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Standard penetration test correlations for Las Vegas soils

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STANDARD PENETRATION TEST CORRELATIONS FOR LAS VEGAS SOILS

by

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ABSTRACT

Standard penetration tests (SPT) are used to approximate soil properties including the consistency, cohesion and the internal angle of friction. Due to the frequency of cemented sands, gravel and clay in the Las Vegas Valley, the generally accepted SPT correlations vary from actual local conditions. The following discussion will present SPT correlations, based on field test data, for consistency, cohesion and the internal angle of friction, specifically for the Las Vegas Valley. The Las Vegas soil correlations are compared to general soil correlations.

Sampling methods other than the Standard Penetration Test are used to estimate soil characteristics. The STP uses a 1.375 inch inside diameter sampler with a 150# hammer dropped 30 inches. The driven sample method, often used in Las Vegas, utilizes a 2.625 inch inside diameter sampler with a 350# hammer dropped 30 inches. Correlations, relative to Las Vegas soils, between the two tests are discussed.

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CHAPTER 1

INTRODUCTION

Purpose of Discussion

The population in the Las Vegas Valley increased from approximately 275,000 inhabitants in 1970 to approximately 1,000,000 residents in 1995. The rapid population growth required additional development and infrastructure which, in turn, led to an increase of the local engineering population. Needless to say, the majority of the engineers arrived from outside the Las Vegas Valley.

In practice, the author encountered engineers who often use blow count values, N, to estimate local soil properties based on ranges displayed in generalized charts. The purpose of this discussion is to determine if correlations are present between corrected blow count values, the internal angle of friction and the cohesion for the different soil types and consistencies encountered in the Las Vegas Valley.

Objective

The objective of this discussion is to compare the correlations derived for Las Vegas soils to general soil correlation tables.

Methodology

The following steps are taken in an effort to establish soil correlations for Las Vegas soils and to compare them to the general soil correlation tables:

- Background
  - Discuss subsurface soil sampling
  - Discuss Standard Penetration Test corrections
  - Discuss existing general correlation tables
- Discussion of Las Vegas Data Base
- Analysis of Data
  - Discuss the chronology of analysis
  - Analyze soil from two Las Vegas regions
- Conclusions

CHAPTER II

BACKGROUND

Subsurface Soil Sampling

Subsurface soil sampling is an integral step in any construction process requiring foundations or facilities in contact with soil. Soil sampling is used to provide insight to the following:

- How the soil reacts under stress and loading conditions.
- The location of the ground water table.
- Soil stratification.
- Provide material for laboratory testing.

Several methods for obtaining soil samples are commonly used including the Standard Penetration Test (SPT), Cone Penetration Test (CPT), Field Vane Testing (FVT), Bore hole Shear Test (BST) and the Pressuremeter Test (PMT). The standard penetration test is the most economical and widely used sampling method.

The CPT pushes a cone into the soil at a constant rate. The resistance to the penetration and the frictional resistance of the casing to the soil surrounding it are measured. The CPT may be used for all soils except very course granular soils. Bore holes are not required for the test.

The VST is standardized as ASTM D 2573 and is used to determine the in-situ undrained shear strength of clay soils. The VST is most effective in soft clays. The vanes of the testing device are pushed into the soil at the bottom of the bore hole and are then rotated. The torque can be related to the undrained strength of clayey soil.

The BST incorporates a device which expands against the sides of the bore hole. The incremental test results are used to plot Mohr diagrams for confined-drained tests. The BST is best utilized for silty soils.

The PMT, similar to the BST, utilizes a cylindrical device which incrementally applies pressure to the sides of the bore hole. The PMT may be used for all soil types.

The following discussion will focus on the Standard Penetration Test and a similar split spoon method known as the Driven Sample Test (DS), with regard to Las Vegas Valley soils.

Split Spoon Soil Sampling

Standard Penetration Test

The SPT, developed in 1927, was standardized in 1958 as ASTM D 1586. Because of its simplicity, economy and the availability of equipment necessary to perform the test, the SPT is used throughout the world and is the most commonly used sampling method in North and South America.

The SPT is conducted using a split-spoon sampler. The typical split-spoon sampler consists of a barrel shoe, or split barrel or tube, a solid sleeve and a coupling at the top. The coupling attaches the assembly to the drill rod of the drilling rig or apparatus. When the sampler is removed from the bore hole, the halves of the split barrel are separated and the soil sample is removed.

The sampling is conducted by driving the split barrel sampler into the ground with hammer blows on the top of the drill rod. The Standard Penetration Test incorporates the following parameters:

- A 140 pound hammer dropped 30 inches.
- A split barrel sampler with an inside diameter of 1 3/8 inches and an outside diameter of 2 inches.

- The number of hammer blows for three (3) consecutive six inch intervals are recorded. The number of blows required for the last 12 inches is referred to as the *standard penetration number*, N. The initial 6 inches are typically disregarded due to potentially disturbed conditions.

Uses of the Standard Penetration Test

The SPT is used to develop a variety of correlations including; liquefaction assessment and susceptibility, bearing capacity, relative density, modulus of elasticity and the settlement and end-bearing point and shaft resistance of piles.

Driven Sample Test

Due to the frequency of cemented soils in the Las Vegas Valley, split-spoon sampling incorporating a larger sampler and hammer with a greater mass is in common practice. The larger sampler also allows for better "undisturbed" samples of cemented or very dense soils.

The DS method specifically discussed in this thesis incorporates a 340 pound hammer dropped 30 inches. The sampler has an outside diameter of 3.25 inches and an inside diameter of 2.625 inches. With regard to this discussion, the larger sampler and hammer were typically used with the same drilling rig which conducted the standard penetration tests.

Standard Penetration Test Corrections

In the early years of penetration testing and even after the method was standardized, great discrepancies in the comparison of N values between adjacent bore holes led to the analysis of the sampling process. The continuing problem of non-reproducibility of data provided further difficulties. The inconsistencies were discussed by Gibbs and Holts (1957) who hypothesized the difficulties were the effects of overburden pressure and drill rod length. De Mello (1971) then provided the first comprehensive document discussing energy loss as a factor in sampling inconsistencies. Sampling inconsistencies are generally attributed to energy loss, effective overburden pressure, and site characteristics such a particle size, soil aging and overconsolidation.

Energy Loss

Input driving energy and its dissipation around the sampler into the surrounding soil is the principal factor in the wide range of N values encountered while trying to reproduce sampling results (Bowles 1988). Total energy loss is attributed to the actual input energy dissipation before hammer contact in addition to the energy loss encountered after contact is made between the hammer and the drill rod.

In a effort to normalize SPT values, the actual input energy of various testing methods and equipment is used as a base for comparison. For world wide comparison purposes, the commonly agreed upon input energy, Er, also referred to as the rod energy ratio or energy ratio, of 60 % of free fall energy is typical. Almost all researchers and engineers agree that for comparison purposes, an input energy of 60 % of the theoretical free fall energy, should be considered as a reference (DeCourt 1992). The corresponding blow count correction is symbolized by N_{60}. A higher value of N_{70} has been suggested by Riggs (1986) based on a focus on ASTM D 1586 standards and procedures with the use of a safety hammer in North America. Because of equipment and testing method assumptions, the conservative approach of N_{60} will be used for the duration of this paper. A thorough discussion of this topic has been provided by Decourt, Skempton and others as shown in Table 1.

Equipment type and method of testing largely determine the actual input energy, which is symbolized as, Ea. Hammer type, either safety or donut, and the method of release, such as the auto-trip method or the rope-cathead method, may lead to differences between testing results. A safety hammer is a weighted cylinrical sleeve, enclosed at the top, which surrounds a guide rod. The guide rod then couples to the top of the drill rod.

In North America, the most common sampling technique utilizes the rope-cathead method incorporating a safety hammer. This is the method used to conduct the borings discussed in this paper. Additional variable factors of the rope-cathead method include; cathead diameter, type and condition of the rope, and the number of rope turns around the cathead. Correction factors for these discrepancies are presented in Table 2.

Table 1, Author and subject reference list †

Overburden pressure and	Gibbs and Holtz (1957)
	Meyerhof (1957)
	D'Appolonia et al. (1968)
	De Mello (1971)
	Biegamousky and Morcuson (1976)
	Clayton (1985)
	Skempton (1986)
	Liao and Whitman (1986)
	Leonards et al. (1980)
Driving Energy	Schmertmann (1975)
	Schmertmann and Palacios (1979)
	Kovacs and Salomone (1982)
	Riggs et al. (1983, 1986)
	Robertson et al. (1983)
	Skempton (1986)
Length and Weight of Drill Rod	Gibbs and Holtz (1957)
	Mclean et al. (1975)
	Schmertmann and Palacios (1979)
	Seed (1985)
	Skempton (1986)
	DeCourt et el. (1992)
Aging	Seed (1979)
	Mitchell and Solymar (1984)
	Skempton (1986)
	Tokimatsu (1986)
	DeCourt et al. (1992)
Particle Size and Shape	Gibbs and Holtz (1957)
	De Mello (1971)
	Holubec and D'Appolonia (1973)

† Table derived from Skempton (1986) and DeCourt (1992).

Table 2, Standard Penetration Test Corrections †

Hammer Input Energy (Ea), %

Hammer Type:	Donut		Safety	
	Rope Cathead	Auto Trip	Rope Cathead	Auto Trip
Country:				
USA/ N. America	45	---	60-80	80-100
Japan	67	78	---	---
UK	---	---	50	60
China	50	60	---	---

Hammer energy ratio correction, η_1

η_1 = Er/Ea

Er = 60%

Rod Length Correction, η_2

Length	> 30 ft.	η_2= 1.00
	20-30 ft.	= 0.95
	10-20 ft.	= 0.85
	0-10ft.	= 0.75

Sampler correction, η_3

Without Liner		η_3= 1.05
With Liner		
	Dense Sand and Clay	= 0.80
	Loose Sand	= 0.90

Bore hole Correction, η_4

Hole Diameter		
	2.5"-5"	η_4= 1.00
	5"-6"	= 1.05
	6"-8"	= 1.15

† Table derived from Skempton (1986), Bowles (1988) and DeCourt (1992).

The correction for the energy ratio may be computed based on the following equation.

$(Er)(N1) = (Ea)(N)$ (2-1)

$N1 = (\eta_1)(N)$

$\eta_1 = Er/Ea$

Er = Rod energy ratio of 60 % , as discussed above

Ea = Actual hammer energy of sampler, from Table 2

N1 = $N_{60,}$ as discussed above

N = Field determined N value

After the hammer makes contact with the drill rod, additional energy is dissipated into the sampler and the surrounding soil. The dissipation is the result of three main factors; rod length, bore hole diameter , and the use of a liner in the sampler.

Rod length does not seem to have a significant effect if the length of the rod is greater than 30 feet and with N values greater then 30 (Bowles 1988). Corrections for rod length, η_2, are presented in Table 2.

Further energy is dissipated by the sampler at the bottom of the bore hole relative to the size of the bore hole. SPT tests are typically conducted in 2 1/4 inch or 4 inch diameter bore holes, but in some areas bore holes with diameters up to 6 inches are used. In cohesive soils, lower N values appear due to energy dissipation resulting from the particle displacement (Lake 1974). Bore hole corrections, η_4, are also shown in Table 2.

The use of a liner inside the sampler leads to additional slide frictional losses. A sampler with a liner requires about 20% more blows per foot penetration than does a sampler without a liner (Seed 1989). Liners have a greater effect in sands than in cohesive soils. Table 2 lists sampler corrections, η_3.

Effective Overburden Pressure

As mentioned earlier, Gibbs and Holtz (1957) determined difficulties in reproducing data was related to overburden pressures. Overburden pressure has a greater effect on pure sands than on cohesive soils. Typical N values should be normalized to N_1, which is relative to the effective overburden pressure.

$$N_1 = C_n N \tag{2-2}$$

Several documents discuss methods for determining C_n and are detailed in Table 1. The most commonly used and simplest method is:

$$C_n = (1/\rho)^2 \tag{2-3}$$

$$\rho = \gamma H \text{ (tons/sf)} \tag{2-4}$$

This correction is based on the assumption that the overlaying soil strata is of a uniform relative density and grain size. This allows the overlying stratum to be treated as single unit.

Overconsolidation

Extensive study has been conducted to determine corrections for overburden pressure (see Table 1). For the most part, the sampling areas discussed in this document fall in the central and south-central portions of the Las Vegas valley which are assumed to be normally consolidated.

Additional Corrections

Site characteristics such as aging, cementation, and particle size and shape also lead to variations in N values. Several relationships between site characteristics have been developed but typically correspond only to the locality for which they were derived.

Aging

In general, aging increases the consolidation pressure, shear strength and stiffness of sands. Aging is an important factor for constructing on fill or reclaimed areas. A site that is deemed undisturbed for a period greater than 100 years is considered aged. Although the sites discussed in this document are not in their natural state, for the purpose of this paper, they are deemed aged. References for discussions of aging are presented in Table 1.

Particle Size and Shape

Extensive study has developed several relationships between blow counts and relative density based on particle size and shape (see Table 1). The equations are typically site specific and do not transfer well to other areas. The typical granular, angular shaped Las Vegas soils tend to exhibit an increase in the cohesion of the cemented soils which leads to high typical N values. Specific site testing is needed to determine the effects of the particle size and shape for Las Vegas soils.

Determining $N_{60corrected}$

To correct the standard penetration value N, to N_{60corr}, the following equation may be used.

$N_{60corr} = N \times C_n \times \eta_1 \times \eta_2 \times \eta_3 \times \eta_4$ (derived from Bowles 1988) (2-5)

N = Field determined N value

C_n = Overburden correction

η_1 = Energy ratio correction, from Table 2

η_2 = Rod length correction , from Table 2

η_3 = Sampler correction, from Table 2

η_4 = Bore hole diameter correction, from Table 2

Existing Correlations

As mentioned earlier, generalized tables correlating soil properties to soil consistencies are often used for Las Vegas soils. Tables 3 and 4 are typical examples of generalized tables and will be used for comparison purposes with Las Vegas soil correlations.

Table 3, Empirical values for granular soils for ϕ and N_{60} based on the SPT at about 20 ft depth and normally consolidated †

	Description	Medium Dense	Dense	Very Dense
SPT N_{60} (blows/ft):	fine	8-18	19-35	>35
	medium	9-23	25-47	>47
	course	12-29	30-53	>53
ϕ (degrees):	fine	30-34	33-38	
	medium	32-36	36-42	>50
	course	33-40	40-50	

† Table derived from Bowles (1988)

Table 4, Empirical values for clay soils for ϕ and N_{60} based on the SPT †

Soil description:	N_{60} (blows/ft)	ϕ (degrees)
medium stiff	7-11	26-35
stiff	12-19	35-39
very stiff	19-37	39-42
hard	>37	>42

† Table derived from Das (1985) and Bowles (1988)

CHAPTER III

DISCUSSION OF LAS VEGAS DATA BASE

Sampling in Las Vegas

The Las Vegas Valley is bounded on each side by north-south oriented mountain ranges (Wyman et al. 1993). The bedrock in the ranges to the west and north of the Valley is mainly sedimentary, while the ranges to the east and south are composed of Tertiary volcanics (Cibor, 1983).

The Valley is comprised of a variety of sedimentary deposits resulting from alluvial deposits from Tertiary and Quaternary age sediments from the surrounding mountains (Cibor 1983). The geologic setting in the west and central portions of the Valley contains clays and calcareous cemented deposits. The east side and southern ends of the Valley consist of finer alluvial deposits of sand, silt and clay as a result of their increasing distances from the alluvial source area (Cibor 1983).

One hundred and fourteen soil samples were analyzed for this investigation. The borings generally indicated sands with fines and clays with the majority comprised of dense, very dense, stiff, very stiff and hard consistencies. The boring locations were in the typically normally consolidated central and south-central portions of the Las Vegas valley. Specific boring locations are discussed in the analysis portion of this document. The boring data are attached in Appendix A.

Acquisition of Data

The following discussion and analysis is based on 114 samples from eleven sites throughout Southern Nevada. The data were extracted from the project files of Kleinfelder and Associates of Las Vegas, Nevada. Often, several samples were obtained at various depths from the same test bore hole. Information gathered from the borings includes:

- Test type, either standard penetration test or driven sample test.
- N, in blows per foot.
- Soil description and classification.
- Soil consistency.

The inexact science of geotechnical engineering leads to the use of assumptions. Field testing methods and personnel differences may lead to great discrepancies in test data. The data collected for discussion and analysis were collected by a single local geotechnical firm.

The majority of the borings were conducted by two drill rigs using similar sampling devices for each test site between 1991 and 1993. The personnel conducting the field tests remained relatively consistent. Possible human errors in field testing include; consistent height of the hammer drop, frequency of hammer blows per minute, the placement of the sampler in the bottom of the bore hole and the visual classification of the soils by the geotechnical engineer. Because of the consistency of the equipment and personnel used to conduct the field tests, it is assumed testing methods and soil classifications are consistent and constant.

Lab Test Data

Once the samples are collected in the field, they were transported to the laboratory for further analysis. Direct shear tests were conducted on each sample and the internal angle of friction, ϕ, was derived. The shear strength, τ, was determined by placing a sample in a shear box which is split horizontally in two halves. A normal force, σ, was applied to the top of the shear box and a shear force was horizontally applied to the top half of the box and increased until failure. The failure occurs along the horizontal plane at the split of the box.

Direct shear testing utilizes several assumptions. First, the sample is considered undisturbed. This is may lead to incorrect or questionable readings because the soil is not in its undisturbed state and encounters several opportunities to become disturbed including; the removal of the soil from the sampler, the transportation of the sample and the placement of the sample in the shear box. Remolded samples were utilized in the testing, but were deleted in the analysis of the data. It is also assumed the sample shears at its strongest point rather than the plane of the split of the shear box.

For soils obtained at a depth of less than ten feet, shear tests were conducted with a normal forces of 500 pounds, 1000 pounds and 2000 pounds. For samples gathered at a depth greater than ten feet, larger normal forces of 1000 pounds, 2000 pounds and 3000 pounds were applied in the direct shear test. The soil was forced to split along the plane of the split of the box which may not necessarily be the weakest plane of the sample.

After the completion of the test, the shear values are plotted against the each of the corresponding incremental normal loads as noted above. The internal angle of friction, ϕ, is determined from the inverse tangent of the shear force divided by the normal force. The cohesion, c, is determined by the Y intercept of the plotted line. The equation for calculation of the internal angle of friction is:

$$\phi = \tan^{-1}(\tau/\sigma) \qquad (3\text{-}1)$$

Figure 1 demonstrates how the internal angle of friction is derived. The internal angle of friction, ϕ, is the angle between the plotted line and the horizontal axis. In this case, ϕ is approximately 25 degrees.

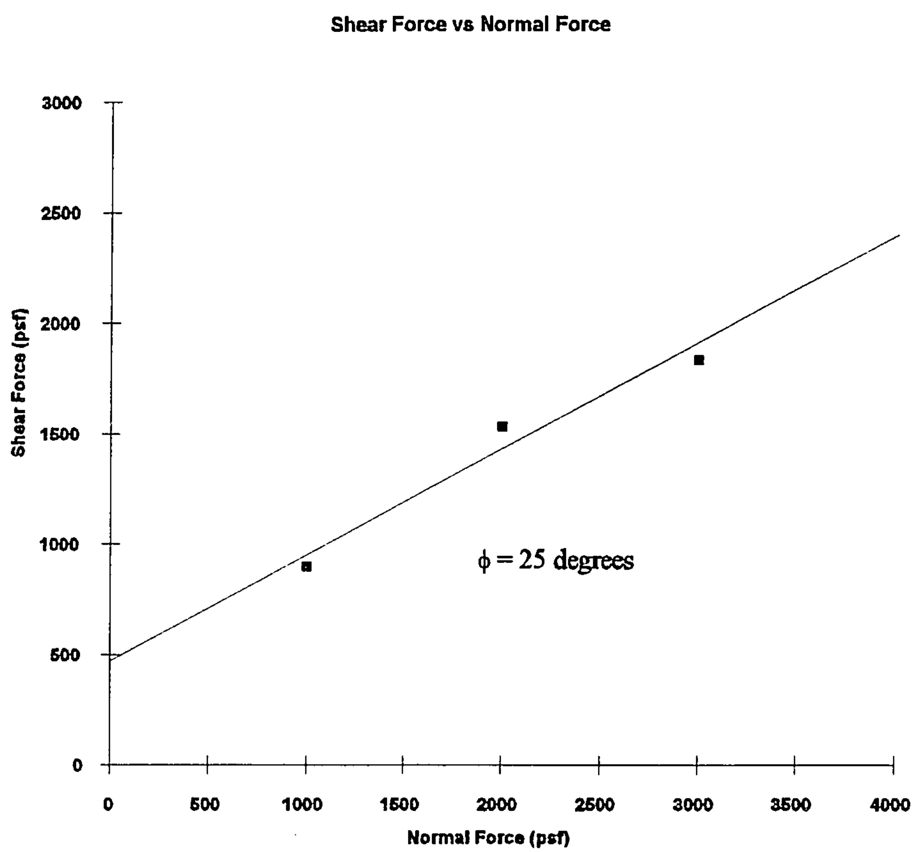

Figure 1, Shear Force vs Normal Force

CHAPTER IV

ANALYSIS OF DATA

Analysis of the Numerical Data

Due to the frequency of cemented soils and the angular shape of Las Vegas soils, N values are relatively high compared to often used basic values. The judgement of the geotechnical engineer is also a variable. The consistency of a soil is a judgement call of the engineer. Even though the percent of the sample passing the #200 sieve may be greater than fifty percent, because of the cementation and in-situ conditions, the soil description may be classified as a sand or gravel.

A blow count test is considered rejected if the N count exceeds 50 blows for any six inch interval. The frequency of rejected blow count tests is higher relative to areas where cementation is less prevalent. DeCourt et al. (1992) provided an estimate of 4N for any rejected value. If this were used for rejected tests for cemented Las Vegas soils, N values of 150 or greater would be common. This is not a realistic. Initially, the author analyzed the blow counts using the assumption of N = 100 for borings with rejected values of 50 for an interval of seven inches or less. This led to correlations which were unproportionately skewed toward the higher N values. In the final analyses and conclusions of this discussion, the rejected values were not used.

Chronology of Analysis

Soil Consistency

The following charts and tables are the result of several derivations of analysis of the soil boring data. The initial analysis of the data separated the boring samples by soil consistency (i.e. dense, very stiff). A broad range of soil types occurred in each consistency category. Correlations between the corrected blow counts, N_{60corr}, and the cohesion, c, and between N_{60corr} and the internal angle of friction, ϕ, were scattered at best. A typical plot of the cohesion versus the N values for a specific soil consistency, medium dense sands and gravels in this case, is shown in Figure 2.

Test Type

The second phase of the analysis sorted the boring information by test type, either the Standard Penetration Test or the Driven Sample Test. This was an attempt to determine a relationship between N_{60corr} values for the two test types. Again, N_{60corr} was plotted versus both c, and ϕ, for various soil consistencies. No correlations appeared. Figure 3

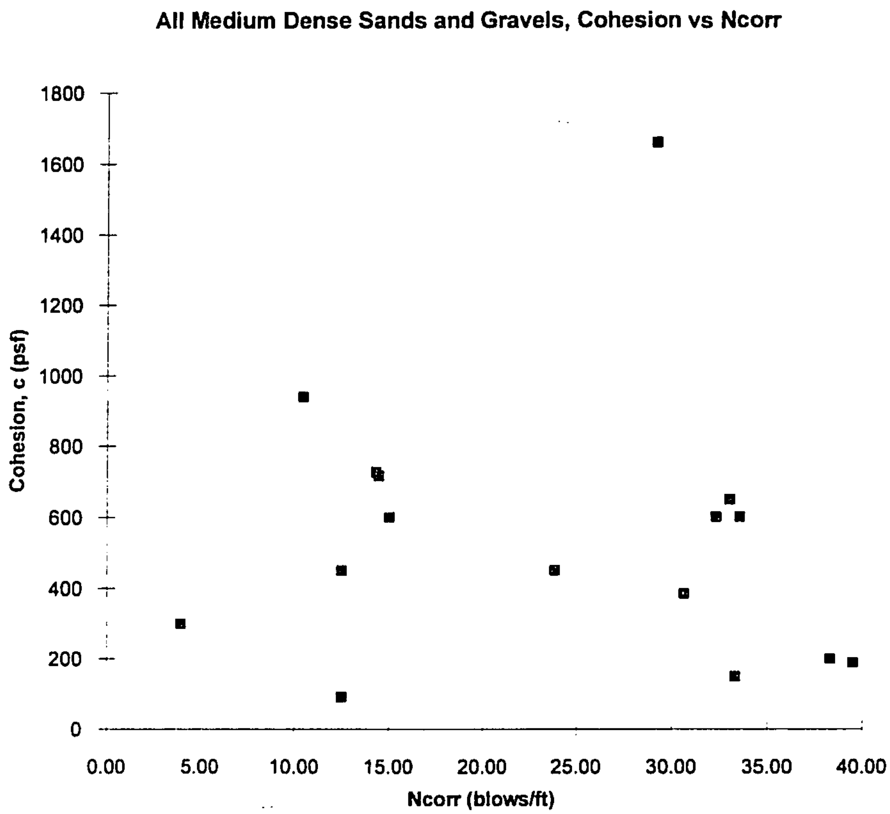

Figure 2, All Medium Dense Sands and Gravels, Cohesion vs N_{corr}

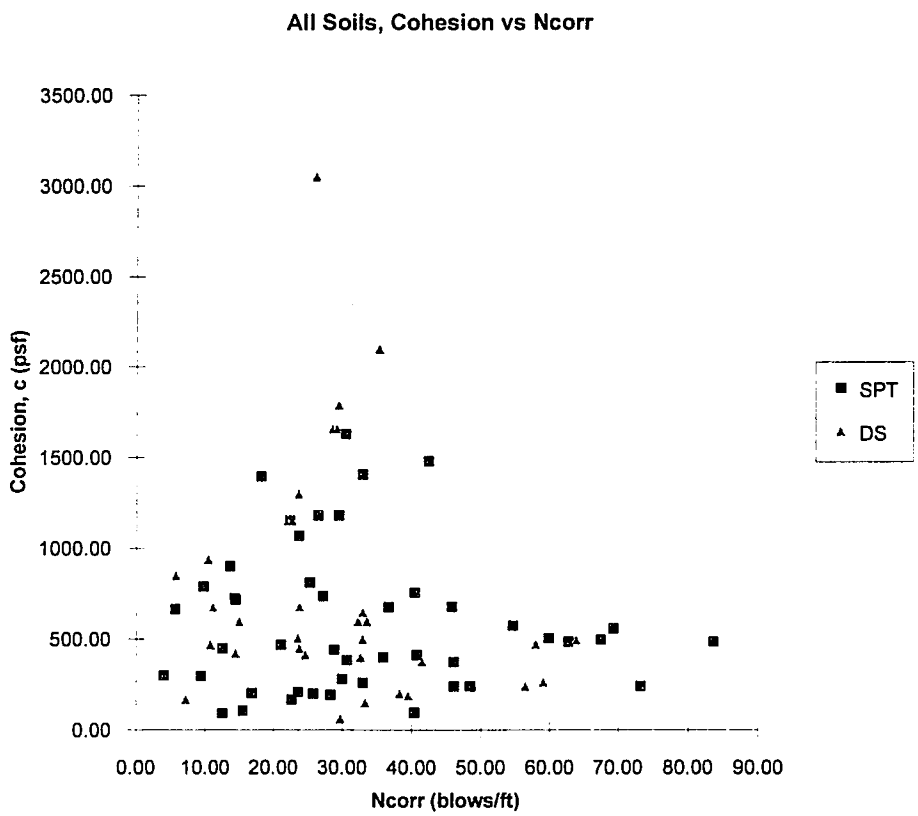

Figure 3, All Soils, SPT and DS Test, Cohesion vs N_{corr}

displays a typical scatter plot of the cohesion versus the N values for both the SPT and the DS test.

Soil Type

Sorting the boring data by soil type, (i.e. sands with fines, clays), shows correlations with generally increasing ϕ values when plotted against N_{60corr}. Plotting N_{60corr} against c started to show very general trends.

Region

The literature review conducted prior to the analysis of the boring data typically developed correlations for regions with generally uniform soil conditions. This led to the initial assumption that the soils consistencies for different soil classifications in the Las Vegas Valley were consistent independent of geographic location. The assumption proved to be incorrect. Further study of the boring data led to the discovery that borings in certain regions correlated with each other. This fits well with experience that demonstrates Las Vegas soils can vary tremendously between sites within short distances of each other.

Of the boring data initially gathered from 11 sites, seven sites were selected for further analysis based on relative geographic proximity and soil type. The seven sites selected are geographically separated into two areas as shown in Figure 4. Area "A" consists of four

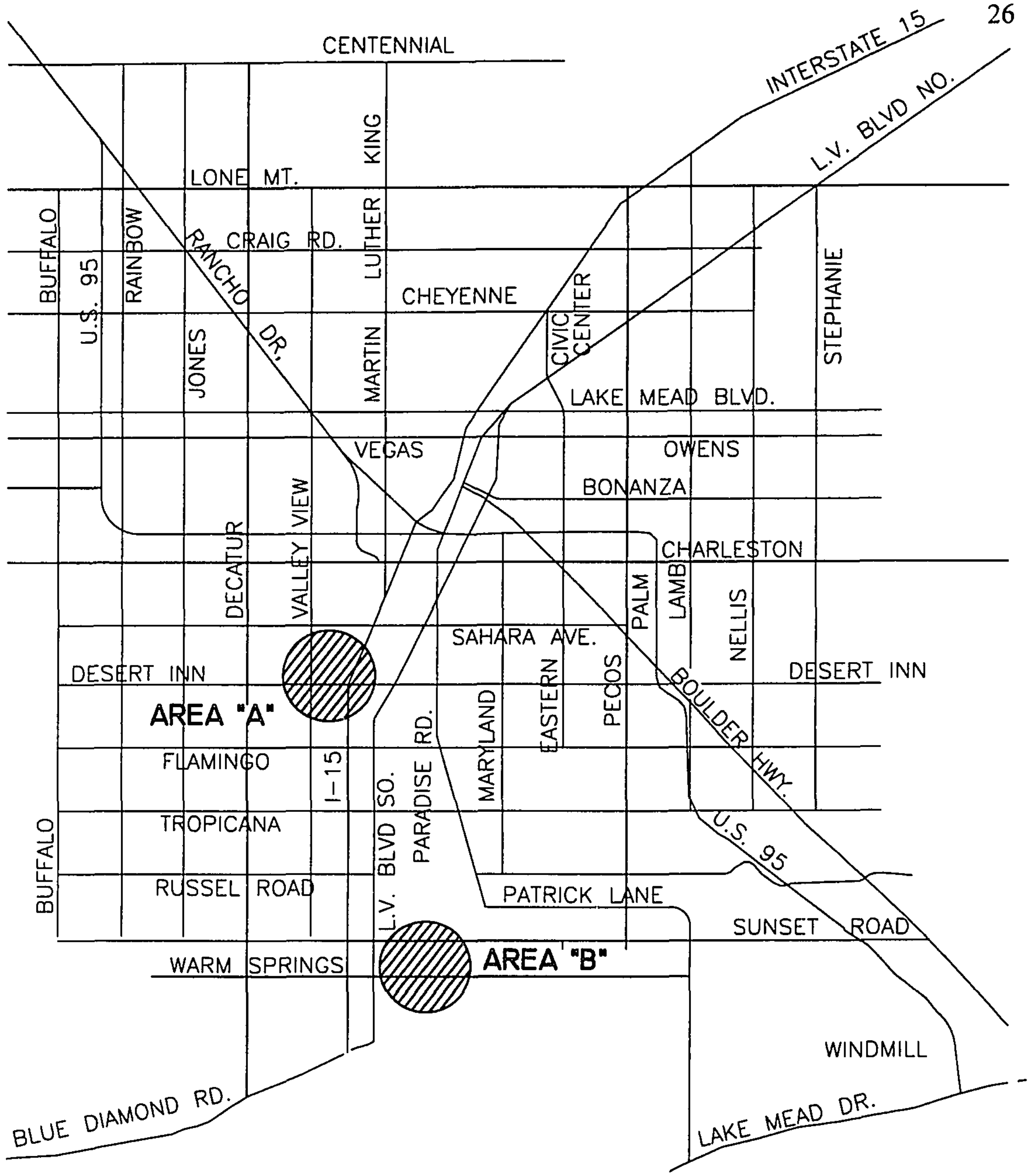

Figure 4. Las Vegas Valley Location Map, Area 'A' and Area 'B'

boring groups with a total of 44 samples. Area "B" consists of three soil boring groups with a total of 26 borings.

Graphs plotting the corrected N_{60} values against both the soil cohesion, c, and the internal angle of friction, ϕ, are shown for specific soil categories for both Area "A" and Area "B". General ranges derived for N_{60corr}, c and ϕ, based on soil consistencies for each region, are shown in tables 5 through 12. It is imperative to note that the ranges portrayed in the tables are general approximations based on several assumptions and should not be used for design values. Specific testing should be conducted to determine if any site is appropriate for known design criteria.

Statistical Analysis

Linear regression was used to calculate the coefficient of determination, r^2, for data analyzed in each category. The coefficient of determination is used to determine the strength of the relationship between two independent variables. The r^2 values range between 0 and 1. The closer the value is to 1, the stronger the relationship is between the variables. If the r^2 value is close to 0, little or no correlation exists between the two independent variables. A brief discussion of the coefficient of determination is presented in Appendix II.

Analysis of Area "A"

Area "A" is generally located in the proximity of the intersection Desert Inn Road and US I-15 (Fig. 4). The soils in Area "A" consist of a variety of sands, gravels and clays. The majority of the boring soil samples consisted of sands with fines, with 24 samples, and clays, with eight samples. Borings, which were rejected by encountering greater than 50 blows for any six inch interval, were eliminated from the analysis due the generated bias toward high N values. Outliers from the specific sites within a test group were also removed from the analysis. The boring samples were then segregated by soil type starting with a broad categorization then broken into individual soil types.

All Area "A" Soils

To provide an overall picture of Area "A", the c and ϕ values are plotted against the N_{60corr} values for all the samples located in the region and are shown in Figure 5 and Figure 6. The c values do not correspond to the increasing N_{60corr} values. The coefficient of determination value, r^2, of 0.0055 further demonstrates that little or no correlation exists. In Figure 5, it appears the ϕ values increase relative to increasing N_{60corr} values. The r^2 value of 0.2037 shows a slight relationship between the ϕ and N_{60corr} values. As can be seen later in the analysis, this is mainly associated to the clay soils.

General ranges for the N_{60corr} , c and ϕ values are shown for different soil consistencies in Table 5. A review of Table 5 shows little or no correlation between the soil properties and

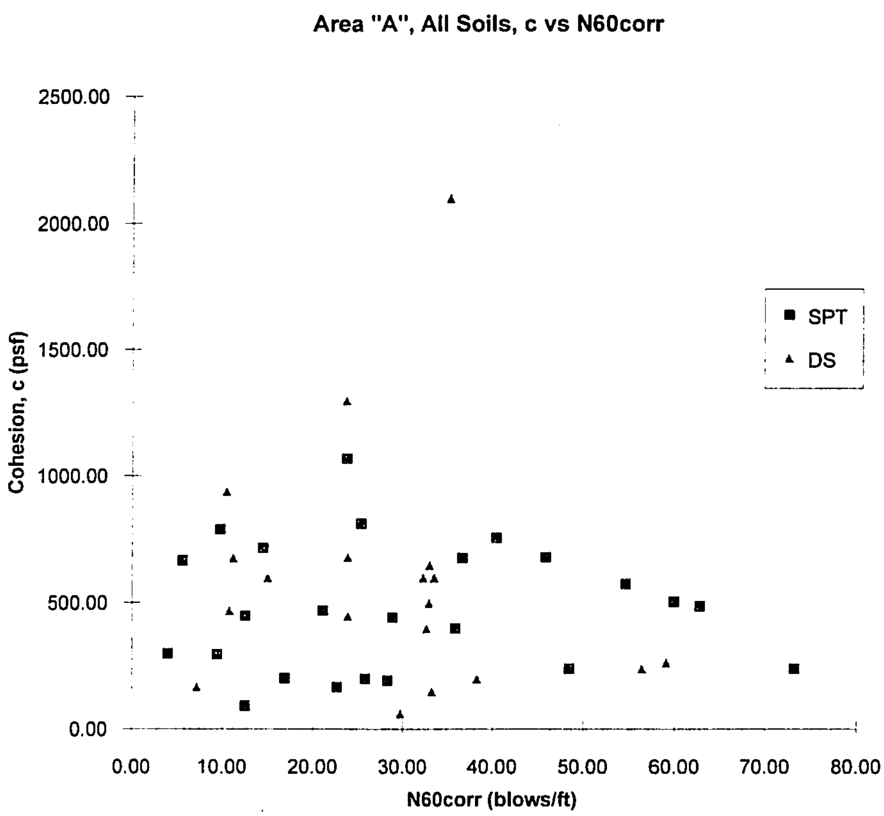

Figure 5, Area "A", All Soils, c vs N_{60corr}

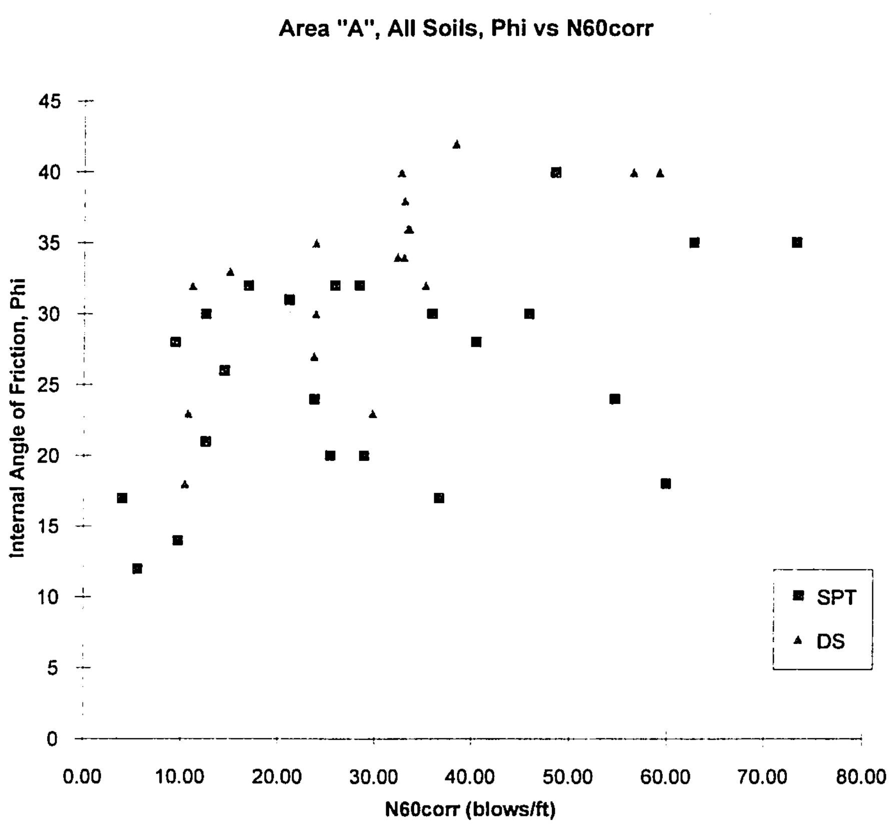

Figure 6, Area "A", All Soils, ϕ vs N_{60corr}

the soil consistencies. The significance of this will be discussed in the analysis and conclusion .

Table 5, Area "A", All Soils, correlations between consistency, N_{60corr} , c and ϕ

Consistency:	# of samples	N_{60corr} (blows/ft) Ave	Range	c (psf) Ave	Range	ϕ (degrees) Ave	Range
ALL SOILS	44	30	4-73	523	60-2100	29	12-42
SANDS AND GRAVELS							
Medium dense	12	22	4-38	479	93-940	31	17-42
Dense	9	32	9-73	462	193-1070	30	20-40
Very dense	14	38	7-63	388	63-680	29	18-40
CLAYS							
Medium stiff to stiff	4	27	6-35	917	400-2100	30	12-40
Very stiff	3	15	10-24	853	470-1300	21	14-27
Hard	2	38	37-40	717	680-760	23	17-28

Sands with Fines

The first category segregated from Area "A" is sands with fines. Sands with fines consists of silty sands and clayey sands as defined by the Unified Classification System (ASTM designation D-2487). Sands with fines are part of the larger categorization of Coarse-grained soils which consists of soils with more than 50 % of the sample retained on the No. 200 sieve. Area "A" yielded 24 samples falling into the sands with fines category.

Corrected N values for the sands with fines are plotted against both the cohesion, c, and the internal angle of friction, ϕ. Figure 7 and the corresponding r^2 value of 0.0055 demonstrates that little or no correlation exists between the N_{60corr}, and c values. Figure 8 demonstrates that ϕ falls in a consistent range but is not necessarily relative to increasing N_{60corr} values. The r^2 value of 0.0018 for the relationship between the ϕ and N_{60corr} values again demonstrates the lack of any correlation. The two graphs further emphasize that specific testing is required dependent upon design requirements.

Table 6 shows general correlations between soil consistency, N_{60corr}, c and ϕ for sands with fines for Area "A". The N_{60corr} ranges increase relative to increasing soil consistency. The c values and ϕ values for the medium dense sands with fines do not correspond to the dense and very dense soils. Of the seven samples in the medium dense category, five of the samples are from a single test group. The high c and ϕ values for the sample group

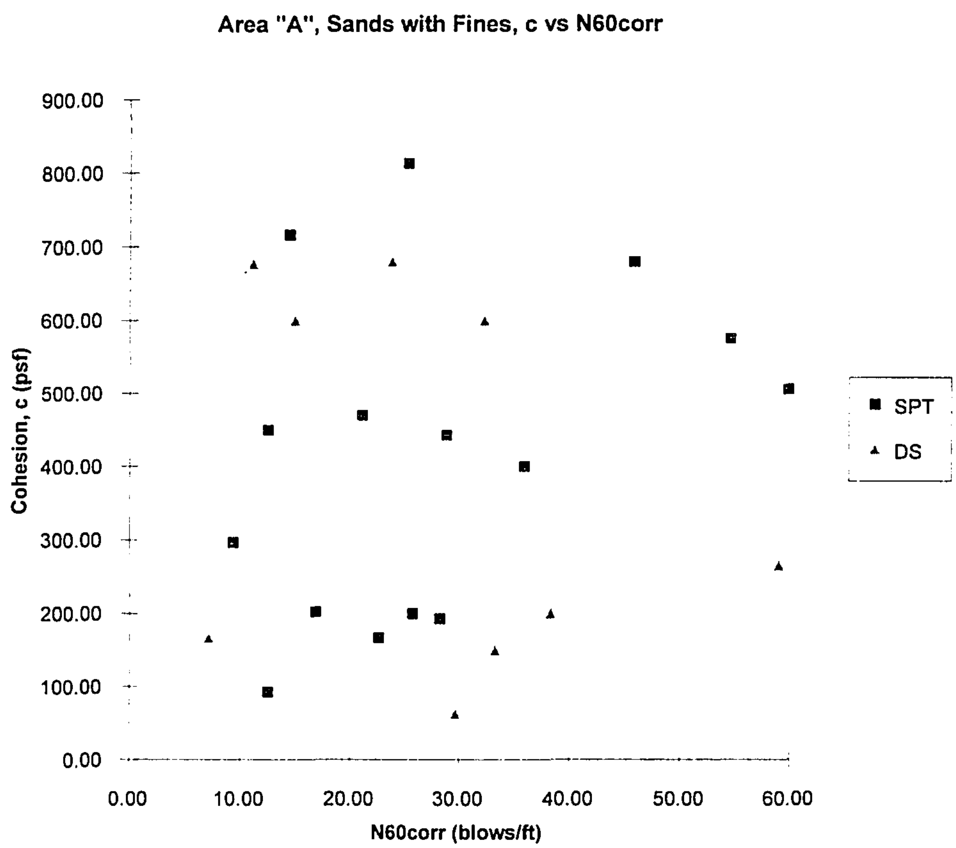

Figure 7, Area "A", Sands with Fines, c vs N_{60corr}

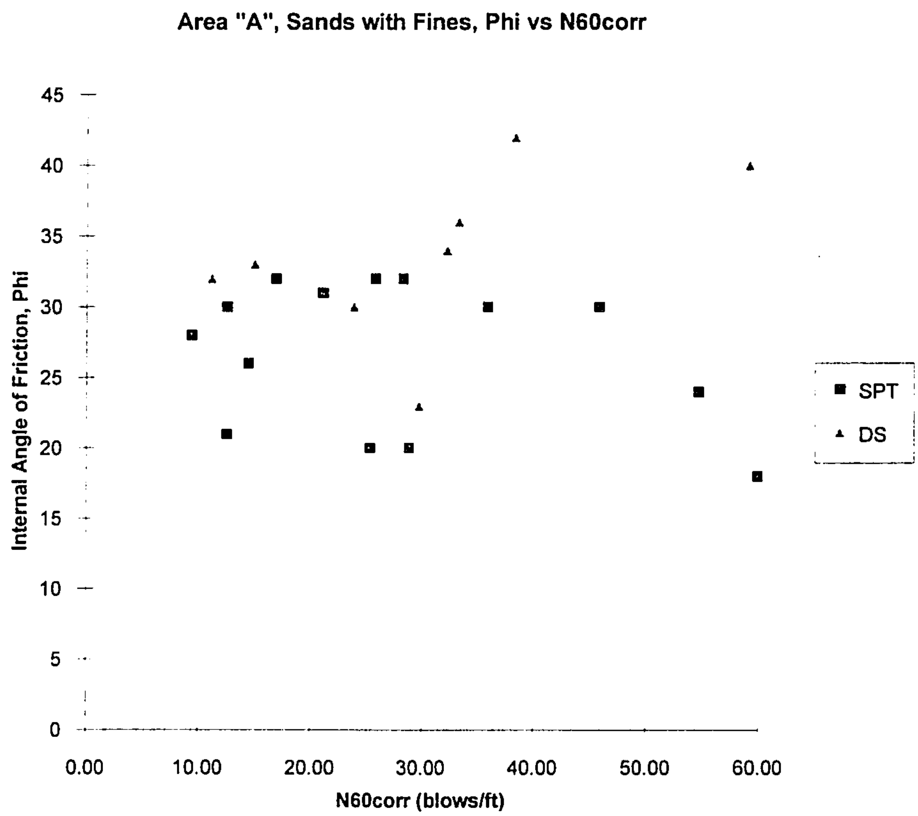

Figure 8, Area "A", Sands with Fines, ϕ vs N_{60corr}

containing the five subject samples of the medium-dense category, further demonstrate the differing soil properties in the same general geographic proximity.

Table 6, Area "A", Sands with Fines, correlations between consistency, N_{60corr}, c and ϕ

		N_{60corr} (blows/ft)		c (psf)		ϕ (degrees)	
Consistency:	# of samples	Ave	Range	Ave	Range	Ave	Range
Medium dense	7	23	12-39	401	150-700	32	25-40
Dense	7	27	11-40	406	200-680	31	25-40
Very dense	10	32	20-60	435	165-680	28	25-35

The sands with fines classification is further divided, separating the clayey sands and the silty sands. The N_{60corr} values are plotted against C and ϕ for both the clayey sands and the silty sands, as shown in Figures 9 through 12.

Clayey Sands

Figure 9 and the relative r^2 value of 0.0018 shows little or no correlation between increasing c values and increasing N_{60corr} values for the clayey sands samples. Of the 13 samples included in the clayey sand category, nine are from the same test group. It would seem that within the same test group, c values should increase with increasing N_{60corr} values, but Figure 9 shows that is not the case. Figure 10 demonstrates that the ϕ values fall in a

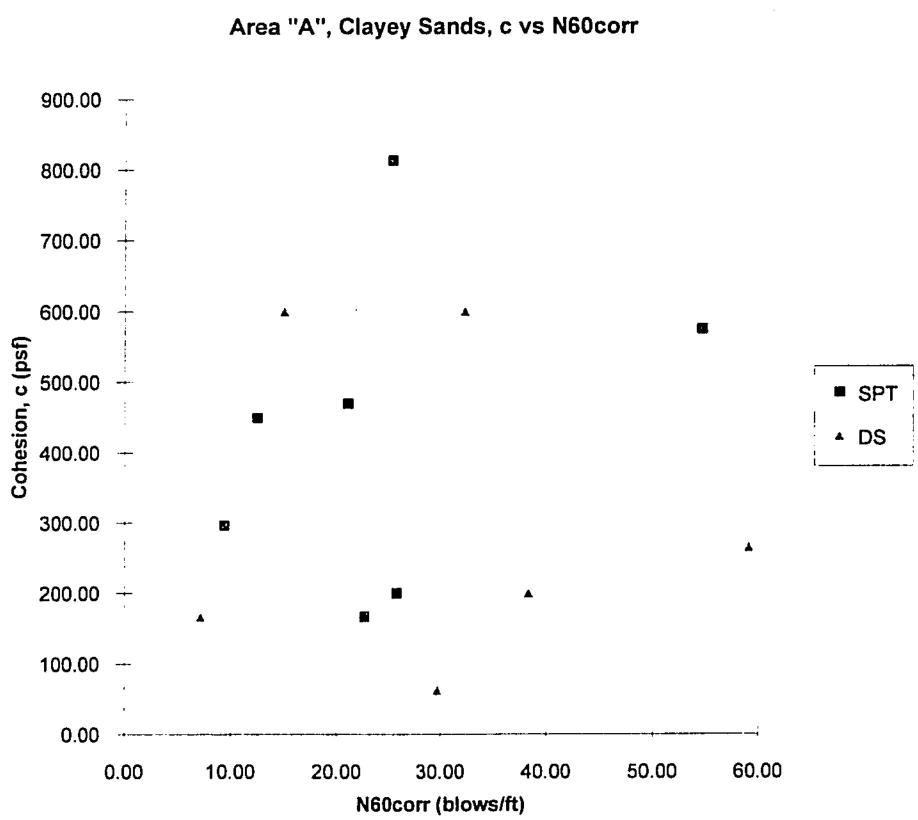

Figure 9, Area "A", Clayey Sands, c vs N_{60corr}

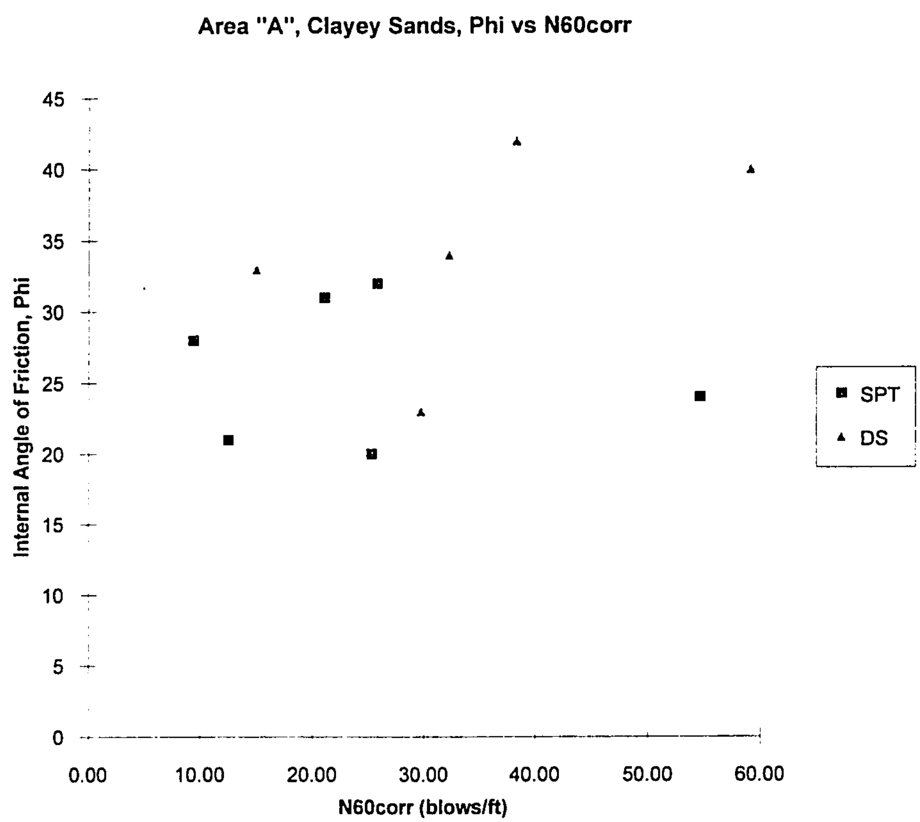

Figure 10, Clayey Sands, ϕ vs N_{60corr}

consistent range, but do not correspond to increasing N_{60corr} values. The r^2 value of 0.1348, which corresponds to Figure 10, illustrates a slight relationship.

Table 7 portrays general correlations between the soil consistency and N_{60corr}, c, and ϕ values for the clayey sand classification. The clayey sand category, SC, is comprised of 13 samples from three test groups.. As with the sands with fines, the medium dense values portray high c and ϕ values relative to the dense and very dense soils. Of the four samples in the medium dense range, three are from a single test group. One of the test groups places a single sample in the SC category. This single sample falls in the dense category and has a c value of 813 psf which causes a high c average for the three total samples in the dense category. As the number of available samples for each soil classification decreases, the correlations between the soil consistencies and the measured values become more random. Again, this demonstrates the need for site specific testing for known design requirements.

Table 7, Area "A", Clayey Sands, correlations between consistency, N_{60corr}, c and ϕ

		N_{60corr} (blows/ft)		c (psf)		ϕ (degrees)	
Consistency:	# of samples	Ave	Range	Ave	Range	Ave	Range
Medium dense	4	25	12-39	462	200-600	33	21-42
Dense	3	31	10-60	458	265-800	29	20-40
Very dense	6	27	8-55	395	65-580	28	24-31

Silty Sands

Figures 11 and 12 correspond to the Area "A" silty sands. Eleven total samples from five test groups from area "A" portray silty sand soils. Consistent with the clayey sands and sands with fines from Area "A", the ϕ values fall in a consistent range, but do not correspond to increasing N_{60corr} values. The slight relationship between the ϕ and N_{60corr} values is illustrated by the r^2 value of 0.1926.

The soil consistency correlations shown in Table 8 demonstrate the logical trend of increasing N_{60corr}, c and ϕ values relative to increasing soil density.

Table 8, Area "A", Silty Sands, correlations between consistency, N_{60corr}, c and ϕ

		N_{60corr} (blows/ft)		c (psf)		ϕ (degrees)	
Consistency:	# of samples	Ave	Range	Ave	Range	Ave	Range
Medium dense	3	20	12-33	320	90-717	31	26-36
Dense	4	23	11-36	370	200-675	31	30-32
Very dense	4	36	24-60	542	440-680	29	18-30

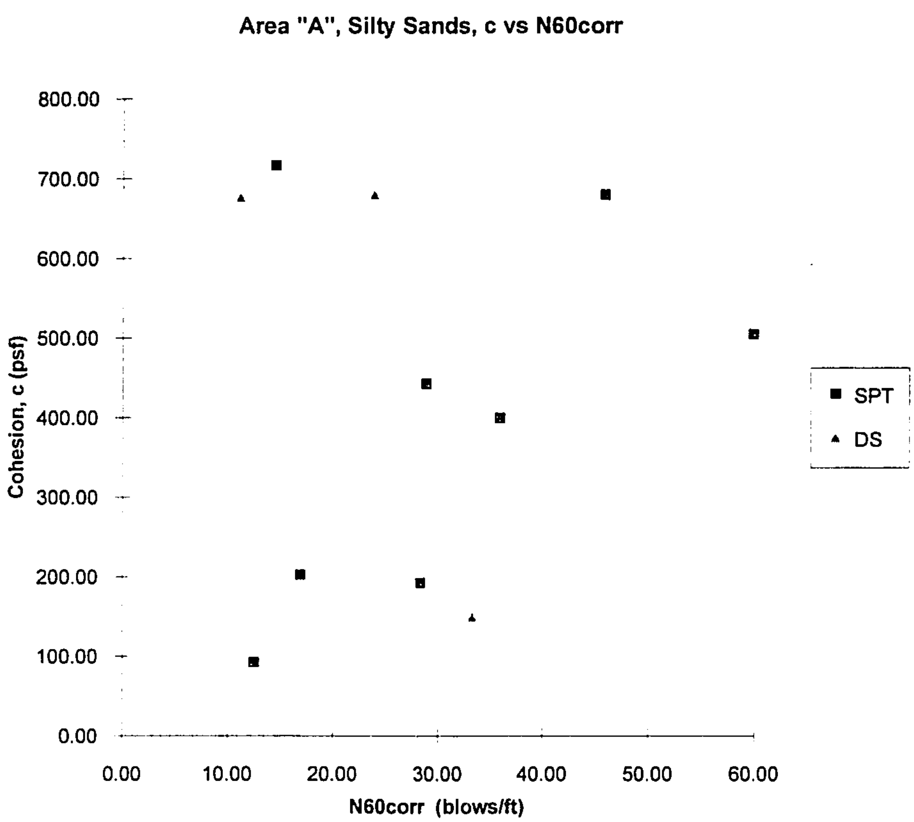

Figure 11, Area "A", Silty Sands, c vs N_{60corr}

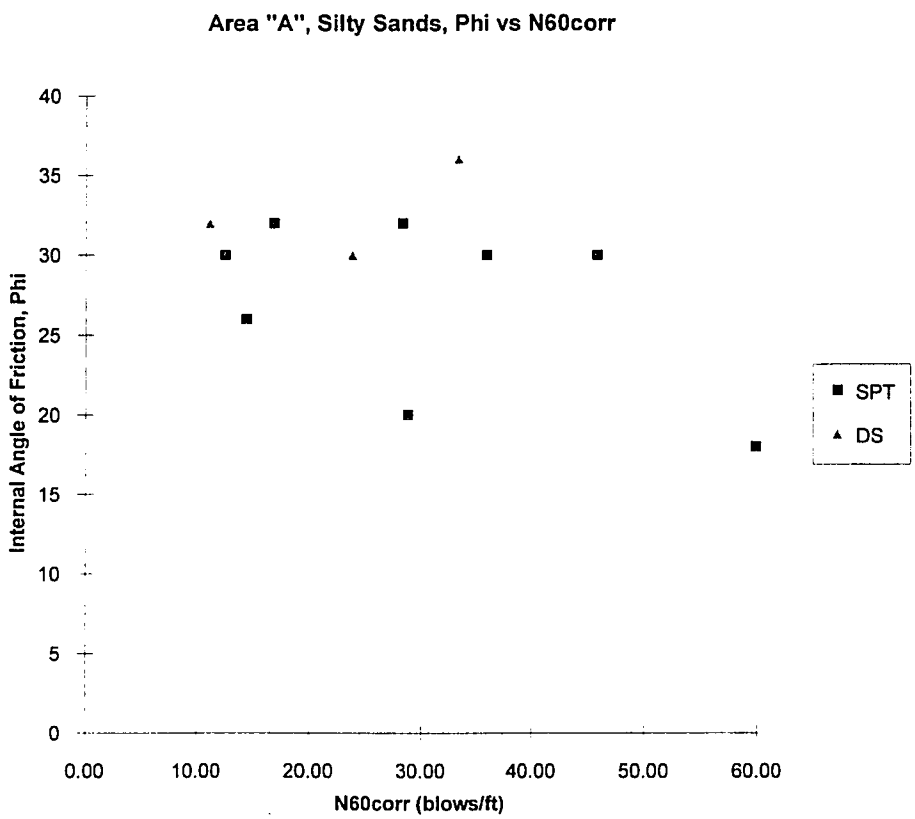

Figure 12, Area "A", Silty Sands, ϕ vs N_{60corr}

Clays

Eight Samples from six test groups from Area "A" consisted of clays. Figures 13 and 14 show the most consistent trend of increasing c and ϕ values relative to increasing N_{60corr} values for Area "A" soils. The r^2 value of 0.4399 describes the noticeable relationship between the ϕ and N_{60corr} values. The eight clay samples portray medium stiff to hard soil consistencies, which are shown in Table 9 relative to N_{60corr}, ϕ and c. The high c values of the medium stiff to very stiff samples are the result of a single sample with a c value of 2100 psf.

Table 9, Area "A", Clays, correlations between consistency, N_{60corr} , c and ϕ

		N_{60corr} (blows/ft)		c (psf)		ϕ (degrees)	
Consistency:	# of samples	Ave	Range	Ave	Range	Ave	Range
Medium stiff to stiff	3	25	5-35	1089	500-2100	26	12-34
Very stiff to hard	5	24	10-41	799	470-1300	22	14-28

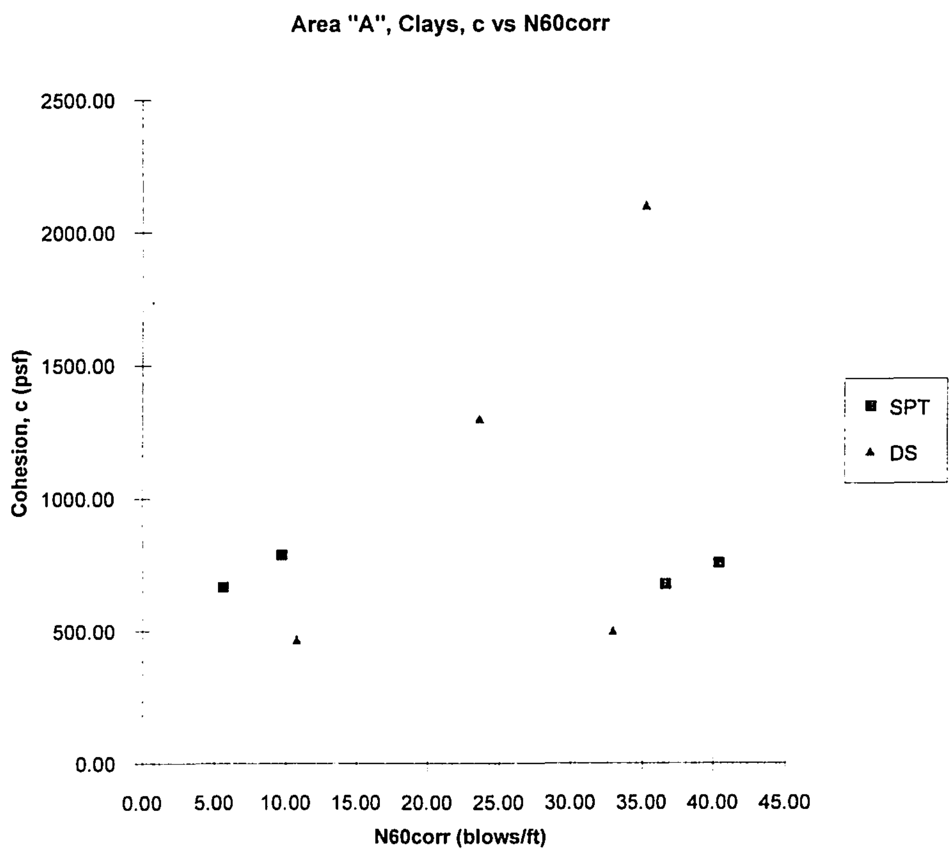

Figure 13, Area "A", Clays, c vs N_{60corr}

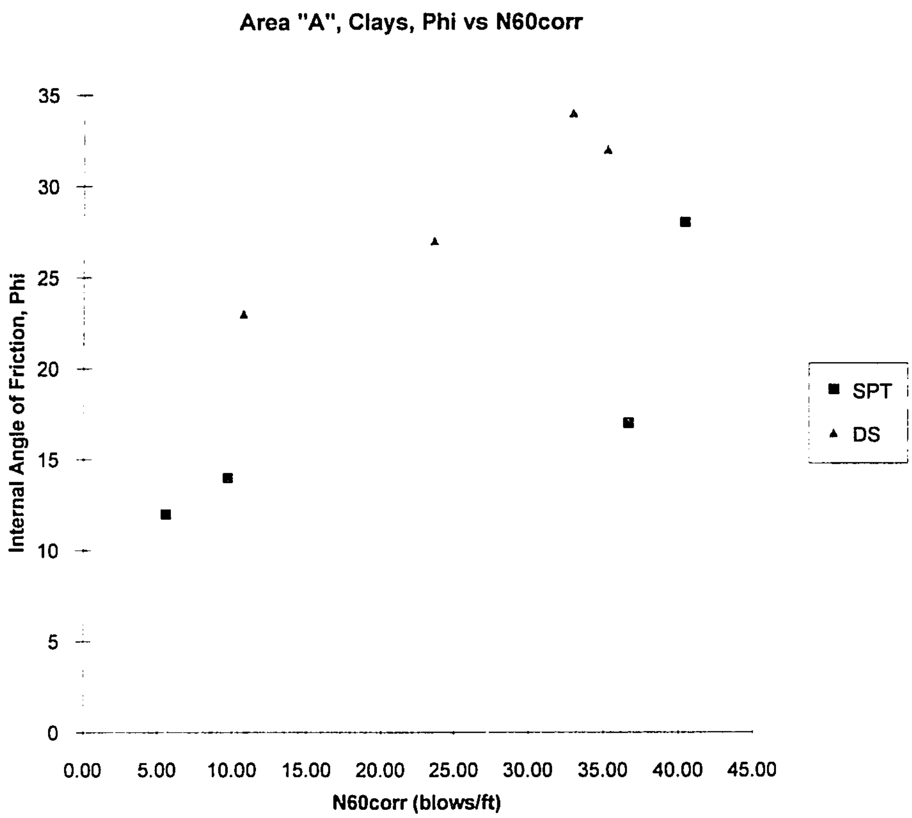

Figure 14, Area "A", Clays, ϕ vs N_{60corr}

The consistent correlations for the clays are probably due to the cohesive forces of the clay material and the scattered results of the sands with fines may be due to the cementation and varying particle size and shape.

Analysis of Area "B" Data

Area "B" is bordered by Warm Springs Road to the south, Sunset Road to the north, Las Vegas Boulevard to the west and Eastern Avenue to the east (Fig. 4). After the borings which were rejected were removed form the Area "B" data, 25 samples from five different boring groups remained. The Area "B" soils consist of sands with fines and clays.

All Area "B" Soils

A broad overview of all the samples in Area "B" is provided by Figure 15, which plots the c values against the N_{60corr} values and by Figure 16 which plots the ϕ values vs the N_{60corr} values. Figure 15 and a near zero r^2 value shows no correlation between increasing N_{60corr} values and increasing c values. As with Area "A", Figure 16 appears to portray a slight correlation between increasing ϕ values and increasing N_{60corr} values. The corresponding r^2 value is 0.1217. Also, as with Area "A", this is due to the clay soils. This will be demonstrated in the analysis of the clay soils of Area "B".

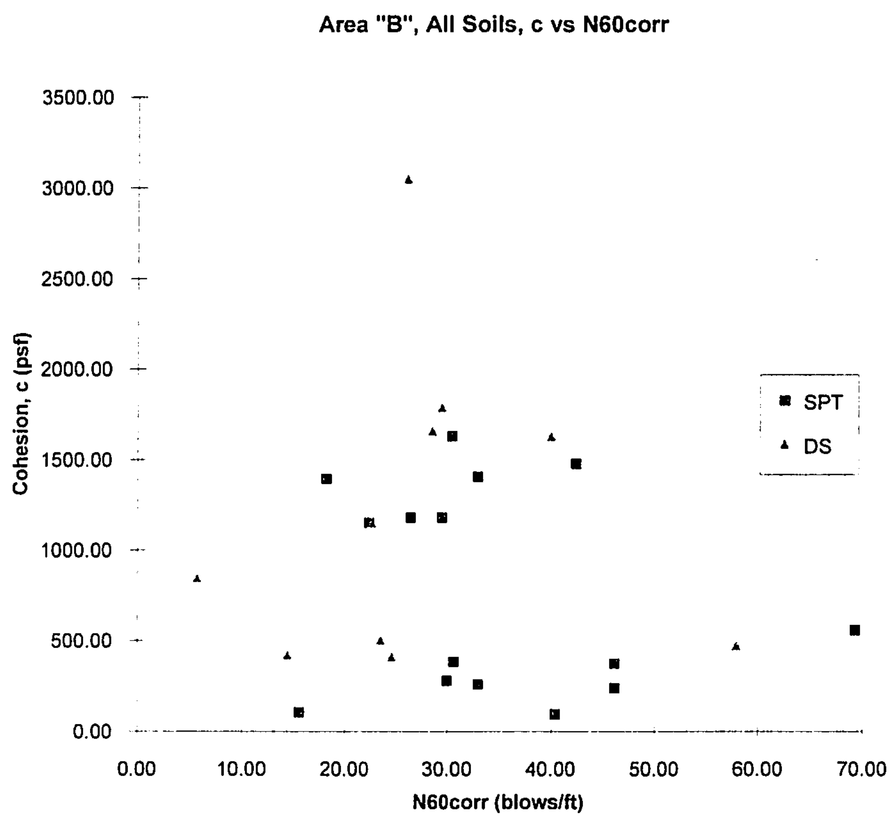

Figure 15, Area "B", All Soils, c vs N_{60corr}

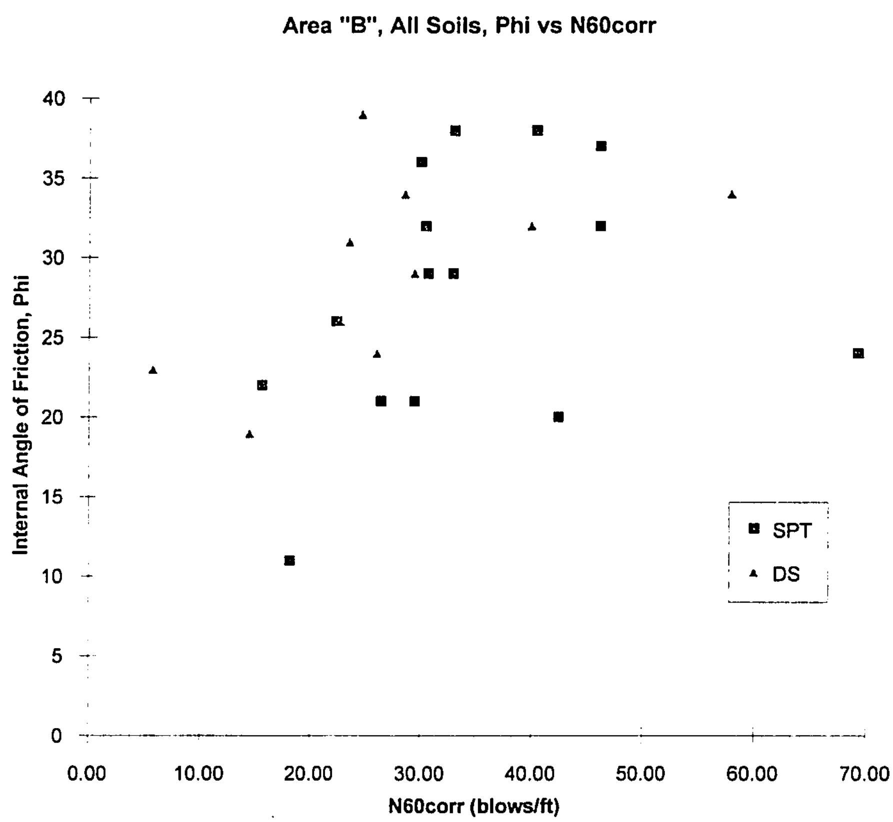

Figure 16, Area "B", All Soils, ϕ vs N_{60corr}

General ranges for N_{60corr}, c and ϕ are provided for various soil consistencies for all of the Area "B" samples and are shown in Table 10. The broad ranges demonstrate the large variations of similar soils located in a relatively small geographic region. An in depth analysis of specific soil types follows.

Table 10, Area "B", All Soils, correlations between consistency, N_{60corr}, c and ϕ

		N_{60corr} (blows/ft)		c (psf)		ϕ (degrees)	
Consistency:	# of samples	Ave	Range	Ave	Range	Ave	Range
ALL SOILS	26	32	6-69	956	95-3050	28	11-39
SANDS AND GRAVELS							
Medium dense to dense	12	36	14-69	631	95-1660	31	19-39
Very dense	3	38	30-60	388	470-1630	33	32-34
CLAYS							
Stiff to Very Stiff	6	22	6-37	982	105-1400	21	11-28
Hard	5	25	22-29	1530	500-3050	27	24-31

Sands with Fines

The sands with fines category consists of 14 samples from four boring groups with ten samples originating form a single boring group. Four Outliers with c values greater than 1400 psf were removed from the analysis. Again, this demonstrates the broad range of soil properties in a specific area. The remaining ten c values plot in a consistent range but do correspond to increasing N_{60corr} values. The N_{60corr} values for the sands with fines for Area "B" are plotted against both c and ϕ and are shown in figures 17 and 18. The ϕ values fall in a broad range when plotted versus the N_{60corr} values. The respective r^2 values of 0.0921 and 0.0001 further demonstrate the lack of any relationships.

All of the sands with fines samples fall in the dense to very dense consistency category. Table 11 displays general ranges of N_{60corr}, c and ϕ values relative to the soil consistencies. As would be expected, the three samples portraying a very dense consistency have higher N_{60corr}, c, and ϕ values than the 11 samples with a dense consistency.

Table 11, Area "B", Sands with Fines, correlations between consistency, N_{60corr}, c and ϕ

		N_{60corr} (blows/ft)		c (psf)		ϕ (degrees)	
Consistency:	# of samples	Ave	Range	Ave	Range	Ave	Range
Dense	11	33	14-46	560	95-1660	29	19-39
Very dense	3	30	30-57	1170	475-1630	32	29-34

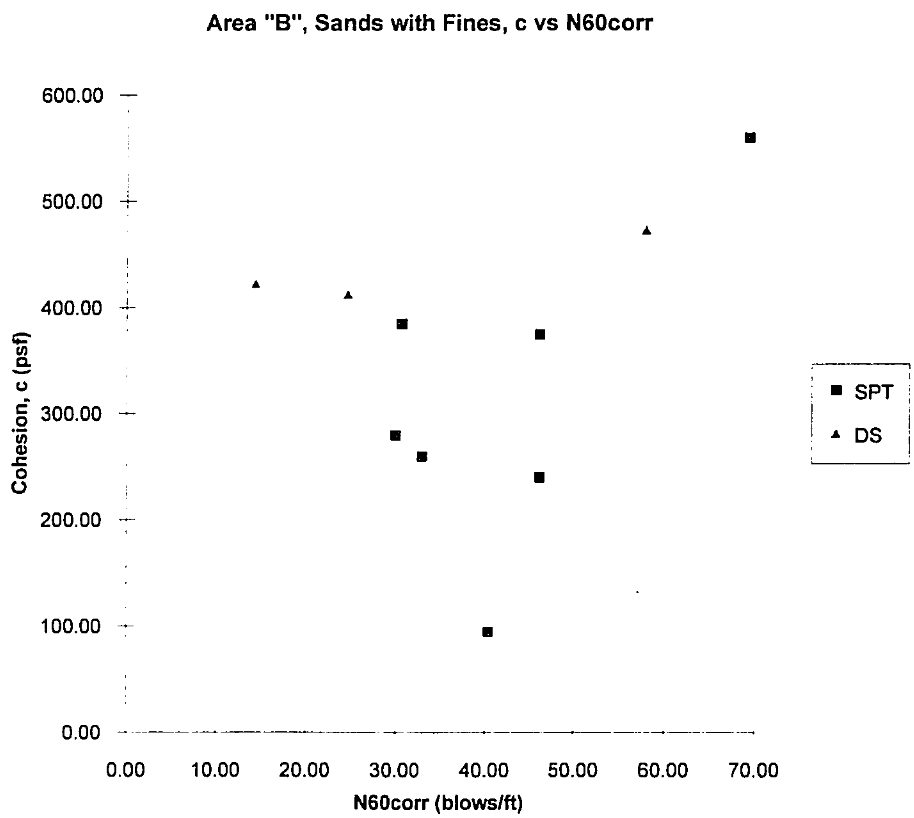

Figure 17, Area "B", Sands with Fines, c vs N_{60corr}

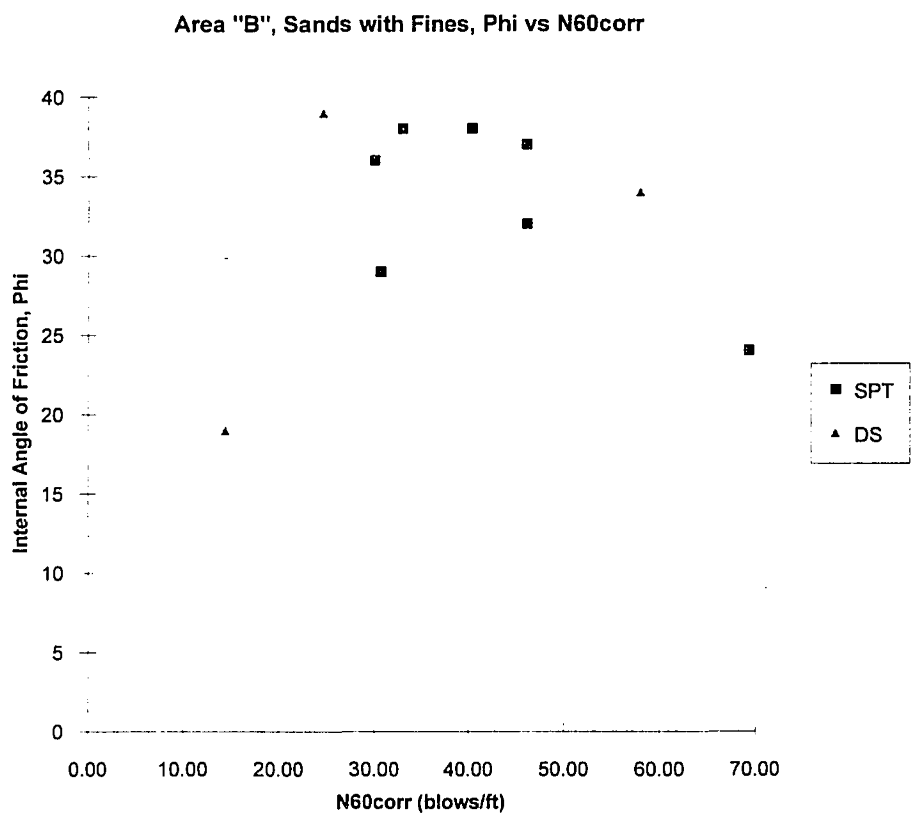

Figure 18, Area "B", Sands with Fines, ϕ vs N_{60corr}

Clays

Area "B" contains ten clay samples from four boring groups. As with the clays from Area "A", the Area "B" clays demonstrate trends of increasing c and ϕ values relative to increasing N_{60corr} values. The r^2 value is 0.1318 for the relationship between the c and N_{60corr} values. The correlation between the ϕ and N_{60corr} values is described by the r^2 value of 0.1261. Figures 19 and 20 portray this information.

Correlations between N_{60corr}, c and ϕ, relative to soil consistencies for Area "B", are shown in Table 12. As the soil consistency increases from stiff/very stiff to hard, the N_{60corr}, c and ϕ ranges increase.

Table 12, Area "B", Clays, correlations between consistency, N_{60corr}, c and ϕ

		N_{60corr} (blows/ft)		c (psf)		ϕ (degrees)	
Consistency:	# of samples	Ave	Range	Ave	Range	Ave	Range
Stiff to very stiff	6	24	16-37	1009	100-1400	21	11-28
Hard	4	25	22-29	1151	500-1790	28	26-31

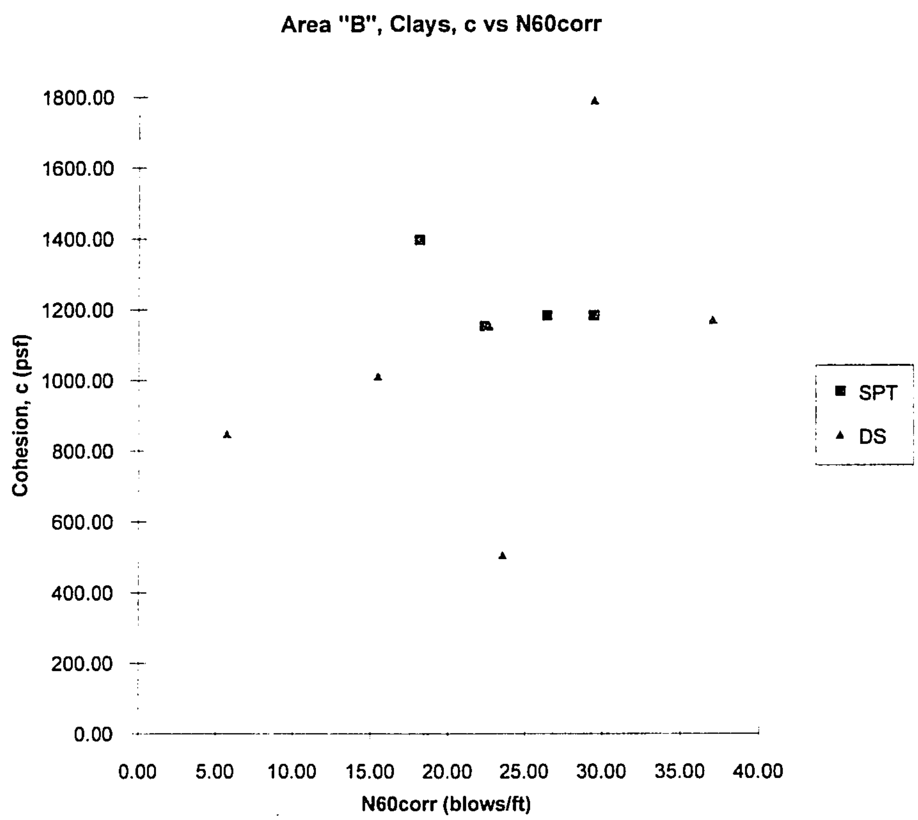

Figure 19, Area "B", Clays, c vs N_{60corr}

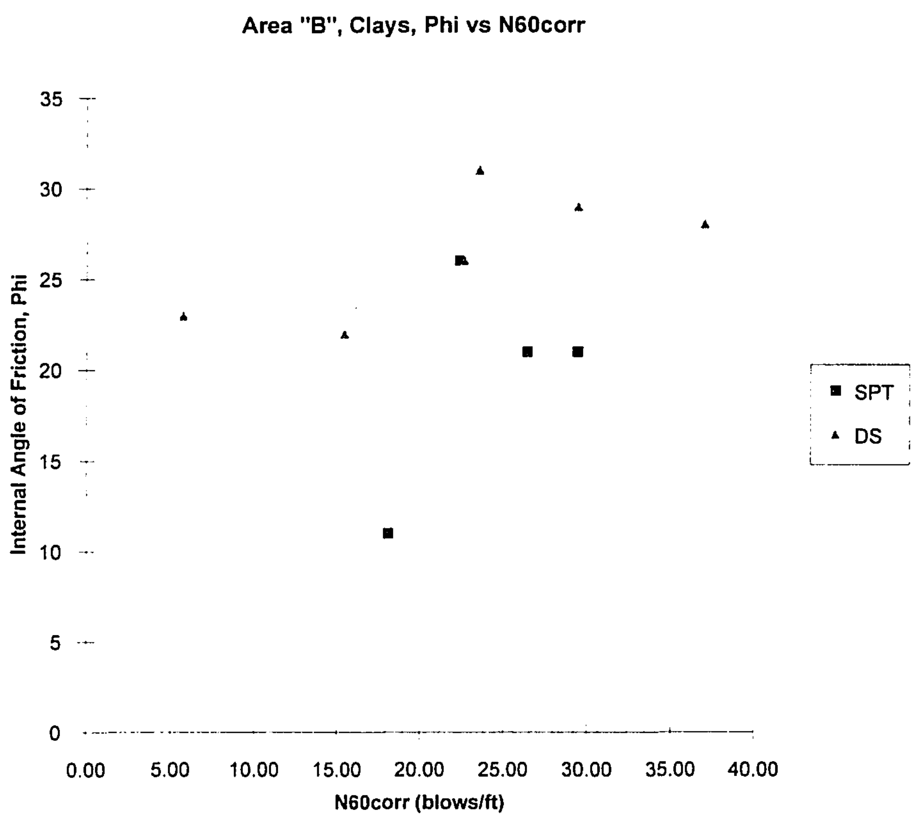

Figure 20, Area "B", Clays, ϕ vs N_{60corr}

As with Area "A", the consistent correlations of the clays are presumably the result of the cohesive forces of the clay and the varying data for the sands with fines is most likely the result of the cementation and the size and shape of the angular particles.

Driven Sample Test vs Standard Penetration Test

At the inception of this discussion, an attempt was made to determine a relationship between DS N_{60corr} values and the SPT N_{60corr} values. As the analysis of each test area's borings progressed, not enough samples with similar soil types and consistencies from each area remained to provide for an extensive analysis. In 12 instances, SP tests were conducted 12 inches below a DS test in the same bore hole. Of the 12 comparable tests, three encountered different soil strata between the tests, which leads to inaccurate comparisons. In four of the remaining nine potential comparable test pairs, one of the tests reached rejection which would exclude the values from analysis. Table 13 shows the remaining five sample pairs.

Three of the five samples show N_{60corr} values within 15% of each other for the two comparable samples. The remaining two tests demonstrate differences of 62% and 103%. Once again, this shows that the SPT and DS test values are subject to a large number of variables which may greatly alter results. Although it appears the DS test generally corresponds to the Standard Penetration Test, not enough useful data is available to determine conclusive results.

Table 13, DS vs SPT Correlations

Group	Boring	Test	Depth (ft)	Soil type	Consist.	N (blows/ft)	N_{60corr}	**Δ**	**Δ** %
II	b-41	DS	10	GM	dense to very dense	50/12	56	8	-15
		SPT	11			45/12	48		
II	b-41	DS	36	SM	dense to very dense	40/12	24	22	62
	b-41	SPT	37			78/12	46		
II	b-44	DS	10	GM	dense to very dense	60/12	68	5	7
	b-44	SPT	11			68/12	73		
II	b-44	DS	80	SC	very dense	18/12	7	15	103
	B-44	SPT	81			57/12	22		
III	w-6	DS	35	CL	hard	35/12	26	3	12
		SPT	36			36/12	23		

CHAPTER V

CONCLUSIONS

Conclusions

Soil samples from two regions in the Las Vegas Valley are analyzed in an attempt to determine correlations between corrected blow count values, N_{60corr}, the internal angle of friction, ϕ , and the cohesion, c. In both regions, the cohesion of the sands with fines showed little or no correlation to increasing N_{60corr} values. The ϕ values for the sands with fines fall in consistent ranges between 19 and 40, but do not increase with increasing N_{60corr} values. The clays in both regions demonstrate increasing c and ϕ values relative to increasing N_{60corr} values. The variety of results demonstrates the need for specific site testing for any Las Vegas valley construction project dependent upon design values.

Comparisons between the generalized ranges portrayed in Table 3 and Table 4 and the ranges established for the two Las Vegas regions display discrepancies. The sands with fines for both Area "A" and Area "B" display ϕ ranges between 19 and 40 and do not increase relative to increasing soil consistency and N_{60corr} values. The ϕ and N_{60corr} values demonstrated in the generalized tables increase with increasing soil consistency. The N_{60corr} values for the sands with fines for both Las Vegas regions portray broader ranges with higher top end values than the ranges shown in the generalized Table 3.

The values for the Las Vegas clay soils differ from the clay values portrayed in the generalized Table 4. The N_{60corr} values for Area "A" and Area "B" demonstrate broad ranges which do not correspond the limited ranges shown in Table 4. The ϕ ranges for both Las Vegas regions have lower average values, as well as lower top end ϕ values, relative to the soil consistencies when compared to ϕ values shown in Table 4

Because of the differences between the soil properties for the Las Vegas soils and the values demonstrated in the Tables 3 and 4, generalized tables portraying correlations between N values and soils properties developed for areas other than the Las Vegas should be used with great care when applied to Las Vegas soils. Hence, based upon this investigation, the properties c and ϕ can not be realistically correlated to N_{60corr}.

APPENDIX I

AREA "A", ALL SOILS, MINUS REJECTED VALUES

GROUP	BORING	TEST	DEPTH	N60corr	COHESION	PHI	N	UNIT WEIGHT	DESCRIPTION		CONSISTENCY
			(ft)		(psf)	ϕ	blows/ft	(pcf)			
2	b1	spt	20	12.48	450	21	15/12	115	clayey sand	sc	medium dense
2	b1a	spt	49	54.57	575	24	107/12	125	clsyey sand	sc	very dense
2	b3	spt	39	25.72	200	32	45/12	125	clayey sand	sc	very dense
2	b4	spt	32	3.95	300	17	6/12	115	clayey gravel	gc	med dense
2	b41	ds	10	56.45	240	40	50/12	125	silty gravel	gm	very dense
2	b41a	spt	11	48.44	240	40	45/12	125	silty gravel	gm	very dense
2	b41b	ds	36	23.80	680	30	40/12	125	silty sand	sm	very dense to dense
2	b41c	spt	37	45.78	680	30	78/12	125	silty sand	sm	very dense to dense
2	b44	ds	5	59.07	265	40	37/12	125	clayey sand	sc	dense to very dense
2	b44d	spt	11	73.19	240	35	68/12	125	silty gravel	gm	dense to very dense
2	b44f	ds	61	29.71	63	23	65/12	125	clayey sand	sc	very dense
2	b44h	ds	71	10.74	470	23	24/12	112	gravelly clay	cl	very stiff
2	b44i	spt	72	21.04	470	31	50/12	125	clayey sand	sc	very dense
2	b44j	ds	80	7.18	167		18/12	125	clayey sand	sc	very dense
2	b44k	spt	81	22.61	167		57/12	125	clayey sand	sc	very dense
2	b44l	ds	90	11.14	677	32	29/12	120	silty, clayey sand	sc-sm	dense
2	b49	spt	20	23.63	1070	24	29/12	120	clayey sand	sc	dense
2	b86	spt	20	35.85	400	30	44/12	120	silty sand	sm	dense
2	b86a	spt	45	16.84	203	32	31/12	120	silty sand	sm	dense
2	b86b	spt	80	9.37	297	28	23/12	120	cleyey sand	sc	dense
2	b86c	spt	95	9.67	790	14	25/12	112	sandy clay	cl	very stiff
5	b13	spt	35	25.25	813	20	41/12	120	clayey sand	sc	dense
5	b13a	spt	40	28.79	443	20	51/12	125	silty sand	sm	very dense
5	b14	spt	40	5.57	667	12	9/12	104	sandy clay	cl	med stiff to stiff
5	b27	spt	15	14.42	717	26	15/12	115	silty sand	sm	med dense
5	b5	cass	35	39.22	510	28	65/12	125	clayey gravel	gc	very dense
8	b208	ds	25	10.42	940	18	14/12	115	clayey sand	sc	med dense to dense
8	b209	spt	15	62.68	487	35	68/12	125	silty, clayey sand	sc-sm	very dense
8	b211	spt	15	40.36	757	28	42/12	115	sandy clay	cl	very stiff to hard
10	b13a	spt	40	28.25	193	32	48/12	115	silty sand	sm	dense
10	b18	spt	10	59.83	505	18	53/12	125	silty sand	sm	very dense
10	b81	spt	20	36.62	677	17	44/12	115	sandy clay	cl	very stiff to hard
14	b103	spt	15	12.49	93	30	13/12	115	silty, clayey sand	sc-sm	medium dense
14	b106	ds	20	23.61	1300	27	28/12	112	sandy clay	cl	very stiff
15	1a	ds	5	38.28	200	42	23/12	115	clayey sand	sc	medium dense
15	1b	ds	4	33.50	600	36	18/12	115	sand	sp	medium dense

15	1b1	ds	10	35.22	2100	32	29/12	108	sandy clay	cl	stiff
15	21b	ds	5.5	23.81	450	35	15/12	115	gravelly sand	sp	medium dense
15	2a	ds	5	14.98	600	33	9/12	115	clayey sand	sc	loose to med dense
15	2b	ds	5	32.63	400	40	19/12	108	clayey silt	ml	stiff
15	4b	ds	5	33.29	150	36	20/12	115	silty sand	sm	medium dense
15	4b1	ds	10	32.96	650	38	28/12	115	gravelly sand	sp	med dense to dense
15	5a	ds	6	32.93	500	34	21/12	108	silty clay	dl	stiff
15	5a1	ds	9	32.26	600	34	26/12	115	clayey sand	sc	medium dense

AREA "B", ALL SOILS, MINUS REJECTED VALUES

GROUP	BORING	TEST	DEPTH	N60corr	COHESION	PHI	N	UNIT WEIGHT	DESCRIPTION		CONSISTENCY
			(ft)		(psf)	ϕ	blows/ft	(pcf)			
1	b1-1	ds	35	24.64	413	39	40/12	120	slity sand	sm	dense
1	b10-1	ds	40	14.40	423	19	25/12	120	silty sand	sm	dense
1	b12-1	ds	45	5.73	850	23	10/12	108	sandy clay	cl	stiff
1	b15-1	ds	25	26.05	3050	24	35/12	115	sandy clay	cl	hard
1	b17-1	ds	20	28.52	1660	34	35/12	120	clayey sand-	sc	dense
4	w4	ds	20	39.91	1630	32	50/10	125	clayey sand	sc	very dense
4	w49	cass	15	37.00	1170	28	38/12	112	sandy clay	cl	very stiff
4	w4a	spt	21	30.38	1630	32	39/12	125	clayey sand	sc	very dense
4	w6	spt	25	26.40	1183	21	35/12	112	sandy clay	cl	very stiff
4	w6a	ds	35	22.65	1153	26	36/12	115	sandy clay	cl	hard
4	w6b	spt	36	22.33	1153	26	36/12	115	sandy clay	cl	hard
6	w6	spt	25	29.42	1183	21	39/12	112	sandy clay	cl	very stiff
6	w61	ds	35	57.93	473	34	96/12	125	clayey sand	sc	very dense
6	w62	spt	25	18.10	1397	11	24/12	112	sandy clay	cl	very stiff
6	w63	spt	10	46.09	240	32	40/12	120	clayey sand	sc	dense
6	w63b	spt	15	42.33	1480	20	45/12	120	clayey sand	cs	dense
6	w64	spt	10	40.33	95	38	35/12	120	silty sand	sm	dense
6	w64b	spt	30	29.94	280	36	45/12	120	clayey sand	sc	dense
6	w65	spt	10	46.09	375	37	40/12	120	silty sand	sm	dense
6	w65b	spt	25	32.84	1407	29	46/12	125	clayey sand	sc	dense to very dense
6	w66	spt	10	30.60	385	29	26/12	115	silty sand	sm	medium dense
6	w66a	spt	20	69.25	560	24	85/12	120	clayey sand	sc	dense
6	w68	spt	15	32.93	260	38	35/12	120	clayey sand	sc	dense
6	w69b	spt	40	15.50	107	22	26/12	112	sandy clay	cl	very stiff
7	b19	ds	40	29.42	1790	29	50/12	115	sandy clay	cl	hard
9	b19	ds	40	23.54	507	31	40/12	115	sandy clay	cl	hard

APPENDIX II

The coefficient of determination , r^2, is an indicator of how well the equation resulting from the regression analysis explains the relationship among the variables. The sum of the squared differences between the y-value estimated for a point and its actual y-value is called the residual sum of squares. The total sum of squares is the sum of the squared differences between the actual y-values and the average of the y-values. The smaller the residual sum of squares is compared with the total sum of squares, the larger the value of the coefficient of determination. The r^2 value can be interpreted as the proportion of the variance in y attributable to the variance in x.

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