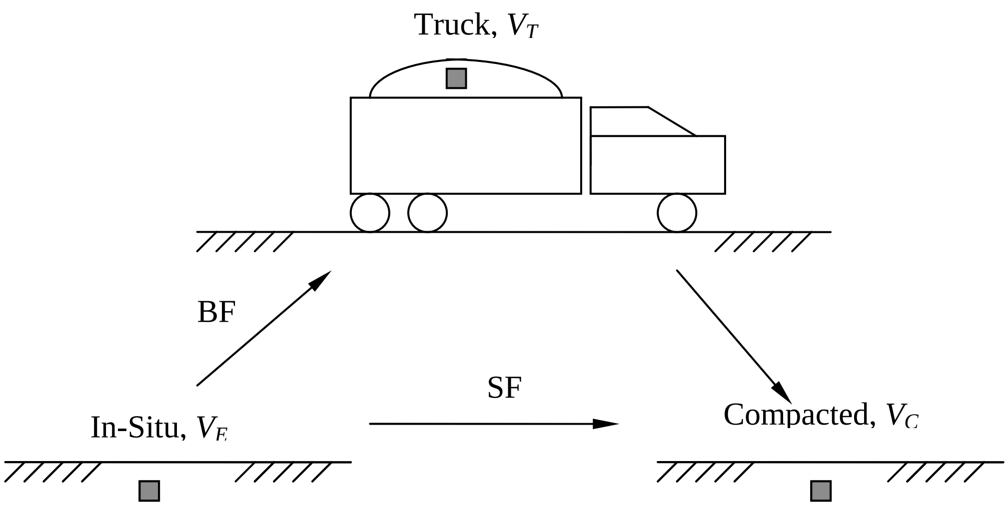

Figure 1. Soil Tracking Program

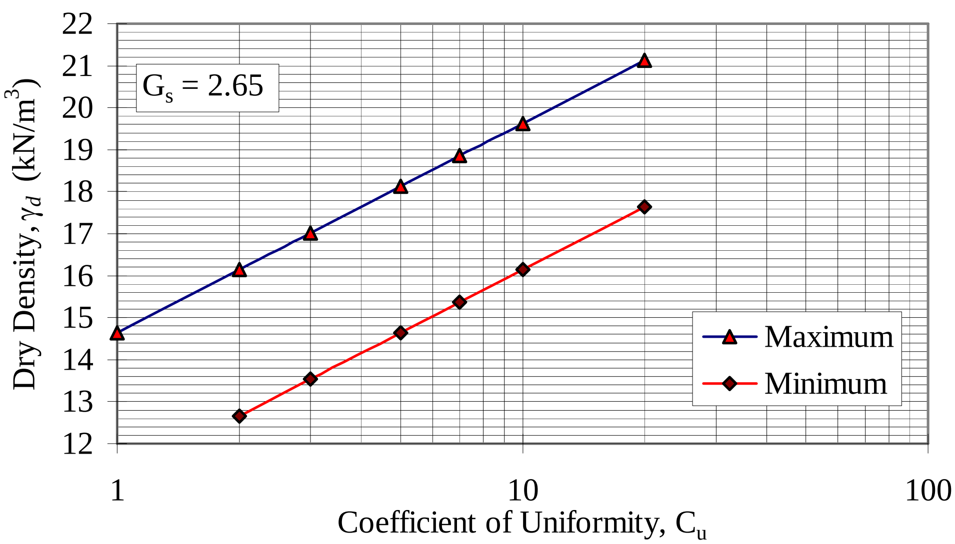

Figure 2. Maximum and Minimum Unit Weights versus Coefficient of Uniformity (G_s = 2.65)

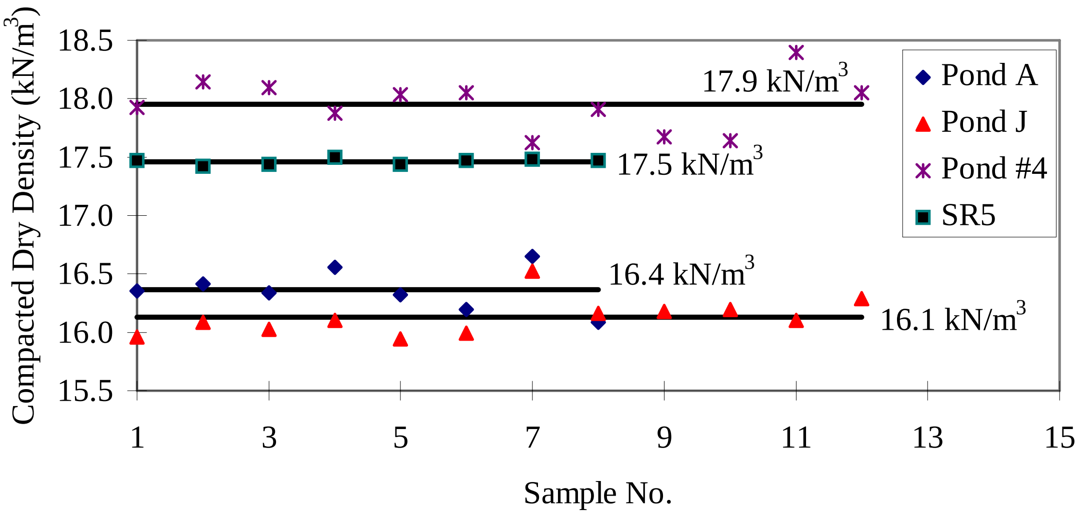

Figure 3. Compacted Dry Unit Weights Using Nuclear Density Tests

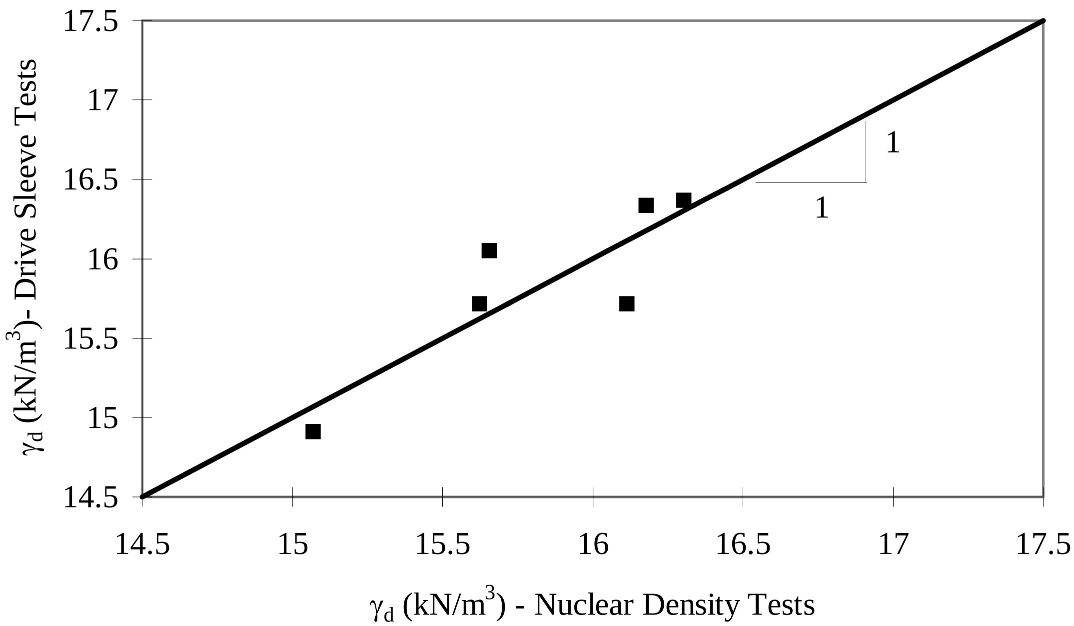

Figure 4. Comparison of Dry Unit Weights from Nuclear Density and Drive Sleeve Tests

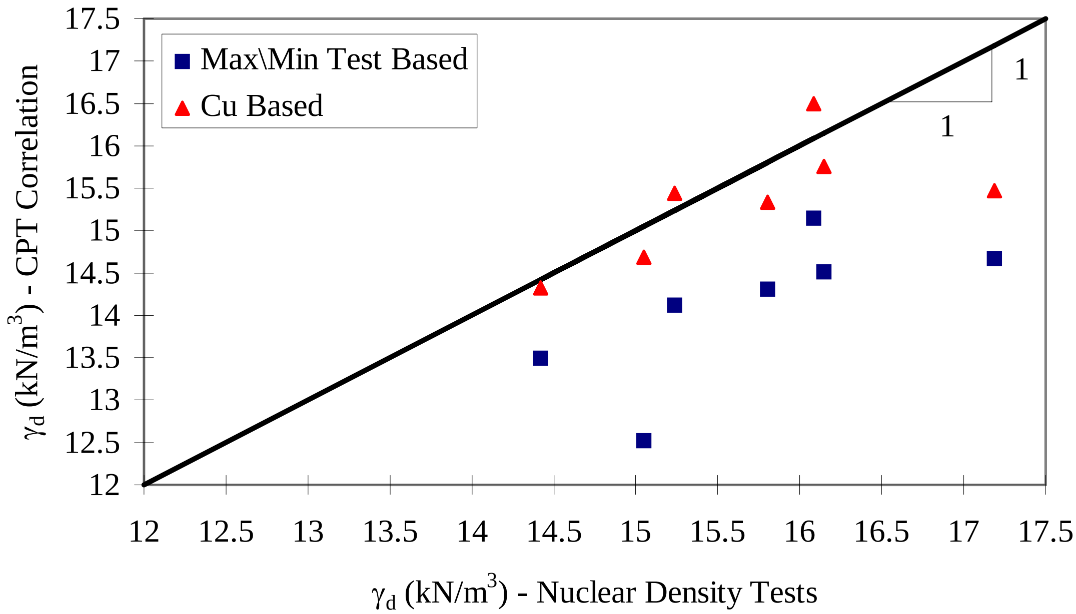

Figure 5. Comparison of Dry Unit Weights from Nuclear Density and CPT Correlation

LIST OF TABLES

Table 1. Soils Encountered at Borrow Pits

Project Site	Borrow Pit	Description of Soil	Average Passing 200 sieve	Uniformity Coefficient C_u
I-4	Pond A	Light Tan to Tan Sand	6%	2.53
I-4	Pond F	Light Gray to Tan Sand	2.5%	2.27
I-4	Pond J	Light Tan Sand	4%	1.67
SR44	Pond #4	Gray, Orange, and Tan Sands	8.5%	2.31
SR5	Pond #1	Gray Sand with Shell	4.5%	8.44

Table 2. Field Results Using Drive Sleeve and Nuclear Density Tests

Borrow Pit - Sample	γ (kN/m^3) - Drive Sleeve Test	ω (%) - Moisture Content	γ_d (kN/m^3)	γ (kN/m^3) - Nuclear Density Test	ω (%) - Moisture Content	γ_d (kN/m^3)
A - 1	17.1	5.3	16.2	17.0	4.9	16.2
A - 2	16.2	3.6	15.6	16.1	3.8	15.5
A - 3	17.0	9.3	15.6	17.4	8.7	16.0
A - 4	16.3	9.9	14.8	16.6	11.0	15.0
F - 1	17.2	6.4	16.2	17.1	6.4	16.0
F - 2	16.6	3.9	15.9	16.1	3.9	15.5
J - 1	18.6	10.9	16.8	15.8	3.7	15.9
J - 2	17.1	4.6	16.3	15.2	5.5	14.4
J - 3	17.8	10.3	16.1	15.6	4.8	14.9
#4 - 1	X	X	X	18.4	7.0	17.2
#4 - 2	X	X	X	18.7	16.1	16.1
SR5 - 1	X	X	X	17.9	20.4	14.9
SR5 - 2	X	X	X	16.2	13.6	14.2
SR5 - 3	X	X	X	15.4	9.9	14.0
SR5 - 4	X	X	X	15.3	9.2	14.0

1 pcf =0.1571 kN/m^3 X = Not Conducted

Table 3. Weighted Average In-Situ Dry Unit Weights Using Cone Penetration Tests

Borrow Pit - CPT Number	Average Q_c (tonne/m^2)	Max/Min Test Based		C_u - Based	
		γ_d (kN/m^3)	ω (%)	γ_d (kN/m^3)	ω (%)
Pond A - 1	1284	14.3	12.0	15.8	0.0
Pond A - 2	1015	13.9	12.0	15.6	0.0
Pond F - 1	476	13.1	12.0	14.5	0.0
Pond J - 1	726	12.9	13.7	14.4	0.0
Pond J - 2	526	12.6	13.8	13.7	0.0
Pond #4 - 1	480	14.5	13.6	15.7	0.0
Pond #4 - 2	433	14.1	12.6	15.0	0.0
SR5 Pond - 1	1041	16.9	14.0	19.1	0.0
SR5 Pond - 2	899	17.3	14.0	19.0	0.0
SR5 Pond - 3	1038	16.8	14.0	19.1	0.0
SR5 Pond - 4	982	15.6	14.0	19.1	0.0

1 tsf = 9.61 tonne/m^2
1 pcf =0.1571 kN/m^3

Table 4. Dry Unit Weights from Nuclear Density Test and Dilatometer Soundings

Borrow Pit - Sounding No.	Nuclear Density γ_d (kN/m^3)	Dilatometer γ_d (kN/m^3)	ω (%)
Pond A - 1	16.1	17.5	12
Pond A - 2	15.2	17.5	12
Pond F - 1	15.8	15.8	12
Pond J - 1	15.0	17.4	13.7
Pond J - 2	14.4	16.8	13.8
Pond #4 - 1	16.1	16.3	13.6
Pond #4 - 2	17.2	16.8	12.6
SR5 Pond - 1	14.9	16.7	14.0
SR5 Pond - 2	14.2	16.1	14.0
SR5 Pond - 3	14.0	16.7	14.0
SR5 Pond - 4	14.0	16.9	14.0

1 pcf =0.1571 kN/m^3

Table 5. Unit Volume Box Test: Average Results for Each Borrow Pit

Borrow Pit	γ (kN/m^3)-Unit Volume Test	ω (%)	γ_d (kN/m^3)
Pond A	12.8	3.69	12.4
Pond F	12.5	3.53	12.1
Pond J	13.2	0	13.2
Pond #4	12.7	1.43	12.5
SR5 Pond	12.3	3.1	11.9

1 pcf =0.1571 kN/m^3

Table 6. Summary of Dry Unit Weights Obtained from Field and Laboratory Tests

Test Performed	Average Dry Unit Weight (kN/m^3)														
	In-Situ					Truck					Compacted				
Pond	A	F	J	#4	SR5	A	F	J	#4	SR5	A	F	J	#4	SR5
Nuclear Density	15.7	16.1	14.8	16.7	14.4	X	X	X	X	X	16.4	X	16.1	17.9	17.3
Standard Proctor											16.0	15.9	16.0	18.1	17.4
Drive Sleeve	15.6	16.1	16.4	X	X										
Unit Volume Box						12.4	12.1	13.2	12.5	11.9					
Cone Penetration - Max/Min Test	14.1	13.1	12.8	14.3	16.7										
Cone Penetration - C_u - Based	15.7	14.5	14.0	15.3	19.1										
Dilatometer	17.5	15.8	17.1	16.5	16.6										
AVERAGE	**15.7**	**15.1**	**15.0**	**15.7**	**16.7**	**12.4**	**12.1**	**13.2**	**12.5**	**11.9**	**16.2**	**15.9**	**16.1**	**18.0**	**17.4**

X = Test Not Conducted Shaded = Not Applicable

1 pcf =0.1571 kN/m^3

Table 7. Shrinkage and Bulkage Factors from Field Project Data

Field Project	Borrow Pits	SF (%)	BF (%)
I-4	Pond A	3.1	26.6
I-4	Pond F	5.0	24.8
I-4	Pond J	6.8	13.6
SR44	Pond #4	12.8	25.6
SR5	Pond #1	2.3	40.3
	Average	**6.0**	**26.2**