THE INFLUENCE OF GRAVEL ON THE RESULTS OF THE STANDARD PENETRATION TEST

by

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ABSTRACT

The engineering properties of soils are often inferred from the results of in-situ testing. A common and easy testing tool is the Standard Penetration Test (SPT). Many empirical relationships have been developed between the results of this test and the engineering properties of soil. These relationships are typically based on tests completed in clean sands. It has been documented that the grain size influences the results of the SPT in that higher penetration resistance is encountered in coarse grained materials than in finer grained materials. The purpose of this study is to determine what percentage of gravel a soil must contain before the results of the SPT become significantly influenced.

The Becker Penetration Test (BPT) is also a penetration test used for in-situ testing of soils. Because the BPT utilizes a larger penetrometer, its results are not as impacted by the grain size of the material being tested. Typically the BPT results are converted to equivalent SPT results in order to be able to use the standard empirical relationships that relate SPT's to engineering properties. In order to realize the goal of this study, data were

collected from 6 dam sites in the Western United States. The data consisted of SPT results, BPT results, and gradations. The penetration test results were compared using statistical techniques.

The outcome of the statistical analysis is that the SPT results become significantly different from the BPT results when a soil contains about 25% gravel, and that the Harder and Seed (1986) procedure used to convert BPT's into equivalent SPT's is viable up to this point. The data that contained more than 25% gravel were analyzed to determine if a relationship between the BPT and SPT still existed and the BPT could be used as a tool to predict an equivalent SPT even under these conditions. The results indicated that there is indeed a relationship that exists, although it is different from than in soils which contain 0% to 25% gravel, and that the relationship can be used to predict equivalent SPT's.

These results are interpreted to mean that the standard empirical relationships between engineering properties and the results of the SPT are useful until a soil contains more than 25% gravel, at which point the SPT is behaving significantly differently that it behaves in clean sands of finer gradation, and the empirical relationships which relate the penetration resistance to engineering properties should be used with caution.

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LIST OF SYMBOLS/ABBREVIATIONS

English Symbol/ Abbreviation	Explanation
ASTM	American Society for Testing and Materials
BPT	Becker Penetration Test
BPT N_{60}	BPT blow count, converted to an equivalent SPT N_{60} blow count
BPT $(N1)_{60}$	BPT N_{60} blow count adjusted for overburden stresses, equivalent to SPT $(N1)_{60}$
Cn	Overburden Correction Factor
CPT	Cone Penetration Test
d	Difference
Dr	Relative Density
D_{50}	Mean grain size
ER	Theoretical free-fall energy of SPT hammer
Ho	Null Hypothesis
LPT	Large Penetration Test
N	Raw SPT blow count
N_{60}	SPT blow count adjusted to 60% of theoretical energy
$N1_{60}$	SPT blow count adjusted to 60% of theoretical energy and overburden stress
NB	BPT raw blow count
NBC	BPT blow count adjusted for bounce chamber energy and elevation
NBC final	BPT blow count adjusted for bounce chamber energy, elevation, and rig
P	Significance Probability
R^2	Coefficient of Determination
SPT	Standard Penetration Test
t_{crit}	Critical *t* value
t_{stat}	Calculated *t* value

Greek Symbol	Explanation
α	Significance Level of Probability of a Type I error (erroneous rejection of H_o)
σ_v'	Effective overburden stress

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CHAPTER 1

INTRODUCTION

In order to understand or predict how a soil at any given site will behave when subjected to structural or seismic loading, the properties of the soil must be determined. These properties are generally predicted with the use of in-situ and laboratory testing procedures. The Standard Penetration Test (SPT) is an in-situ testing procedure that is commonly conducted. Empirical correlations between the SPT penetration resistance of the soil and its relative density (Dr), bearing capacity, strength, and other engineering properties have been developed and are widely accepted by the engineering community. The penetration resistance of the soil is determined by counting the number of blows of a 140 pound hammer, referred to as the blow count, required to advance the penetrometer 12 inches into undisturbed ground.

Many of these correlations have been developed in clean sands. It has been determined in previous studies (Skempton, 1986) that the grain size of the material being tested influences the results of the SPT. When testing a soil, the presence of gravels and coarser grained particles typically result in a higher penetration resistance than would occur in a clean sand of similar relative density. Therefore, when the standard correlations are used to relate the penetration resistance to an engineering property, the result could be an incorrect prediction of the true conditions that exist. The premise of this thesis is that the SPT is influenced by the percentage gravel contained in a soil, and there is a point at which SPT results are dramatically influenced by the presence of gravels. It is at this point that the standard empirical relationships between engineering properties and the SPT blow count may no longer be appropriate or should be used with caution.

The SPT is one of the more simple and common indicators of the in-situ properties of a soil and is commonly used in soils that contain gravel. If the point where these gravels start influencing the SPT results can be quantified, it can help the soils engineer determine if the SPT and the standard correlations with engineering properties are applicable to a particular project and the reliability of the results.

The Becker Penetration Test (BPT) has been developed as an alternate tool for penetration testing in soils. This is also a test where the density, strength, or other engineering property of a soil is inferred from the penetration resistance of a soil. It is different from the SPT in that the driving mechanism is different and the outer diameter of the penetrometer is typically 6.6 inches as compared to 2.0 inches for that of the SPT. Previous studies involving large penetrometers (Tanaka, *et al.*, 1989), have shown that the influence of gravel-sized particles on the BPT results is less significant than on the SPT results due to the larger size of the sampler.

Penetration tests are very useful tools to the engineer as predictors of the in-place characteristics of a soil. The SPT has been the most commonly used test for this function but has limitations in that is does not behave predictably in gravelly soils and can be damaged by large particles. The BPT equipment is durable and capable of penetrating up to 100 feet per hour (Harder, 1988). These attributes make the BPT an economically viable choice for testing in gravelly soils. However, the BPT results have not been directly correlated to the engineering properties of soils. To resolve this deficiency, several correlation procedures have been developed to convert the BPT results into an equivalent SPT values. The correlation procedure used for the data in this study was developed by Harder and Seed (1986).

The hypothesis for this study is that the SPT reacts differently in coarse grained materials than in finer grained materials, and that there is a certain point at which it starts behaving significantly differently. This study will attempt to define this point by comparing the result of SPT's to the results of BPT's in similar soils and statistically analyzing the data to determine the conditions that cause this difference.

CHAPTER 2

BACKGROUND

The background is divided into four sections. The first section discusses previous studies of the relationship between grain size and the SPT results. The next sections review the SPT and BPT. Review of the SPT and BPT testing procedures is important for several reasons. One reason is the equipment and procedures are not typically consistent between sites. In order to view the results on an equal basis, the testing procedures must be first understood and then they can be normalized for procedural and equipment differences. This review will examine how different equipment may influence the results of the procedures, and how to reduce the data to compensate for differences in equipment and procedure. The primary adjustments typically required for these tests are for energy, depth, and equipment variations. The final section discusses the similarities and differences between the testing methods.

2.1. Literature Review of the Influence of Particle Size on the Results of In-Situ Testing Procedures

The purpose of the literature review is to learn about previous studies on the influence of gravel on the standard penetration test and determine if they are in any way pertinent to this study. Overall, very little specific information was found discussing the relationship between gravel and the SPT. The primary source of material was geotechnical journals. The facts from the articles pertaining to the grain size effects are summarized in the following paragraphs.

A study by Marcuson and Bieganousky (1977) tested several sands to determine if the grain-size distribution or grain shape, or both, influenced the SPT results. The tests were performed at various relative densities and overburden pressures in special soil containers. The soils discussed in this particular paper were the Platte River sand and Standard Concrete sand. Both of these sands typically contain less than 10% gravel. The study results illustrated that at a given relative density and overburden pressure, the blow count increases as the median grain size increases. Marcuson and Bieganousky (1977) re-iterated the well established fact that the penetration resistance is influenced by the effective overburden pressure and the density of the deposit. The study also concluded that a simplified family of curves correlating SPT blow count values, relative density, and overburden pressure for all cohesionless soils under all conditions is not valid. The factor used to normalize data to a standard overburden pressure of one ton per square foot, Cn, is not solely a function of the overburden pressure, but is also influenced by the relative density and soil type and possibly other parameters that were not defined.

A study by Yoshida and Ikemi (1988) was conducted in order to expand the applicability of the standard penetration test to gravelly soils. The results of the study indicated that the relationship between the dry density and the penetration resistance and relative density and the penetration resistance changes as the gradation of the material changes. The material types considered were fine sand, sand with 25% gravel, and sand with 50% gravel. For the same SPT blow count, the coarser material had higher dry densities than the finer grained materials. Also, as the blow count increased, the dry density of the fine sand increases at a higher rate than the dry density of the coarser grained material. The study also determined that the relationship between relative density and the SPT resistance is not as distinct as that between dry density and penetration resistance for the different soils in this test. The predicted relative density curve developed by Yoshida and Ikemi was not the same as that developed previously by Meyerhoff (1957). The results of this study indicate that when coarser grained material is present, the resulting SPT blow counts will overestimate the relative densities if the Meyerhoff (1957) curves are used as the predictive tool. This study developed some empirical relationships between the relative density, Dr, the SPT blow count, N, and overburden stress σ'_v(kg/cm^2). These relationships are summarized in the following table:

Table 2.1 Empirical Formulas Developed by Yoshida and Ikemi (1988)

Material	Empirical Formula
Fine Sand	$Dr = 22 \times N^{0.57} \times \sigma'_v{}^{-0.14}$
Gravel fraction 25%	$Dr = 18 \times N^{0.57} \times \sigma'_v{}^{-0.14}$
Gravel fraction 50%	$Dr = 25 \times N^{0.44} \times \sigma'_v{}^{-0.13}$
All soils	$Dr = 25 \times N^{0.46} \times \sigma'_v{}^{-0.12}$

These equations predict lower relative densities for the coarser grained material than for the finer grained material for the same SPT blow count.

These results were developed in a laboratory situation, however they were verified with field testing. The study also concluded that the SPT can be used in gravelly soils if the cutting shoe is constructed with specially hardened metal to prevent it from being damaged by gravel particles. The study developed correlations between the SPT N value and shear wave velocity data and the results of tests conducted with a larger penetrometer (2.0" I.D. and 2.9" O.D).

A study by Tanaka *et al.* (1989) related the results of the SPT and large penetration test (LPT) to the dynamic strength of gravelly soils. A LPT is similar to a SPT except the size of the sampler is larger. The dynamic strength of the soils was determined through undrained cyclic triaxial tests conducted on samples of diluvial dense gravel soil obtained at three different sites by an in-situ freezing sampling method. The results indicated that the strength is not only dependent upon the results of the penetration tests but also on the effective confining pressures and grain-size distributions. The study determined that the SPT is more sensitive to the grain-size effects than the LPT.

Correlations between cone penetration tests (CPT's) and SPT's is a function of the mean grain size, D_{50}. This is shown in studies by Robertson, *et al.* (1983) and Seed and de Alba (1986). These studies are another indicator of the influence of grain size on the testing procedure.

Andrus and Youd made the following observation about the affect of gravel on the penetration resistance when conducting a study on two sites that experienced liquefaction during the 1983 Borah Peak, Idaho, earthquake:

> The low blow count in the loose gravel at both sites suggest a lack of influence of gravel particles and could not have been increased much due to gravel content. In addition, no abrupt irregularities occurred in plots of penetration verses number of blows. Based on these finding and without established guidelines to correct for gravel, the influence of gravel on the SPT resistances was ignored. (Andrus and Youd, 1989).

The study by Andrus and Youd (1989) does not agree with recommendations published by the National Research Council (1985) in regard to the SPT that "the presence of a small quantity of gravel can increase greatly the penetration resistance without having much influence upon the susceptibility to liquefaction."

Standard practice at the Bureau of Reclamation concerning the results of SPT's conducted in gravel bearing soils is that they are disregarded, or the penetration per blow is recorded, the resulting blow counts are plotted versus depth, and when the results start deviating from a straight line it is assumed the gravel has started influencing the results and a straight line is extrapolated to approximate an answer. This method is not founded on any scientific information, and Farrar (1997) has recently conducted a study deeming that the results of this method are not reliable.

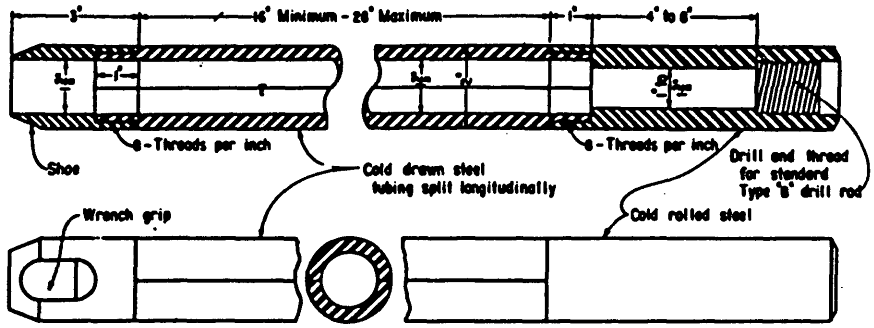
A study by Gibbs and Holtz (1957) studied the effects of the drill rod length and weight, overburden pressure, and moisture content on the SPT results. These studies were conducted in the laboratory on a coarse sand with a D_{50} of 1.5 mm and a fine sand with a D_{50} of 0.30 mm. The coarse sand contained less than 5% gravel. In the effort to determine the effects of overburden pressure on the test results it was shown that the relationship between penetration resistance and relative density is different for the two material types. At relative densities greater than approximately 50%, the difference was within a few blow counts. At lower relative densities the effect is slightly greater.

The literature review concludes that as the grain size of the material increases the SPT resistance increases, but the relative density in not necessarily increasing at the same rate. When a penetrometer larger than that found on the SPT is used, the increasing grain size does not cause an appreciable effect on the penetration resistance.

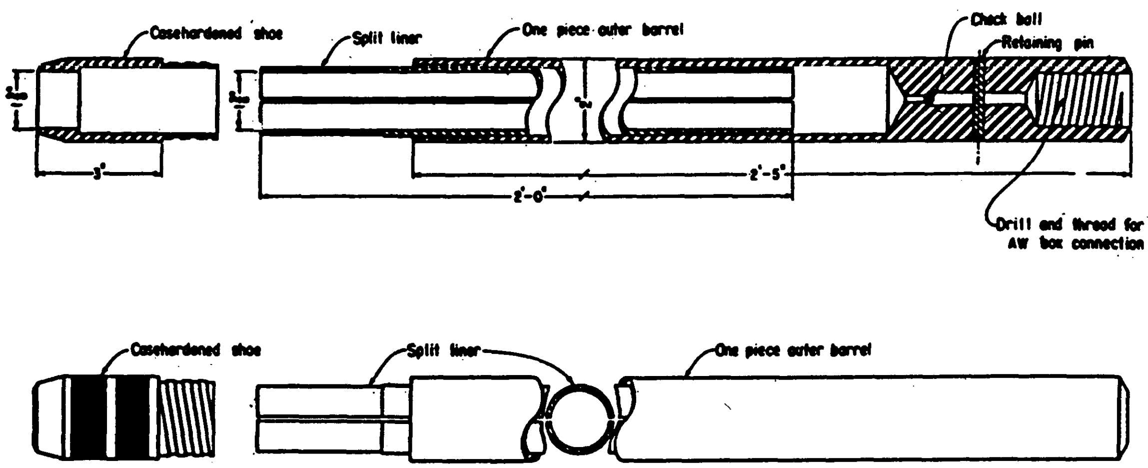
2.2 Review of the Standard Penetration Test

The Standard Penetration Test was developed in the early 1900's and is the test most utilized for in situ soils (Robertson, 1986). The advantages of this test are that the equipment is simple and durable, the procedure is simple, multiple tests can be conducted in a single hole, a soil sample can usually be obtained, usable results can be obtained in most soils, and many correlations have been developed between the test results and anticipated engineering properties. For example, Lambe and Whitman

(1969) show the empirical correlations developed between the SPT resistance and relative density, friction angle, bearing capacity, and strength in clays. The test consists of driving a standard sampler (2-inch O.D. and 1-3/8-inch I.D.) by a 140 pound hammer falling freely 30 inches. A typical sampler is shown on figure 1 (BOR, 1990). The number of blows required to drive the sampler 12 inches, after an initial 6 inch penetration referred to as the seating interval, is the standard penetration resistance. The purpose of the seating interval is to ensure to as much extent as practical that the test interval is undisturbed.



STANDARD SPLIT-TUBE SAMPLER



2-INCH O.D. x $1\frac{3}{8}$-INCH I.D. PENETRATION RESISTANCE SAMPLER

Figure 1. SPT Samplers

(From Bureau of Reclamation, 1985)

The standard penetration resistance is referred to as the SPT N value or blow count. The blow count is an indicator of the relative density or strength of the material being tested and a qualitative guide to the in-situ engineering properties. The test also provides a sample of the soil for classification purposes. Although the SPT is widely used and the procedure is simple, the results are greatly affected by the drilling and sampling equipment and procedures. Table 2.2 was developed by J. H. Schmertmann (1978) to summarize the procedures that may affect the SPT N value.

Other procedures that can influence the test results include inadequate cleaning of the borehole, not seating the sampler spoon on undisturbed soil, driving the sampler spoon above the bottom of the casing, overdrive of the sampling spoon, the sampling spoon being plugged by gravel, a plugged casing, over washing ahead of casing, not using the standard hammer drop or weight, using too large a pump, and loose connections between rods. There are obviously many sources of error and the repeatability of the test is questionable based on these parameters. In order to account for some of the potential deviations, and for the blow count to be

Table 2.2 Some Factors in the Variability of Standard Penetration Test N

Cause		Estimated % by Which Cause Can Change N
Basic	Detailed	
Effective stresses at bottom of borehole (sands)	• drilling fluid • use hollow-stem auger versus casing and water and allow head imbalance • hole diameter	+/-100% +/- 100% +/-50%
Dynamic energy reaching sampler (All soils)	• 2 to 3 turn rope-cathead versus free drop • anvil size • length of rods - less than 10 ft - 30 to 80 ft - more than 100 ft • variations in height drop • A-rods versus NW-rods	+100% +50% +50% +10% +/-10% +/-10%
Sampler design	• sampler designed for use with liners, but they are not used	-10% (sands) -30% (clays)
Penetration interval	• Test from 0 to 12 inches or 12 to 24 inches instead of 6 to 18 inches.	+/-15% (sands) +/-30% (clays)

(Adopted from Schmertman, J.H., 1978.)

reliably related to any properties of that material, some standard procedures need to be followed and appropriate corrections made to the results. Although there are many factors to consider, it is standard to adjust the N-value for just the following five items to allow for comparison on a common basis (Canadian Foundation Engineering Manual, 1992):

- Actual energy delivered to the drill rod. The energy levels between different types of equipment can vary significantly.
- The influence of the overburden stress on N values.
- The length of the drill rod.
- The absence or presence of a liner inside the split-spoon sampler.
- The influence of the diameter of the borehole.

The ratio of the energy (ER) delivered to the rods during a SPT to the theoretical free-fall potential energy can vary from about 30% to 90%. These variances are the result of different hammer release systems, hammer types, anvils, and operator characteristics. Schmertmann and Palacios (1979) have shown that the SPT blow count is approximately inversely proportional to the energy delivered to the drill rods. Studies by Seed *et al.* (1984) have indicated that an ER of 60% is a reasonable historical average for most SPT based empirical correlations, and that for analyses purposes, SPT N values must be corrected to this ER. The energy is normalized with the following equation:

$$N_{60} = N\left(\frac{ER}{60}\right)$$

A blow count normalized to the 60% ER is indicated by N_{60}.

The ER value can be assumed based on the type of drilling equipment used, or the equipment can be calibrated to evaluate its efficiency in transferring energy. There are three types of drive hammers commonly used in SPT testing: the safety hammer, the donut hammer, and the automatic hammer. The effective energy delivered by the safety and donut hammers are typically 55% and 45%, respectively, of the theoretical simple energy. The automatic hammer usually delivers between 55% and 83% of the energy.

The N_{60} value is multiplied by a 0.75 factor if the depth is less than 10 feet in order to account for the energy losses attributed to the first rod. Energy is lost in the first rod because "when the length of the drill rods is less than 10 feet, there is a reflection of energy in the rods which reduces the energy available for driving the sampling tube into the ground" (Seed, *et al.* 1985). Thus less energy goes into moving the tip of the sampler, and the measured penetration resistance is falsely high. The 0.75 factor compensates for this phenomenon.

The resistance to penetration increases with depth due to influences of greater overburden, confining pressures, and energy losses in the drill rods. For example, a loose soil at a significant depth can have a higher blow count than a denser soil at a shallow depth. There are a variety of methods that have been developed for correcting the blow count for overburden pressure. The one chosen for use in this project was developed by Seed *et al.* (1975) and is based on applying an overburden stress correction factor, Cn to the energy corrected N_{60} blow counts. This factor is meant to normalize the blow counts to a constant reference vertical effective normal stress. This adjustment eliminates the increase that would occur to a blow count at constant density due to increasing confining stress. The corrected blow count is the product of Cn and N_{60} and is indicated by the $(N1)_{60}$ designation.

The Cn factors used for this analysis were developed by Marcuson and Bieganousky (1977) for Platte River Sand and are interpolated from the curves on figure 2. These curves were chosen because the Platte River Sand is coarser than the materials for which most of the correction factors were developed. The relative densities were approximated using empirical relationships shown on figure 3. The minimum Cn factor, used for overburden pressure greater than 12000 psf, is 0.4, and the maximum Cn value is 1.6.

The studies by Marcuson and Bieganousky (1977) indicate that the Cn factor is apparently a function of the soil type, relative density, effective overburden pressures, and possibly other factors. The Cn factor applied to this data was the best approximation that could be found considering the coarseness of the materials.

The ASTM Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils (Designation: D 1586-84 (re-approved in 1992)) calls for a sampler with 1-3/8 inch inner diameter (I.D.) shoe and a barrel with a 1-1/2 inch I.D. which can be fitted with a liner to produce a constant I.D.

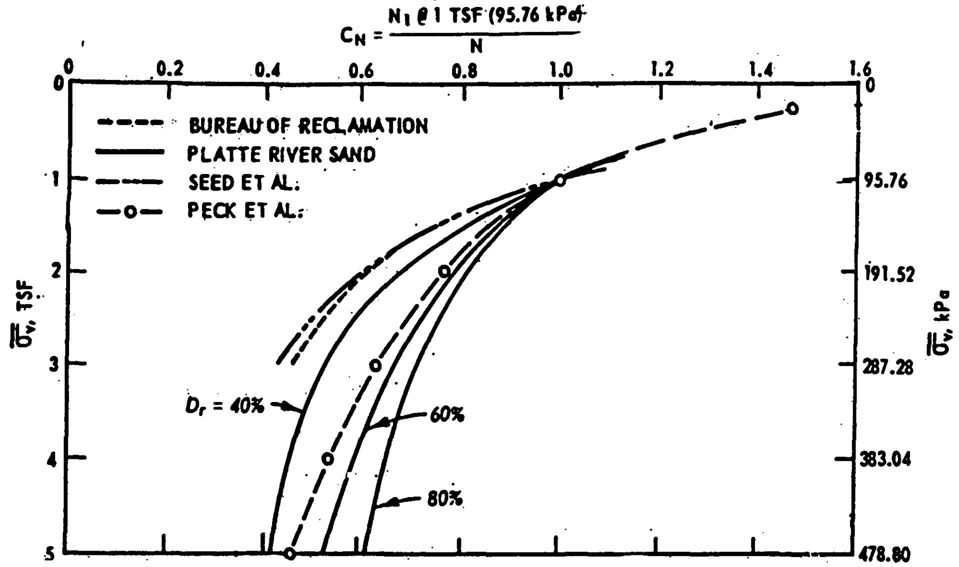


Figure 2. Cn Correction Curves

(From Marcuson and Bieganousky, 1977)

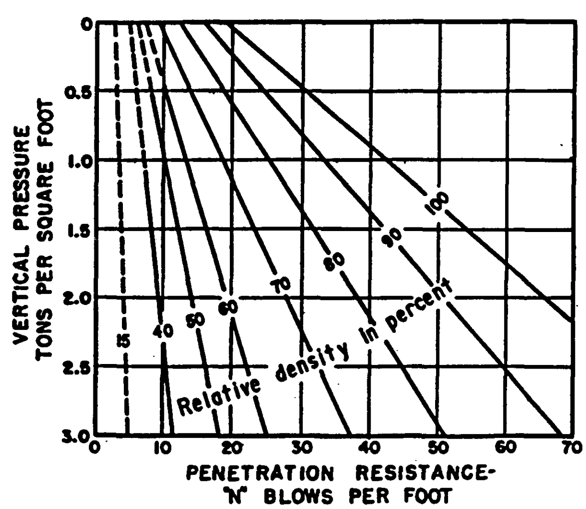


Figure 3. Relationship of Relative Density and SPT

Penetration Resistance

(From Bureau of Reclamation, 1985)

of 1-3/8 inches. The barrel is often used without liners in which case the I.D. is 1-1/2 inches and there is less friction on the inside of the sampling tube than in the test when a constant diameter sampler is utilized. Bureau of Reclamation procedures (1990) require the use of a sampler with a constant I.D. of 1-3/8 inches. However, this procedure is not always followed. Wendell Carlson (1997), a geologist for the Bureau of Reclamation in the Mid-Pacific Region said that, on Bureau of Reclamation jobs, liners are very rarely used because they are difficult. He also said that samplers of constant I.D. are also not standard practice, even though they are specified in the procedure.

Studies conducted by Schmertmann (1979) compared the results of tests performed with a constant I.D. sampler with those performed with ASTM samplers without liners. The results indicated that the tests performed with the ASTM sampler without liners result in lower N-values due to decreased friction than those tests performed with the constant I.D. sampler (Seed *et al.* 1985). It was recommended that the raw blow counts of tests performed with the ASTM sampler without a liner should be adjusted upward by 10% to 30% to make the results conform with recommended practice. The following relationship was used for this analyses: adjust the raw blow count upward by 10% for loose material (up to 5 blows per foot) and 25% for dense materials (blows counts exceeding 30), interpolating adjustments for blow counts between 5 and 30. (Seed, *et al.* 1985, Schmertmann, 1979)

Skempton (1986) reported that the size of the borehole effects the test results in cohesionless material. Previous studies had shown that larger diameter boreholes resulted in low N-values. Skempton (1986) published some conservative factors to account for borehole diameter. These values are 1.0 for boreholes of 65 mm to 115 mm, 1.05 for boreholes of 150 mm, and 1.15 for boreholes of 200 mm.

2.3 Review of the Becker Hammer Penetration Test

The Becker Hammer Drill was developed in the late 1950's by Becker Drills Ltd. in Alberta, Canada as a tool to quickly sample coarse grained deposits. The basic premise of the test is similar to that of the SPT. A double-walled casing is driven into undisturbed ground with a double-acting diesel pile hammer. The penetration resistance is determined by counting the number of diesel hammer blows required to drive the casing 12 inches.

The diesel hammer, an International Construction Equipment Model 180, is rated at a maximum energy of 8100 foot-pounds per blow. The hammer is closed off at the top and part of its energy during driving is developed by the compression of air in the top of the hammer cylinder during the travel of the ram during each cycle. The bounce chamber pressure is a measure of this trapped air and can be used to estimate the driving energy for each blow. The hammer delivers approximately 90 blows per minute and can penetrate up to 100 feet in an hour.

The casing is composed of two heavy pipes arranged concentrically. The pipes are separated by neoprene cushions. The outer pipe absorbs the energy of the hammer. The casing sizes are 5.5 inch, 6.6 inch, and 9 inch.

There are two different types of Becker drilling and penetration equipment in use. There are the older HAV-180 or B-180 rigs and the newer AP-1000 rigs. The energy applied to the drill rods is a function of the type of rig.

There are two basic types of bits used, a crowd-in bit and a crowd-out bit, and the bits can be either open or closed. The crowd-in bits are typically used in open bit drilling when samples are being recovered. The crowd-out bits are typically used in closed bit drilling, where conditions may be more difficult, and when the penetration resistance is the primary goal. Open bit soundings are not recommended for use when penetration resistance is the primary goal of the drill hole as they are believed to underestimate the penetration resistance of a deposit due to the disturbance of the air re-circulation sampling process (Harder and Seed, 1986).

Although widely used, the BPT continues to need improvement and standardization in the areas of equipment, interpretation of driving energy, and the effects of the casing friction. Figure 4 shows a typical Becker Rig set-up for an open-bit test.

Many empirical relationships have been developed to relate the results of the SPT to engineering properties, therefore, the BPT resistance is determined and then converted into an equivalent SPT resistance to evaluate the soil. Several correlations between SPT and BPT blow counts have been developed. The most commonly used and recognized are the Harder and Seed (1986) method and the Sy (1993) method. The Harder and Seed (1986) method corrects the raw

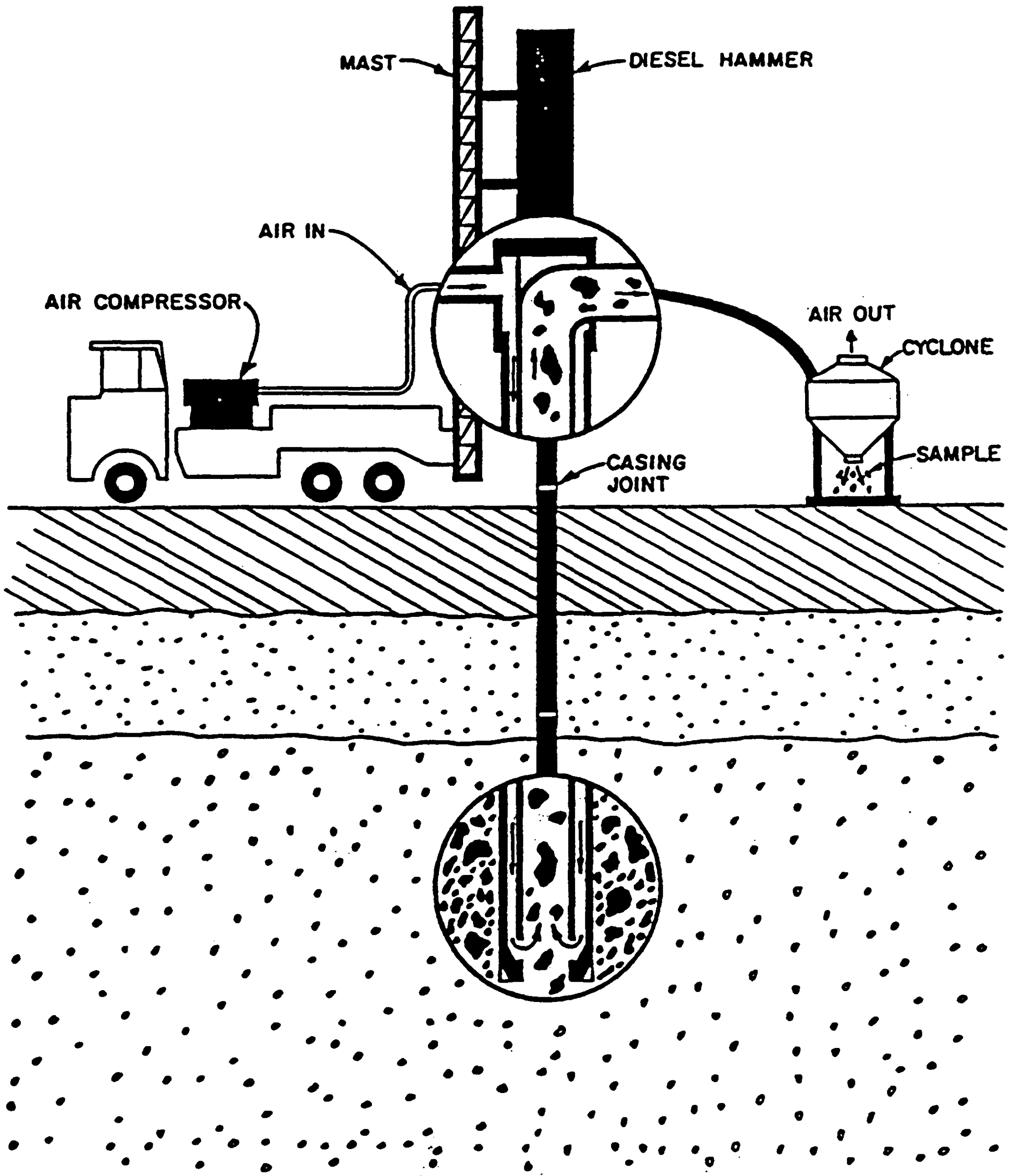


Figure 4. Becker Rig

(From Harder and Seed, 1986)

Becker blow counts for energy based on a correlation between the bounce chamber pressure and the potential hammer energy. The Sy method is based on correcting the raw Becker blow counts for energy using Pile Driving Analyses (PDA) to determine the energy being transmitted to the rods.

The Harder and Seed (1986) method will be used for this analysis because it has been more widely used, and because the Sy method requires the collection of special data which are not as readily available. The first step in Harder's process is to collect the Becker blow counts, NB, and the bounce chamber pressures. When the testing is performed at high elevations, Harder and Seed (1986) recommend that the bounce chamber pressures be converted to equivalent sea level bounce chamber pressures because the standard constant combustion curve developed by Harder and Seed (1986) to account for variable combustion effects were for sea level atmospheric pressures. To obtain equivalent sea level bounce chamber pressures, the measured bounce chamber pressures must be increased. The increase is typically 1.5 to 2 psi at approximately 2000 feet above sea level and 4 to 6 psi at approximately 6000 feet above sea level.

Double acting diesel hammers do not have constant energy conditions. This is due to the fact that energy is dependent upon combustion conditions which include fuel, air, and pressure. The kinetic energy delivered by the ram at impact is dependent upon the energy developed by the previous impact to drive the ram back up the cylinder. The potential energy of the ram at the top of the stroke can be related to the maximum pressure in the bounce chamber at this time. The energy is also affected by the soil. When softer soil is encountered the casing penetrates further and more energy is diverted into the soil and less energy goes back to the ram. The corrected bounce chamber pressure and raw blow counts are used in conjunction with a calibration chart to obtain a blow count that has been adjusted for energy. A standard constant combustion rating curve was adopted by Harder and Seed (1986) to account for variable combustion effects. They developed Correction Curves for correcting data with low combustion efficiencies to this standard rating curve. The Harder and Seed correction curves are on Figure 5. The energy corrected blow count is referred to as N_{BC}.

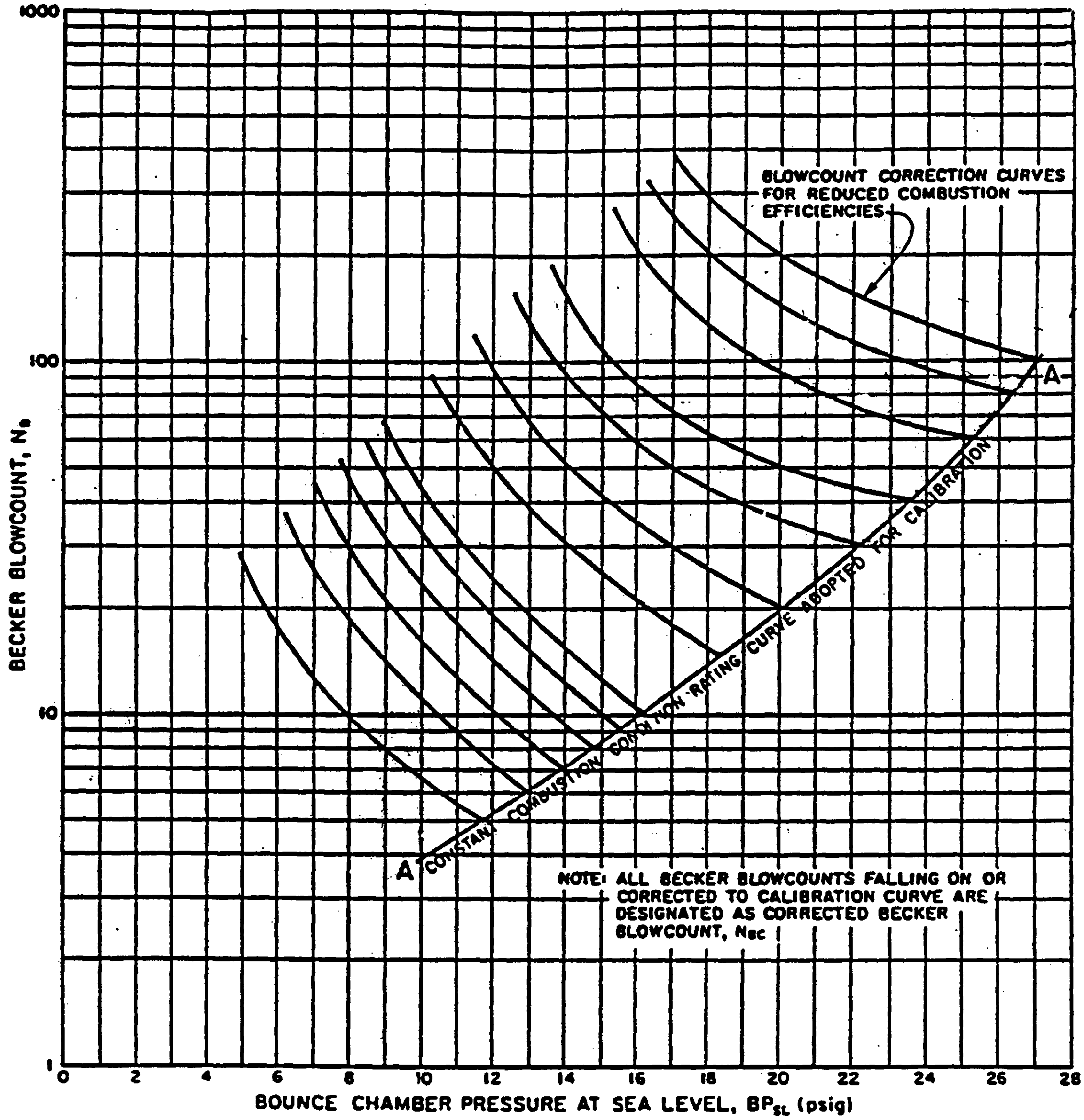


Figure 5. Correction Curves Adopted to Correct Becker Blow Counts to Constant Combustion Curve Adopted for Calibration (From Harder and Seed, 1986)

The N_{BC} values are multiplied by 1.5 if a B-180 drill rig was used to obtain the data. If the AP-1000 rig was used a 1.0 factor is used. Studies by Harder and Seed (1986) have indicated that the B-180 delivers the energy more efficiently that the AP-1000, which was used to develop the SPT-BPT correlation. The product of the equipment correction and N_{BC} is referred to as N_{BC} final.

To develop a correlation between BPT and SPT, Harder and Seed (1986) plotted the energy corrected Becker blow counts, N_{BC} final, against the energy corrected SPT blow counts N_{60}, for paired data from three sites. These sites were chosen because the soils are composed of sands and silts and this ensured that the SPT results were meaningful to the extent that the grain size was not an issue and the standard correlations to engineering properties are appropriate. Harder fit a curve to the data to correlate the BPT N_{BC} final values to equivalent SPT N_{60} values as shown on figure 6. The value which is equivalent to a SPT N_{60} value is referred to as the BPT N_{60}. The chart which empirically correlates the N_{BC} final value to the equivalent N_{60} was developed for N_{BC} final values up to 100.

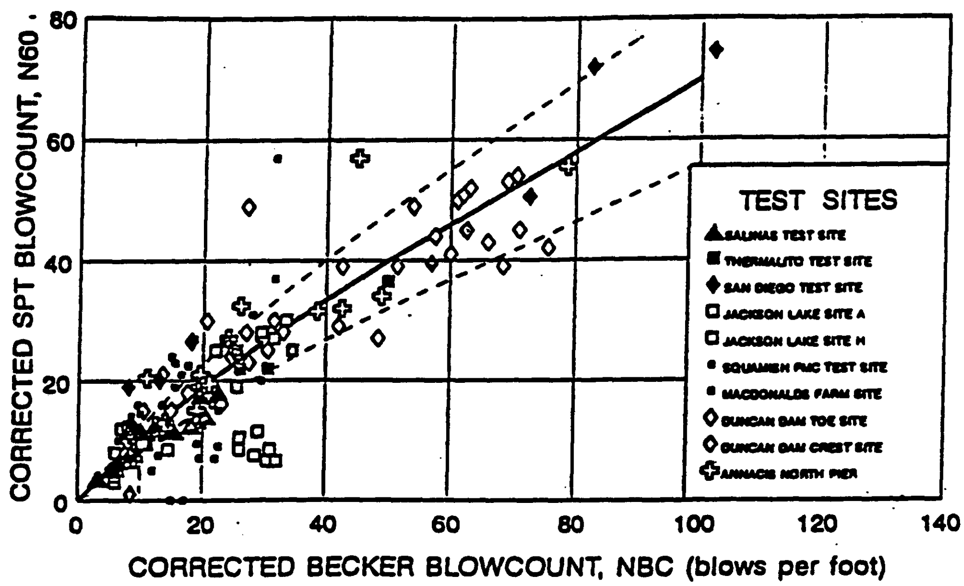


Figure 6. Correlation Curve (From Harder and Seed, 1986) NBC (Becker blow count adjusted for energy and equipment) versus N_{60} (SPT blow count adjusted for energy and equipment)

The method developed by Harder and Seed (1986) to correlate BPT to equivalent SPT blow counts can generally be used with most of the Becker equipment combinations, however, the published correlations are based on use of a crowed-out closed bit, 6.6-inch O.D. casing, and driven with an AP-1000 drill rig.

After the equivalent BPT N_{60} value is determined, it is corrected for overburden using the same procedure described in section 2.2 to obtain BPT $(N1)_{60}$ value which is equivalent to the SPT $(N1)_{60}$ value. Some other errors related to the BPT include friction on the casing, error in the correlation, and plugged lines connecting the bounce chamber to the data collection system. Friction was not specifically accounted for in Harder's correlation, however it is built in to a certain extent. This is one of the differences in the testing methods because the SPT encounters friction only in the testing and seating intervals because the drill hole is advanced independently of the SPT. Due to this procedure, the only portion of the SPT drill rod in contact with the drill hole are the 1.5 feet involved in the test.

2.4 Comparison of Testing Methods

The SPT and BPT are tests that can be used for the same purpose of characterizing soils. There are a few similarities in the tests, but there are also several differences between the testing procedures that should be recognized. Table 2.3 summarizes the primary conditions that influence the results of the tests and their significance.

Table 2.3 Comparison of SPT and BPT			
Condition	SPT	BPT	Significance
Diameter of Sampler	2.0-inch O.D.	6.6-inch O.D.	BPT is less sensitive to grain size effects
Testing Method	6-inch seating and 12-inch test intervals	continuous	BPT can give more information
Bit	open	closed	SPT collects soil samples
Friction	friction only acts in seating and test interval	friction acts upon the entire length of the casing	effects of friction on BPT not directly accounted for
Energy	free-fall hammer	diesel hammer	adjustment methods different
Overburden Pressure	adjusted with Cn	adjusted with Cn	no significance to results
Liner	correction required if liner not used when there is space	not applicable	no significance to results
Elevation	not applicable	adjustment required for elevations greater than 1000 feet	a function of energy difference
Drill Rod Length	adjustment for rod length less than 10-feet	adjustment for rod length less than 10-feet	no difference
Equipment	not applicable or accounted for with energy correction	factor of 1.5 required for older B-180 rigs	no significance to results

CHAPTER 3

DATA AND METHODS

The task of determining the point at which the SPT results are significantly affected by grain size was divided into the following steps:

- Data collection
- Data preparation
- Statistical analysis of data
- Validation of results

3.1 Data Collection

The data collected were from five Bureau of Reclamation (BOR) projects and one Army Corp of Engineers (COE) project. The data consisted primarily of SPT results, BPT results, gradations, and material type. The projects are all dams and the data were initially collected in order to help characterize the foundation conditions. These six projects were chosen primarily because of the accessibility of the data and because they had SPT's in close proximity to BPT's. BPT's have not been used extensively until recently on BOR projects, so the database is limited. The goal was to collect at least two hundred SPT's in order to have a reasonable database. Gradations of the samples recovered during the SPT's were required in order to determine the approximate percentage gravel and grain sizes of the material tested. All of the data collected were initially considered for the analysis and none of the data were predetermined to be "good" or "bad".

The data that were collected consisted of the following when it was available: the drill logs, plan view map, material classifications and gradations, and geologic description of the site. This information was not always readily available for each of the sites. When the drill logs were not available the primary data such as raw blow count and energy correction were available in reports summarizing the exploration at a particular project. The following paragraphs detail the equipment and procedures used at the sites and give a brief description of the foundation materials.

3.1.1 Description of Data Sites

Bradbury Dam is located on the Santa Ynez river northwest of Santa Barbara, California. The alluvium at the site is predominantly sand and gravel, although a wide variety of materials were identified at the site, varying from well graded gravel with sand, cobbles and boulders, to lean clay. Most of the alluvium is composed of hard, rounded, un-cemented sandstone gravel, and sand.

Casitas Dam is located near Ventura, California on Coyote Creek. The exploration is located downstream of the embankment. The first thirty feet of material sampled is loose fill which is composed of sands, silts, and gravels. Beneath the fill is approximately fifty feet of alluvium which consists of sands, silts, clays, and gravels.

Lahontan Dam is located near Fallon, Nevada. Data from 4 SPT and 4 BPT drill holes were used in this study. The holes were drilled through alluvium downstream of the dam.

Lost Creek Dam is located on the western slope of the Wasatch Mountains on Lost Creek about 12 miles northeast of Devils Slide, Utah, and 30 miles east of Ogden. Data from 5 BPT and 5 SPT drill holes were used in this study. The holes were drilled downstream of the dam through approximately 5 feet of fill consisting of silty sand with organic material and then through Quaternary Alluvium. The alluvium consists of clean to silty, fine to coarse, predominantly sub-rounded sand and poorly graded, hard, sub-rounded to sub-angular gravels and cobbles with sandstone, quartz, and limestone boulders.

Mormon Island Auxiliary Dam is located near Sacramento, California on the American River. The dam is mainly founded on alluvial sands, gravels, and cobbles. Portions of the alluvium were apparently dredged in the early 1900's leaving behind zones of loose sand, gravel, and intermixed fill (Harder, 1992). The explorations were from both the upstream and downstream sides of the dam. The official drill logs were not obtainable and the data were taken from a report written by Harder for the U.S. Army Corp of Engineers (1992).

Success Dam is a Corp of Engineers Project (COE) project. The dam is located on the Tule River near Porterville, California. The foundation consists of slopewash, recent fan and alluvial deposits, terrace deposits, cemented older alluvial deposits, and bedrock. The holes were drilled downstream of the dam and also from benches on the upstream and downstream faces of the dam. The detailed laboratory gradation analysis data were not available for this project. The percentage of gravel, sand, and fines were reported on the drill logs.

3.1.2 Equipment Summary

Table 3.1 summarizes the more important aspects of equipment and procedures used in the drilling programs. This table was included to illustrate in a simple format how the equipment varies between projects.

Table 3.1 Data Summary of SPT and BPT Drilling Programs

	Bradbury Dam	Casitas Dam	Lahontan Dam	Lost Creek Dam	MIAD	Success Dam
SPT Drill Rig	Porta-drill TLS-542	Failing 1500-S	CME 75	Sprague Henwood and Gus Pech II	CME 75 Failing 1500-S	CME 75
SPT - Hammer	Mobile Safety	Mobile Safety	auto.	unknown	auto. donut	auto.
SPT - Liner	unknown	unknown	no	unknown	no	no
SPT - drilling fluid	ben-tonite mud	liquid polymer	unknown	LPT polymer water & bentonite mud	unknown polymer	ben-tonite mud
SPT - Hole Diameter (inches)	unknown	3.9-4.5	3.0	3.8-4.0	unknown	3.8
SPT- Energy as percentage of max	65%	65%	65%	60%	95% 65%	95%
BPT - Rig	AP-1000	AP-1000	AP-1000	AP-1000	B-180 AP-1000	AP-1000
BPT - elev. adjust	no	no	no	yes	no	no

3.2 Data Preparation

The first step in the data preparation process was to adjust the data, as discussed in Chapter 2, based on the results of the review of testing methods in order to make sure that the SPT's and BPT's are compared on an "equal" level. Standardized spreadsheets were created for both the SPT's and BPT's to expedite this process. The SPT data required correction for energy, overburden pressure, and absence of liners. Based on the conversation with Wendell Carlson (1997) mentioned in section 2.2, it was assumed that liners were not used unless the drill logs state otherwise. The BPT data required correction for energy, elevation, and equipment. The values were then converted to equivalent SPT values using the Harder and Seed (1986) approach.

Each SPT drill hole was paired with the BPT drill hole that was closest to it in lateral distance. After the holes were paired, the SPT and BPT worksheets were combined and the individual tests were paired by elevation. It was assumed that by pairing the data in this manner that the materials encountered in both the SPT and BPT drill holes would be most closely related in density, moisture content, and composition. Tests that could not be paired based on elevation were deleted from the data set. Each pair was assigned a unique identification number. This was primarily for future trouble shooting. Each site was assigned a range of numbers for easy identification as follows:

Lahonton Dam - 00's
Bradbury Dam - 100's
Mormon Island Dam - 200's and 300's
Casitas Dam - 400's
Lost Creek Dam - 500's
Success Dam -600's

3.2.1 Methodology of Creating Test and Control Groups

The next step in the data preparation stage was to divide the data into 2 groups, a test group and a control group. The purpose of the test group is to develop a hypothesis quantifying the percent gravel that is causing the SPT to behave significantly different than it behaves in clean sands. The hypothesis will be developed based on the results of the statistical analysis described in section 3.3. The purpose of the control group is to validate the results of the test group.

The first step in dividing the data into 2 groups was assigning each data pair a random number using a random number generator. The paired holes were then combined onto one spreadsheet for each site, and the data pairs were sorted in ascending order based on the assigned random numbers. Every fourth data pair from each site was moved to the control group file, the remaining pairs were moved to the test group file. The data from all the sites were combined in these two files. When the above was accomplished it was determined that the plotting package in EXCEL could handle only 255 pairs, and there were 265 pairs in the TEST file. The 265 were sorted by their assigned random numbers, in ascending order, and every 27th pair (265/10=26.5) was moved to the control group file.

At this point in the process, no data had been deleted from the data set in order to create unbiased groups. However, after reviewing the data, it was determined that different refusal criterion was followed at the sites. The standard ASTM (1995) procedure for the SPT dictates that if 50 blow counts are obtained before 1-foot of penetration has been achieved, then refusal has been encountered and the test is terminated. The data from the sites that followed this criterion were never included in the database. At some of the sites this procedure was not followed and blow counts of greater than 50 were obtained without the driller terminating the test in order to achieve the required 1-foot of penetration. This discrepancy in procedure biases the data set. Due to this discrepancy, 52 pairs from the test group and 16 pairs from the control groups that have uncorrected SPT blow counts greater than 50 were deleted from the database.

3.2.2 Testing the Data for Outliers

The z-score was used to check the data for outliers. The z-score or standard score is the position of a value in terms of the number of standard deviations from the mean it is located (Johnson, 1980). This test was chosen to determine if there are outliers in the data set. An outlier is defined as an extreme data point. It is important to identify outliers for two reasons. The first is when outliers are included with legitimate data points, the calculated mean might misrepresent the population. The second reason is the outliers can greatly affect the calculated standard deviation value. These reasons are especially true for small data sets, but it is also more difficult in a small data set to determine if a point is an outlier. If there are outliers, it should be determined if there is a legitimate reason these data are outliers and if they should remain in the data set. If there is not an identifiable reason to remove the outlier, it must remain in the data set.

The z-score value is calculated using the following equation where x is the value, s is the standard deviation, an $\bar{x}$ is the mean of the group:

$$z = \frac{(x - \bar{x})}{s}$$

If the absolute value of the z value is greater than three, which is three standard deviations from the mean, the data point is an outlier.

The z-score test was applied to the entire set of SPT N_{60} and $(N1)_{60}$ values and the BPT N_{60} and $(N1)_{60}$ values in the TEST group. The test showed none of the groups have z-score values with absolute values greater than 3, indicating all of the data belongs to the data set.

The control group was also tested for outliers using the z-score test. One SPT outlier was found, pair number 304. Pair 304 has a SPT $(N1)_{60}$ value of 84, and BPT $(N1)_{60}$ value of 14. The soil sample associated with this pair contains 38% gravel. The value was an outlier because of the large SPT value in comparison to the other SPT values in the Control group as opposed to a large discrepancy between the SPT and BPT values. The SPT was checked to determine if there was a reason for the high value. The uncorrected blow count is 46, which is high but not high enough to be refusal. There was no indication that the piece of data is invalid and it cannot be eliminated.

Table 3.2 summarizes the number of pairs left in the database after the data preparation. These are the data to which the statistics will be applied.

Table 3.2 Distribution of Data Between Sites

Site	Number of Data Pairs in the Test group	Number of Data Pairs in the Control group
Bradbury Dam	14	2
Casitas Dam	26	11
Lahontan Dam	26	6
Lost Creek Dam	31	15
Mormon Island Auxiliary Dam	69	30
Success Dam	22	8

The spreadsheets containing the test group and control group are in Appendix B.

3.2.3 Dividing the Test Data into Subsets

For the statistical analysis, it was necessary to group the data in a manner that was not arbitrary. For this reason the data were divided into subsets based on some general engineering properties of soils containing gravels. The following relationships between the amount of gravel in a soil and the permeability and density of the soil were used to define the subsets:

- At approximately 20% gravel the percentage of proctor maximum dry density obtainable with standard compaction efforts starts decreasing (BOR, 1985, p. 764). This relationship is shown on figure 7.

- The typical minimum and maximum dry densities of soils containing gravel increase up to 65% gravel, with the rate of increase changing at 20%, 35%, and 50%. The densities of the soils start decreasing when they contain 65% gravel and decrease more rapidly when they contain 80% gravel (BOR, 1985, p. 39). This is illustrated on figure 8.

- The permeability of soils typically decreases from 0% to 20% gravel, remains constant from 20% to 35% gravel, generally increases from 35% to 50% gravel, generally decreases from 50% to 65%, and increases sharply from 65% gravel (BOR, 1985, p. 60). Figure 9 shows this relationship.

These groupings that result from these relationships are:

- 0% to 20% gravel
- 21% to 35% gravel
- 36% to 50% gravel
- 51% to 65% gravel
- 66% + gravel

The subsets of data containing 0% and 0% to 5% gravel were also considered as a baseline of comparison since Harder and Seed's (1986) correlation curves were created using soils with a maximum of approximately 5% gravel.

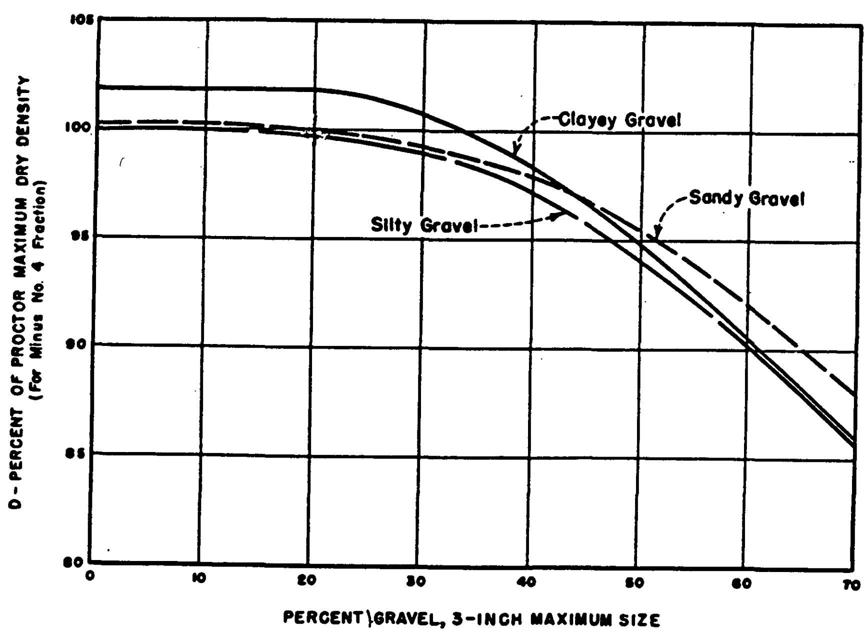


Figure 7. Proctor Maximum Dry Density vs. Percent Gravel (From Bureau of Reclamation, 1985)

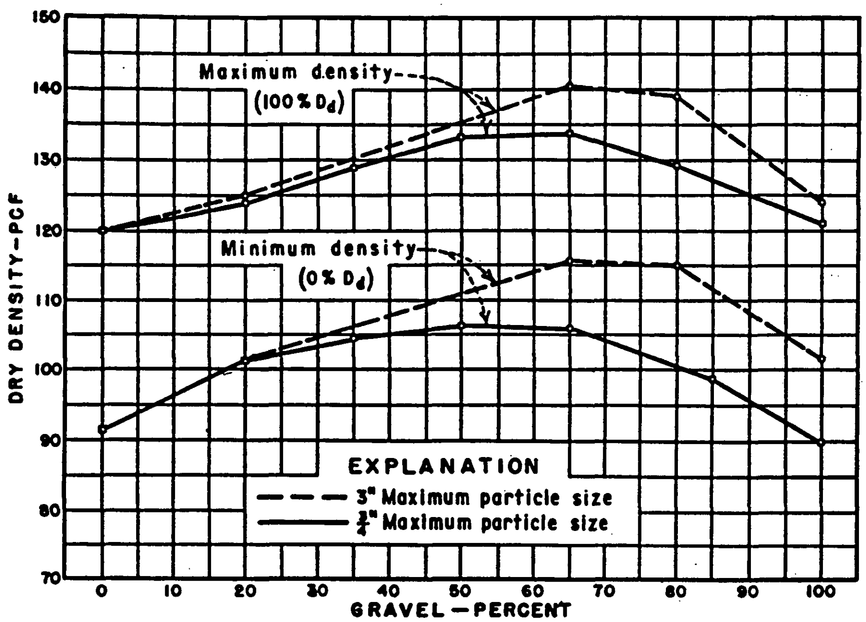


Figure 8. Dry Density vs. Percent Gravel

(From Bureau of Reclamation, 1985)

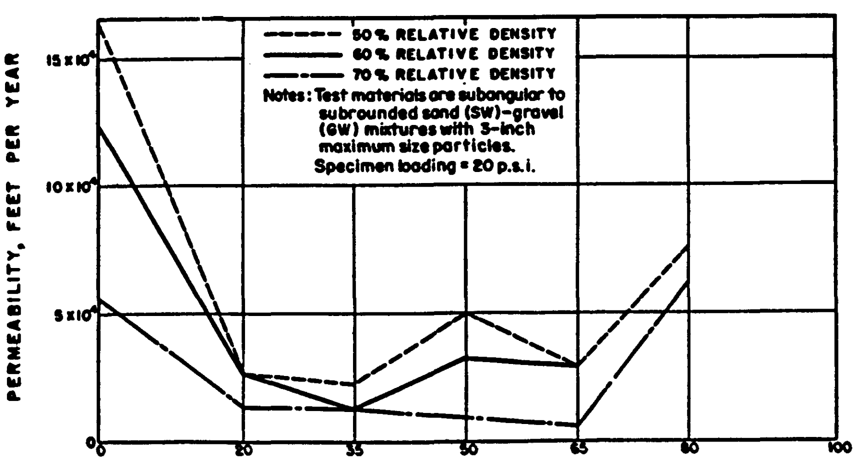


Figure 9. Permeability vs. Percent Gravel

(From Bureau of Reclamation, 1985)

3.3 Statistical Methods

In order to determine if the effects of gravel on the SPT results are significant, a statistical comparison between the SPT and BPT data will be conducted. The focus of the statistical testing will be on the $(N1)_{60}$ values because due to the energy and depth corrections, they are the "fairest" indicator of the differences between the data pairs. The statistical testing will not be performed on the uncorrected and partially corrected blow count values. The statistical tests will be performed on each of the 5 groups defined in section 3.2.3. The statistical functions that will be applied to the data are the descriptive statistics, the one-way analysis of variance (ANOVA), and the paired *t*-test. It is anticipated that the paired *t*-test will be the primary indicator of where the gravel starts influencing the SPT results.

3.3.1 Descriptive Statistics

The descriptive statistics calculated will be the mean and standard deviation. These numbers will be calculated for the entire data set and for the data subsets as a preliminary indication of the trends of the data and to see if there are any changes in the values between the groups. If the values do change between the groups this may indicate that gravel is influencing the test results. If these values are changing in a certain pattern that may also be significant.

3.3.2 One-way Analysis of Variance (ANOVA)

The ANOVA was performed on the SPT and BPT $(N1)_{60}$ values in order to determine if the SPT and BPT means are different between each of the five groups of data. The ANOVA test is a statistical test which is used to determine if the means between 2 or more groups of data are from populations with the same mean. The procedure tests the hypothesis that the means from several groups of samples are equal. This will validate the trends seen in the descriptive statistics and help determine if they are statistically meaningful. This test assumes the population variances are equal. The null hypothesis that is tested is H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$ where μ is the population mean. If the F ratio is greater than the critical F statistic associated with a 0.05 level of significance, the null hypothesis that the means are the same can be rejected. The F ratio is found by dividing the mean square of the data being tested by the mean square error of the data.

3.3.3 Paired *t*-Test

The paired *t*-test will be used to determine if the SPT values are equal to the BPT values in each group of samples. The paired *t*-test is a parametric statistical method that is used to determine if "the effect of a single treatment on the same individual is significant" (Fox, *et al.*, 1994). Typically this test would be used to examine the changes on an individual before and after it is subjected to an experimental treatment. For this analysis the individual is the soil and there is no treatment on the soil, therefore the results of SPT and BPT performed on the "individual" should be nearly the same. If the test shows that they are significantly different, then that indicates that the testing and correlation procedures are significantly different.

Data are considered paired when there are 2 pieces of data that come from the same source. These data are compared by using the difference between their numerical values, which is the paired difference. For paired observations, the *t*-statistic is applied to a group of paired values and then tested against the null hypotheses that the SPT values are equal to the BPT values, or that SPT minus BPT is equal to zero. The equations used for the paired *t*-test are as follows:

$$\bar{d} = \frac{\sum d}{n}$$

The difference between the SPT and BPT values for each pair is designated by *d*. The mean difference between all the pairs in the group is $\bar{d}$. The number of pairs in each group is denoted by *n*.

$$sd = \sqrt{\frac{\sum d^2 - n\bar{d}^2}{n-1}}$$

The standard deviation of the differences between the paired observations is sd. The standard error of the mean of the differences is $s\bar{d}$.

$$s\bar{d} = \frac{sd}{\sqrt{n}}$$

The test statistic, t_{stat}, is used to test the hypothesis.

The t_{sta}t value is compared to a critical *t* value t_{crit}, which is from a table of values of students *t* statistics corresponding to a probability of alpha, α and the degree of freedom of the group.

$$t_{stat} = \frac{\bar{d}}{s_d}$$

Alpha is the level of significance which is specified for rejecting the null hypothesis (Schaum p. 155). The alpha value is controlled by the experimenter and is traditionally 0.05 (Fox, *et al.*, 1994). This means that the null hypothesis is rejected only if the actual sample difference is so different from the hypothesized value of no difference that it would occur with only a probability of 0.05 or less. When considering the results of the paired *t*-test one must consider the following statement:

> Disproving the null hypothesis in effect proves that the data sets are from different distribution. Failing to disprove the null hypotheses, on the other hand, only shows that the data sets can be consistent with a single distribution function. One can never prove that two data sets come from a single distribution. (Press, *et al.*, 1989)

Assuming this approach results in a viable conclusion, the outcome of this step is two groups of data, one where the null hypothesis cannot be rejected and one where it can. The group where the null hypothesis cannot be rejected is where there is no significant evidence that the SPT results have been dramatically influenced by the gravel.

3.3.4 Correlation Procedure

The next step in the statistical analysis of the test group is to determine if a relationship exists between the BPT and SPT for the group of data for where they have been shown to be significantly different. Showing that a different correlation is viable for this group of data indicates that a relationship still exists between the SPT and BPT and the BPT can be used to predict the actual response of the SPT in that material. In order to estimate the new correlation, trendlines will be fit to the data using quadratic, linear, power, and logarithmic functions. These functions were chosen because they are all typical of relationships in geotechnical engineering, and anything more complex than these four functions would be too sophisticated for this data. The coefficient of determination (R^2) values calculated and the paired *t*-test will be used to determine if any of the four new correlations are significantly different from the actual SPT data. If any of the new correlations are significantly different from the actual SPT data, they will not be developed any further. If more than one of the new correlations is shown not to be significantly different from the actual SPT data, the Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD), and Mean Squared Error (MSE) will be calculated and the results with the least amount of error will be used to pick the new correlation for the data which is significantly affected by the percentage gravel.

The MAPE is the mean of the absolute percentage error between the two values in each pair for each of the 5 groups of data. This value is calculated using the following equation where a_i is the actual value or SPT $(N1)_{60}$ value and p_i is the predicted or BPT value:

$$MAPE = \left(\frac{1}{n}\right)\sum_{i=1}^{n}\frac{|a_i - p_i|}{a_i}$$

MAPE is useful as a measure of error relative to the magnitude of the blow count. It is typically the most useful measurement of error for those working in the field as it is a percentage as opposed to a magnitude. The MAD is calculated with the following equation:

$$MAD = \frac{1}{n}\sum |a_i - p_i|$$

MAD is a proxy for standard deviation; a rule of thumb used in forecasting is the standard deviation is equal to 1.25 MAD (Maurer, 1997). Basically, the absolute percent error and the absolute deviation are calculated for each pair and then the mean value is determined for the entire group.

The MSE is the squared error and is similar to variance. Because this value is squared it results in a value higher than the actual error. This value is calculated with the following equation:

$$MSE = \left(\frac{1}{n}\right)\sum_{i=1}^{n} (a_i - p_i)^2$$

3.3.5 Validation of Results

The final step in the statistical process is to test the control group based on the results of the test group and determine if the results can be validated. If the control group validates the results of the test group, the data from one of the dam sites will be analyzed with the information learned from this process to show how this information would influence the analysis of the data.

CHAPTER 4

RESULTS OF STUDY

4.1 Results of Data Preparation

The data from the spreadsheets were plotted to show the general trends of the data and the effects of the adjustments for equipment, energy, and overburden pressure. Figure 10 is the unadjusted SPT N versus the unadjusted BPT NB. Figure 11 shows the energy and liner corrected SPT N_{60} versus the BPT energy, elevation, and rig corrected N_{BC} final value. Figure 12 is the plot of SPT N_{60} versus the equivalent BPT N_{60} shows the impacts of applying Harder's correlation curve to the data.

The SPT $(N1)_{60}$ and equivalent BPT $(N1)_{60}$ values shown on figure 13 show the effect of the overburden correction on the data. This plot shows that the data have substantial scatter even after the data has been normalized. Ideally the data on this plot should fall on a 1:1 line because if the normalization to the data and the BPT to SPT correlation are appropriate, and no other factors are influencing the data, then each equivalent BPT value would be equal to its paired SPT value. The results of the statistical analysis should indicate if one of the reasons the data is so scattered is due to the presence of gravel.

The $(N1)_{60}$ difference is the SPT $(N1)_{60}$ value minus the BPT $(N1)_{60}$ value for each data pair. This value is important because it indicates the gap between the SPT and BPT values. These values are plotted against percent gravel on figure 14 to see if any obvious trends exist.

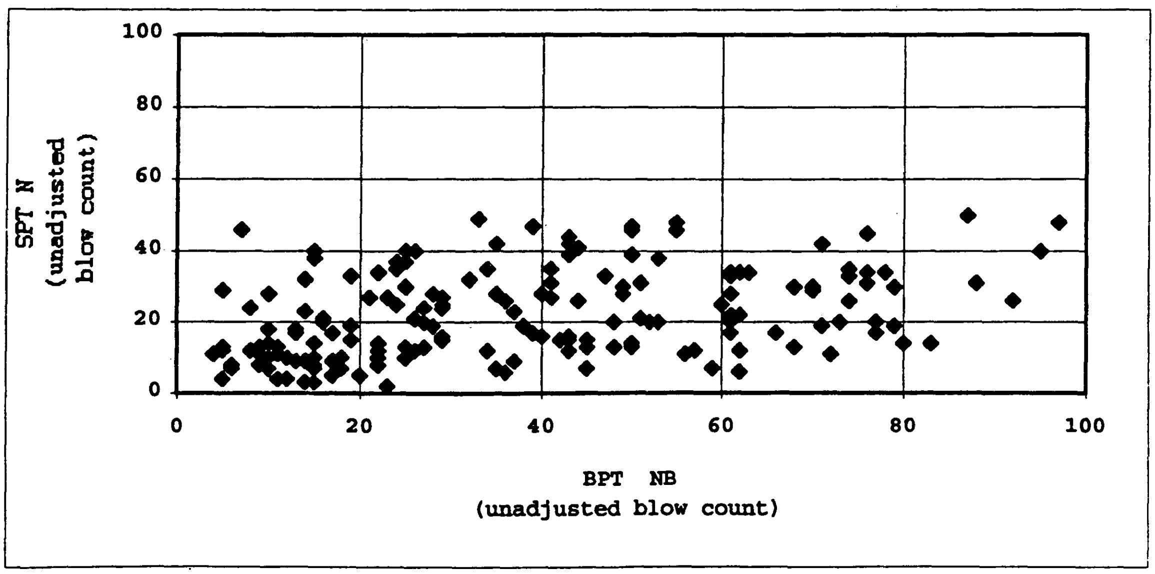


Figure 10. SPT N vs BPT NB

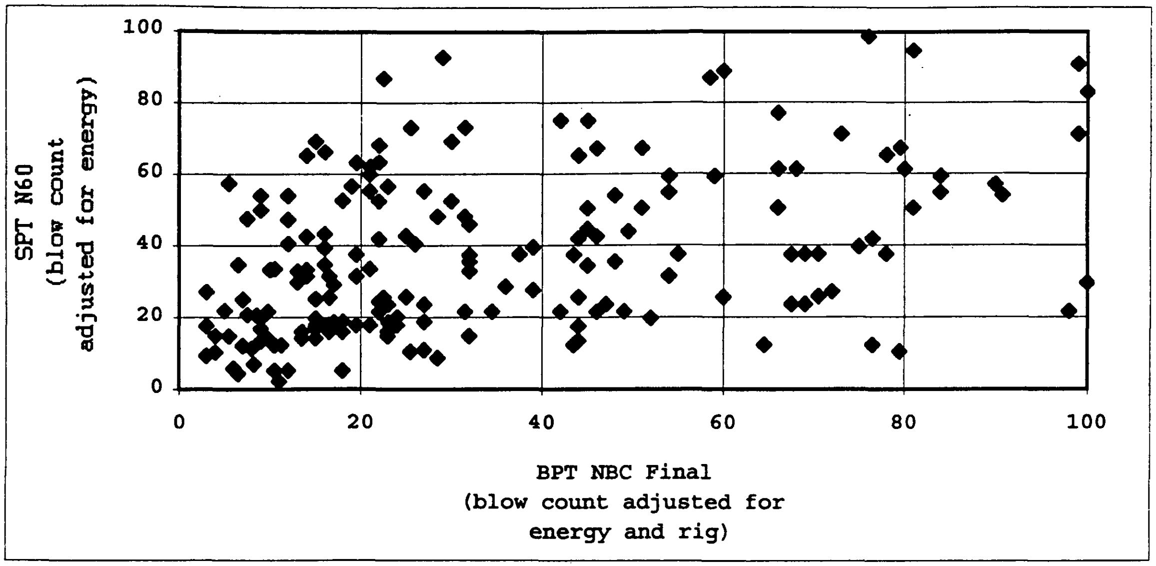


Figure 11. SPT N_{60} vs BPT NBC final

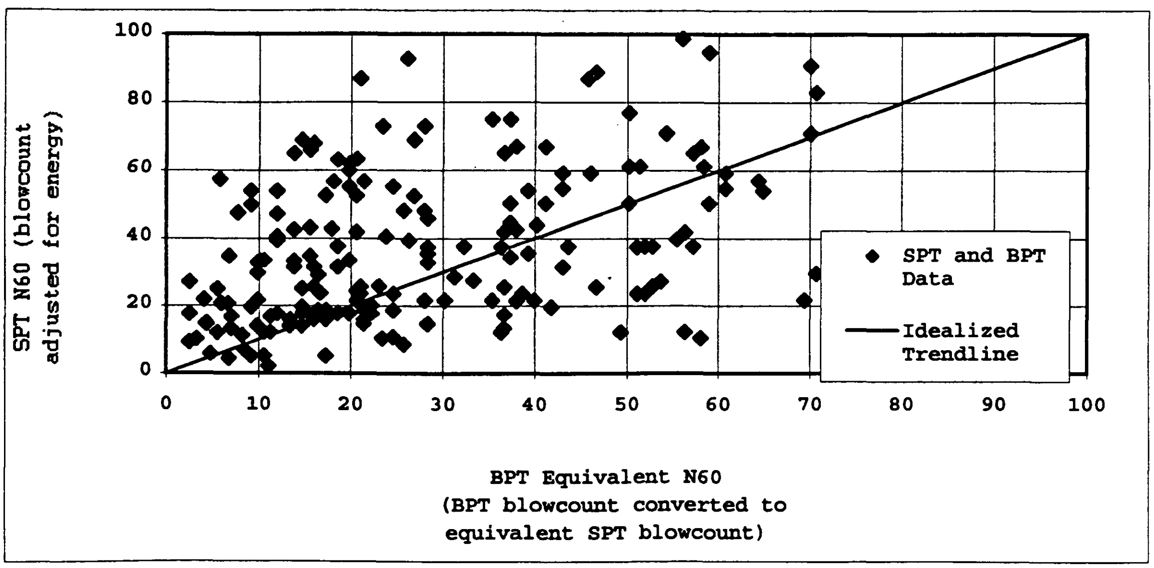


Figure 12. SPT N_{60} vs BPT Equivalent N_{60}

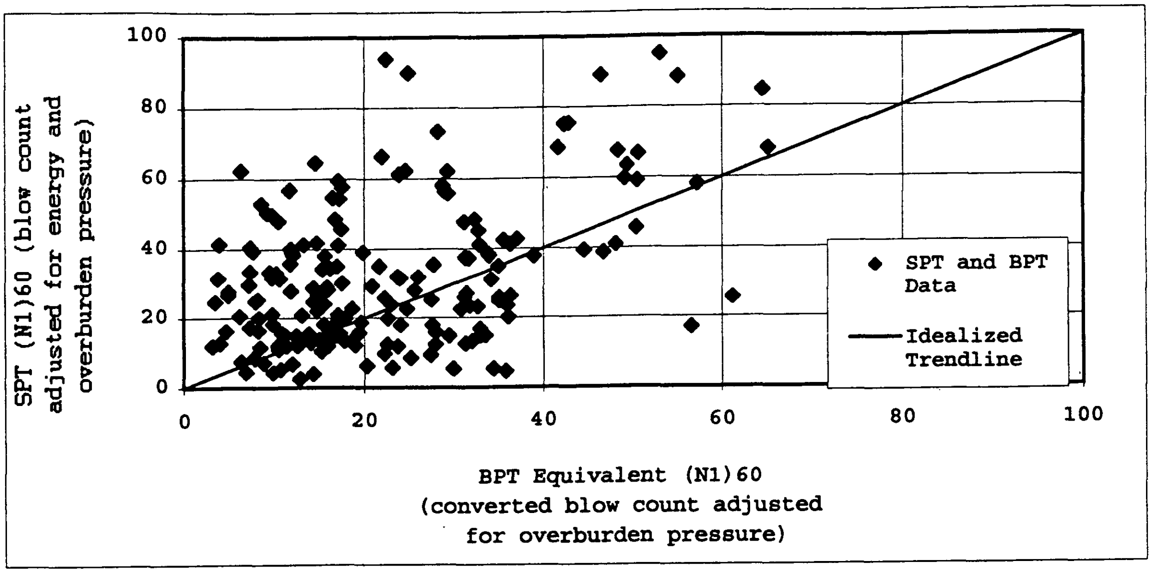


Figure 13. SPT $(N1)_{60}$ vs BPT Equivalent $(N1)_{60}$

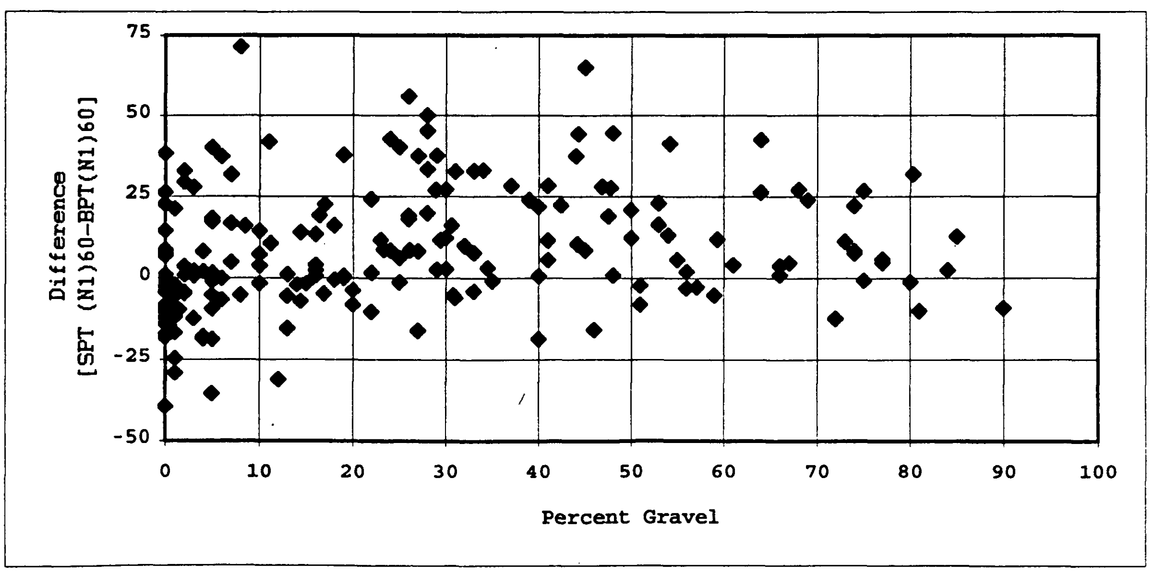


Figure 14. $(N1)_{60}$ Difference versus Percent Gravel

4.2 Statistical Analysis of Test Group

The descriptive statistics were calculated for the Test data and are summarized in the table 4.1. The data are grouped as discussed in section 3.2.3.

Table 4.1 Mean and Standard Deviation Values for Test Group Data

Data Group					1	2	3	4	5
Percentage Gravel		all data	0	0-5	0-20	21-35	36-50	51-65	66+
SPT $(N1)_{60}$	Mean	31.5	21.2	21.0	24.8	42.3	37.6	34.8	31.2
	StDev	20.4	13.3	14.8	19.4	24.6	18.4	11.5	10.0
BPT $(N1)_{60}$	Mean	22.5	21.9	21.9	22.1	24.8	18.2	23.7	23.2
	StDev	13.5	13.4	13.3	13.5	16.9	10.0	11.0	10.6
$(N1)_{60}$ Diff.	Mean	9.1	-.77	-.89	2.78	17.4	19.4	11.1	8.0
	StDev	18.9	17.2	17.6	18.5	18.1	19.3	16.3	12.7
Number of Pairs		188	22	54	91	40	22	15	20

The numbers in the table indicate the mean difference increases in groups 1 through 3 and then decreases in groups 4 and 5. The mean $(N1)_{60}$ and difference values are plotted for each of the 5 groups on figure 15.

As discussed previously, the groupings in the above table are partially based on the density trends shown in the

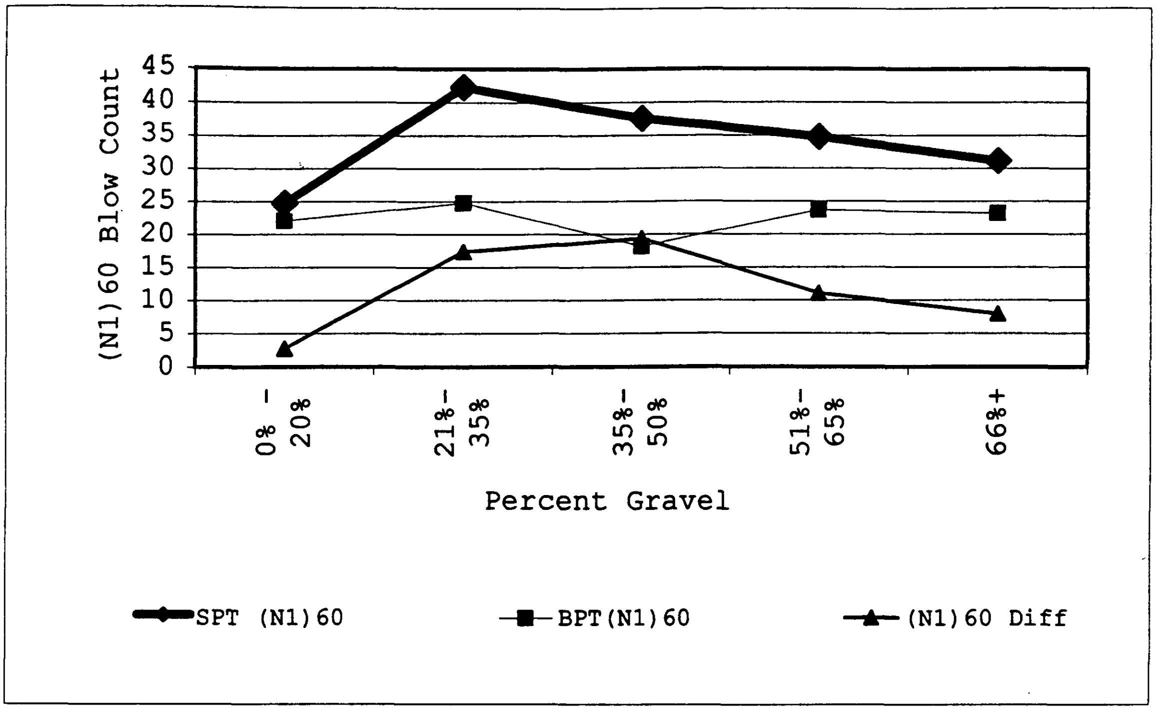


Figure 15. Mean $(N1)_{60}$ Values for Test Data

Earth Manual (1985) which indicate the density of soils containing gravels generally increases until the soils are composed of 65% gravels, at which point the density typically stops dropping. If the BPT data are used as an indicator of density under the assumption that the gravel content has minimal impact on the BPT resistance, the data do not follow the published density trends (figure 8). This is reasonable because the gradation of the material used to create the density trends was probably quite different from the variable gradations of the material collected for this project.

The mean $(N1)_{60}$ values for the SPT and BPT data shown in table 4.1 and on figure 15 indicate that the BPT data do not vary as greatly as the SPT data. The purpose of the ANOVA test is to determine if the means vary significantly between the 5 groups. The test was applied the BPT $(N1)_{60}$ data. The null hypothesis could not be rejected indicating the difference between the groups means is not significant. When the ANOVA test was applied to the SPT $(N1)_{60}$ data, the null hypothesis was rejected indicating significance difference between the group means. The test results are in Appendix C.

This paired *t*-test was applied to the SPT and BPT $(N1)_{60}$ data. The computer program EXCEL was used to calculate the results and the computer program Sigma Stat was used to check the results. The programs calculate the test statistic t_{stat}, based on the paired data, the critical t, t_{crit} based on the alpha value, the degrees of freedom of the group (equal to one less than the number of pairs in the group), and a P value which is the significance probability. P is the probability of wrongly concluding that there is a true effect, or that the SPT and BPT results are not the same. The smaller the P value, the greater the probability that the SPT and BPT are not equal. The null hypothesis can be rejected if $t_{stat} < t_{crit}$, or if P<0.05, the specified level of significance. The test results are in appendix D. The P value for each group is shown in table 4.2. The test was conducted with the data divided by the engineering properties of gravels as discussed in section 3.2.3.

Table 4.2 Results of Paired *t*-test on Test Group Data

Group	0%	0%-5%	0%-20%	21%-35%	35%-50%	51%-65%	66%+
$(N1)_{60}$ P value	0.837	0.717	0.158	4.01E-07	1.19E-04	0.019	0.010

When the *t*-test is applied to these groups of data, the null hypothesis cannot be rejected in the 0%, 0% to 5%, and 0% to 20% gravel groups, but would be rejected for the 21% to 35%, 36% to 50%, 51% to 65% and the 66% to 100% gravel ranges.

The data were analyzed more closely to determine if any of the data in the 21% to 35% group would not be rejected. This was accomplished by systematically adding data from the

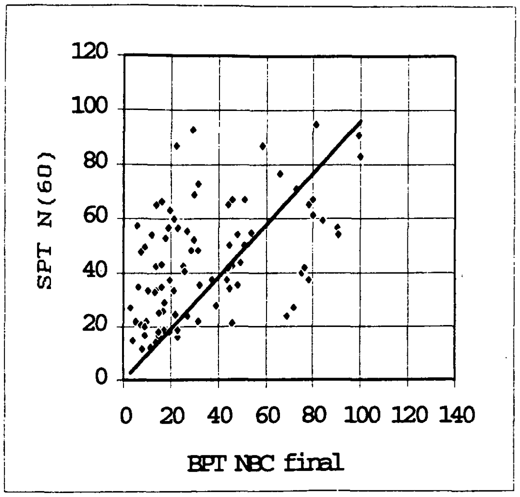
21% to 35% group to the 0% to 20% group in ascending order of percentage gravel and then applying the paired *t*-test to the $(N1)_{60}$ data. The null hypothesis could not be rejected for the set of data containing 0% to 25% gravel, but would be rejected if the percentage gravel was higher. Based on the *t*-test, it can be said that when the soil contains more than 25% gravel, the SPT and BPT values are significantly different, and the difference in the mean values of the two groups is greater than would be expected by chance.

4.2.1 Analysis of Test Data Rejected by Paired *t*-Test

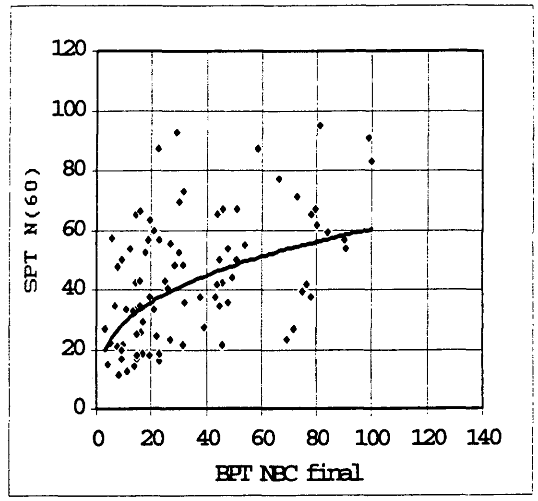
Trendlines were fit to the data with more than 25% gravel using linear, logarithmic, quadratic, and power functions in order to determine the relationship between the SPT and BPT values for this group of data. The table 4.3 lists the resulting R^2 values for each of the trendlines and the equations that were fit to the data:

Table 4.3 Empirical Equations Developed for Test Group Data with 26%+ Gravel		
Trendline	R^2 values	Equation
Linear	-0.495	$y = 0.9603x$
Logarithmic	0.244	$y = 12.526Ln(x)+3.4416$
Quadratic	-0.006	$y = -0.0143x^2 + 1.9283x$
Power	0.256	$y = 13.794x^{0.3198}$

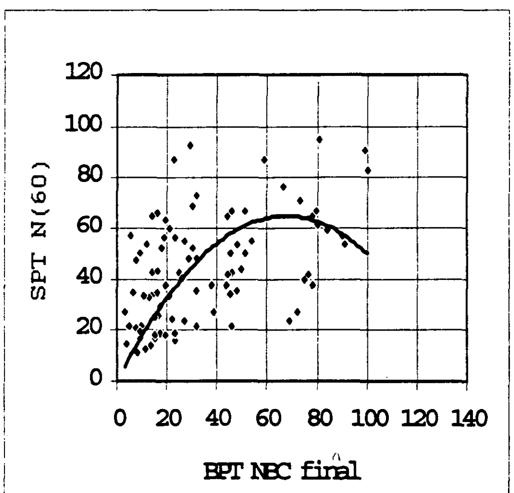
In the equation, y is equal to the SPT N_{60} and the x is equal to NBC final. The data and trendlines can be seen on figure 16. The R^2 values for the quadratic and linear fits are negative as a result of being forced through zero, and therefore are not a good indicator of fit. The R^2 values for the Power and Logarithmic (Log) trendlines are low, but considering the scatter of the data, and the low R^2 values for the entire data set, they have some merit. The paired *t*-test was applied to these four relationships, comparing the calculated equivalent BPT $(N1)_{60}$ values to the SPT $(N1)_{60}$ values. The resulting P values are 0.03 for the Power equation, 0.81 for the Log equation, 1.06E-06 for the Line equation, and 0.02 for the Quadratic equation. Based on these results, the Log equation is the best fit for the data, and there is no need to look at another method to



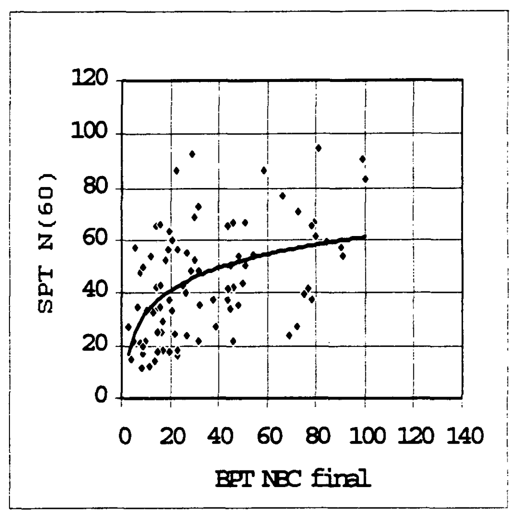
a) linear



b) power



c) quadratic



d) log

Figure 16. Experimental Trendlines fit to Data with 26%+ Gravel

compare results with the other relationships, however, the MAPE, MAD, and MSE were calculated for each of the relationships as a check and to quantify the improvement of the fit over the Harder and Seed (1986) relationship. These values are summarized table 4.4.

Table 4.4 Comparison of MAPE, MAD, and MSE for the relationships developed in the data with 26%+ gravel

Relationship	MAPE	MAD	MSE	Mean SPT $(N1)_{60}$	Mean BPT $(N1)_{60}$
Harder and Seed	0.45	18.0	537	38.4	23.2
Log	0.45	13.4	269	38.4	38.0
Power	0.41	13.3	275	38.4	34.7
Line	0.48	17.9	523	38.4	27.2
Quadratic	0.44	14.8	351	38.4	33.7

The values in table 4.4 indicate that based on the MAPE and MAD, the Power relationship is a better fit to the data than the Log relationship. The reason the results of the paired *t*-test rank the Log relationship over the Power relationship is primarily because this relationship calculates the BPT $(N1)_{60}$ such that the mean of these values corresponds more closely to the mean of the SPT $(N1)_{60}$ values for the group of data with 26%+ gravel than do the other relationships.

The new Log equation was applied to the data with 0% to 25% gravel and then tested with the paired *t*-test to see if it is applicable to this set of data. The resulting P value is 1.1E-09, which means the null hypothesis would be rejected and the Log equation is not applicable to this set of data.

The MAPE indicates that the Log correlation is not an improvement over the Harder and Seed correlation, however, the MAD, MSE, and percentage error values indicate the error between the SPT and Log correlated values are an improvement over the Harder and Seed correlated values.

The Harder and Seed (1986) correlation curve was plotted with the new Log correlation curve on figure 17. This plot show that the new curve predicts higher equivalent SPT blow count values than the Harder and Seed curve up to approximately 80 NBC final blow counts. This is consistent with the literature review and all other indicators that the SPT blow counts are higher in coarser grained material.

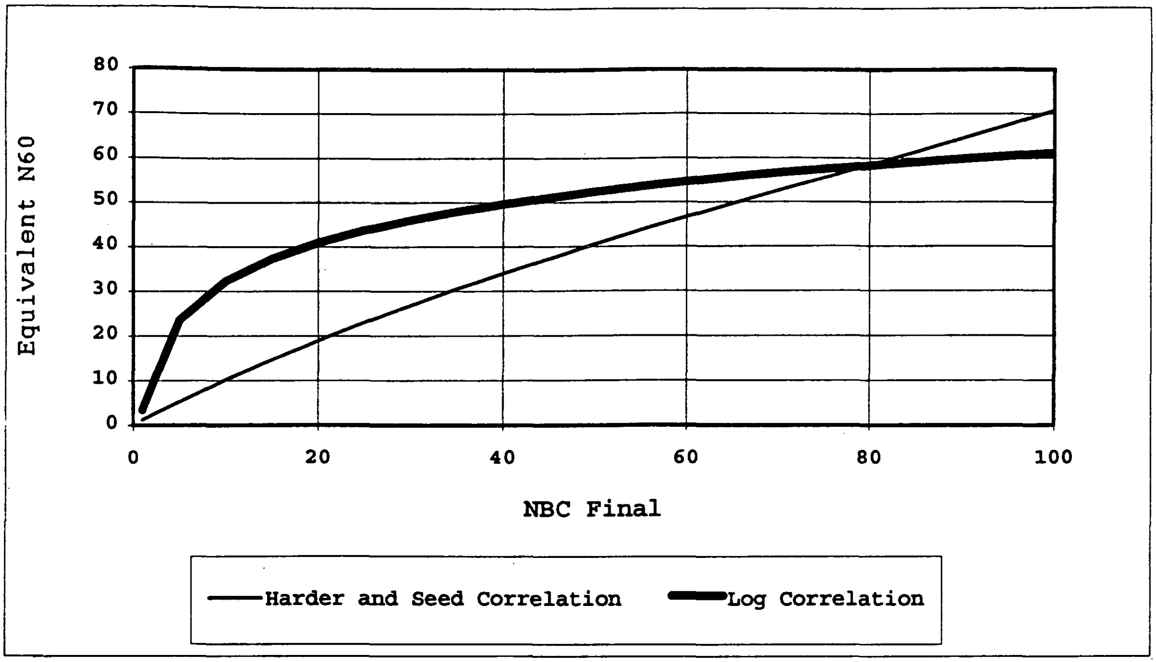


Figure 17. Log Correlation Curve and Harder and Seed (1986) Correlation Curve

4.2.2 Validation of Test Group Results

The results of the statistical testing of the Test group data indicate that when there is more than 25% gravel in the soil the results of the SPT are significantly impacted. The purpose of this step is to determine if the findings of the Test group are also true with the Control group data. The data in the Control group contains gravel ranging from 0% to 100%. The basic statistics of the data is summarized in table 4.5 along with the statistics of the test group for the purposes of comparison:

Table 4.5 Comparison of Control and Test Group Data

control group n = 72	test group n = 188	SPT $(N1)_{60}$		BPT $(N1)_{60}$		$(N1)_{60}$ Diff.		Percent Gravel	
Control (C)	Test (T)	C	T	C	T	C	T	C	T
Mean		25	32	21	22	4	9	24	27
Standard Deviation		18	20	11	14	19	19	23	24
Standard Error		2.1	1.5	1.3	1.4	2.3	1.4	2.7	1.8
$(N1)_{60}$	Minimum	2	3	5	3	-35	-39	0	0
	Maximum	84	95	46	65	69	71	100	90

The control group was subjected to the paired *t*-test. The individual groups based on engineering properties were not tested, just the groups that resulted from the statistical testing of the test group. The results of the paired *t*-test are summarized on the following table.

Table 4.6 Results of Paired *t*-test on Control Group Data (Correlated w/ Harder and Seed Method)			
	All control group data	Control Group data with 0-25% gravel	Control Group data with 26%+ gravel
P value for $(N1)_{60}$ pairs	0.058	0.607	0.002

The results are different from the test group in that when the entire test group was tested, the null hypothesis was rejected. The fact that the null hypothesis that SPT $(N1)_{60}$ is equal to BPT $(N1)_{60}$ cannot be rejected for the group with less than 25% gravel, but can be rejected for the group with more than 25% gravel validates the grouping of the data as determined by the test group.

The new log correlation was applied to the data containing 26% and more gravel. The paired *t*-test was applied to the results of the log correlation and the SPT $(N1)_{60}$ values. The resulting P value was 0.914, which means that the null hypothesis cannot be rejected. This also agrees with the results of the test group.

CHAPTER 5

DISCUSSION

5.1 General Discussion

It was the premise of this study that after the results of the SPT become affected by the amount of gravel in the soil being tested that the standard empirical relationships between the SPT and the engineering properties of the soil should be used with caution or not at all. This is supported by previous studies on the effects of grain-size on the results of the SPT and on the engineering properties. If the effects on the test are known or can be quantified, the results will be more meaningful and site characterization more accurate. This study was an attempt to quantify the gravel fraction in a soil that causes the SPT to behave significantly different than it does in clean sands.

In order to accomplish this task, a statistical analysis was conducted on the data from SPT's and BPT's that were conducted in close proximity to each other. It was assumed that due to the fact the data was paired from tests completed in the same general location that the material tested in each pair was similar. The deficiency in this assumption is that the material tested was alluvial, which is known to be highly variable. Based on the data available, an improved method of pairing the data or determining if the material tested in each pair was similar was not identified. A possible statistical way of determining if the material was similar between pairs is the z-score test, which was used to test for outliers. For example, if the data fell beyond 2 standard deviation of the mean, it is possible this deficiency would have been minimized. However, the data was looked at from the standpoint that all data was included unless there was a viable reason to have it removed.

5.2 Statistical Analysis

The statistical analysis of the data consisted of the following:

- descriptive statistics
- ANOVA
- paired *t*-test
- correlation procedure

- validation of results

The descriptive statistics consisted of determining the mean and standard deviation for each of the 5 groups of data described in section 3.2.3. The values in table 4.1 show that the mean values for the BPT $(N1)_{60}$ data does not appear to change significantly between the groups but that the SPT $(N1)_{60}$ mean values increased from the first group of 0% to 20% gravel to the third group with 36% to 50% gravel, and then started to decrease. The fact that the SPT $(N1)_{60}$ values increase agrees with previous studies that increasing grain size causes an increased SPT blow count regardless of the density of the material (Yoshida and Ikemi, 1988).

The ANOVA test was applied to the data and this confirmed that there was no evidence the mean BPT $(N1)_{60}$ values were changing significantly between the groups, but that the mean SPT $(N1)_{60}$ values were significantly different between the groups. The results of this indicated that the gravel was influencing the SPT results more than the BPT results. This validates the trends seen in the results of the descriptive statistics.

The paired *t*-test was applied to the Test group data and the results summarized on table 4.2. The results indicate that the SPT $(N1)_{60}$ values are significantly different from the BPT $(N1)_{60}$ values in the groups of data that contain more than 25% gravel, but there is no evidence that the $(N1)_{60}$ values are significantly different in the group with 25% and less gravel.

The fact that the null hypothesis was rejected for the group of data with more than 25% gravel indicates two things. The first is that the SPT values have become significantly affected by the presence of gravel, the second is that the correlation developed to convert the BPT values into equivalent SPT values is reliable up to 25% gravel but should no longer be used to predict equivalent SPT values when there is more than 25% gravel in the soil. This is all still based on the assumption that the BPT results are not being significantly affected by the presence of gravel and is still a viable tool to predict equivalent SPT's. This is supported by the results of the ANOVA and descriptive statistics, which indicated that although the SPT values generally increased with the percentage gravel, the BPT values did not follow this trend. This assumption is also supported by the studies conducted by Tanaka *et al.* (1989)

that larger penetrometers are not as significantly impacted by the grain size.

A correlation between the SPT and BPT values was developed for tests conducted in soils with more than 25% gravel. This correlation was between the BPT blow counts corrected for energy and equipment using the Harder and Seed (1986) approach and energy and equipment normalized SPT N_{60} values. The resulting correlation curve can be seen on figure 17.

The results of the statistical analysis of the Test group that the SPT becomes significantly affected by gravel when there is approximately 25% gravel in the soil data was applied to the Control group data. The Control group was tested with the paired *t*-test and MAPE, MAD, and MSE. The results are summarized on table 4.6. The test had similar results as the test group, thus validating the hypothesis.

This study reiterated the point that neither the SPT or BPT should be used as a stand alone tool due to the variability in equipment, procedure, and the applicability of correlation procedures. This is a known but not always practiced standard due various factors including cost and convenience. The results of the tests can be correlated to relative densities or strengths, however these relationships should be validated with the use of site specific test pits and testing of the materials in place. The more knowledge and information pertaining to the site that the engineer has, the more accurately the conditions can be analyzed.

The study also strongly indicated that the use of one correlation procedure to relate BPT results to SPT results is not reliable. The results of both testing methods can show trends in the soil profile, and those trends can be seen in the results of both the SPT and BPT for the majority of the individual sites. However, to take one data point and try to infer meaningful results or relationship is stretching the boundaries of the tests.

5.3 Application of Results to Lost Creek Dam Site

In order to see how the results of this study affect the data from an individual site, the new Log relationship for soils containing more than 25% gravel was applied to the Lost Creek Dam site. The data from both the test and control groups was used for this part of the study. The paired *t*-test was applied to the $(N1)_{60}$ data. When the data was converted using Harder and Seed's (1986) procedure, the null hypothesis that SPT is equal to BPT was rejected for the data with more than 25% gravel with a P value of 2.2E-09 and the data with 0% to 25% was also rejected with a P value of 0.04. Just for the sake of comparison, the 0% to 20% data was subjected to the paired *t*-test. This group failed to be rejected. The paired *t*-test failed to be rejected when the Log equation was applied to the data with more than 25% gravel. Except for the 0% to 25% gravel group, this is consistent with the results of the Test group. The fact that the paired *t*-test failed to be rejected at 20% gravel instead of 25% is acceptable. The 25% is primarily a guideline and should not be considered an exact value.

The data at the site consists of 46 paired tests from 5 paired drill holes. The $(N1)_{60}$ data was plotted against depth for each drill hole of figure 18 to show the SPT values, Harder converted BPT values, and Log converted values. Ideally, the Log converted values should be more comparable to the SPT values than the Harder converted values. This appears to be true both visually and analytically as shown by the results of the paired *t*-test.

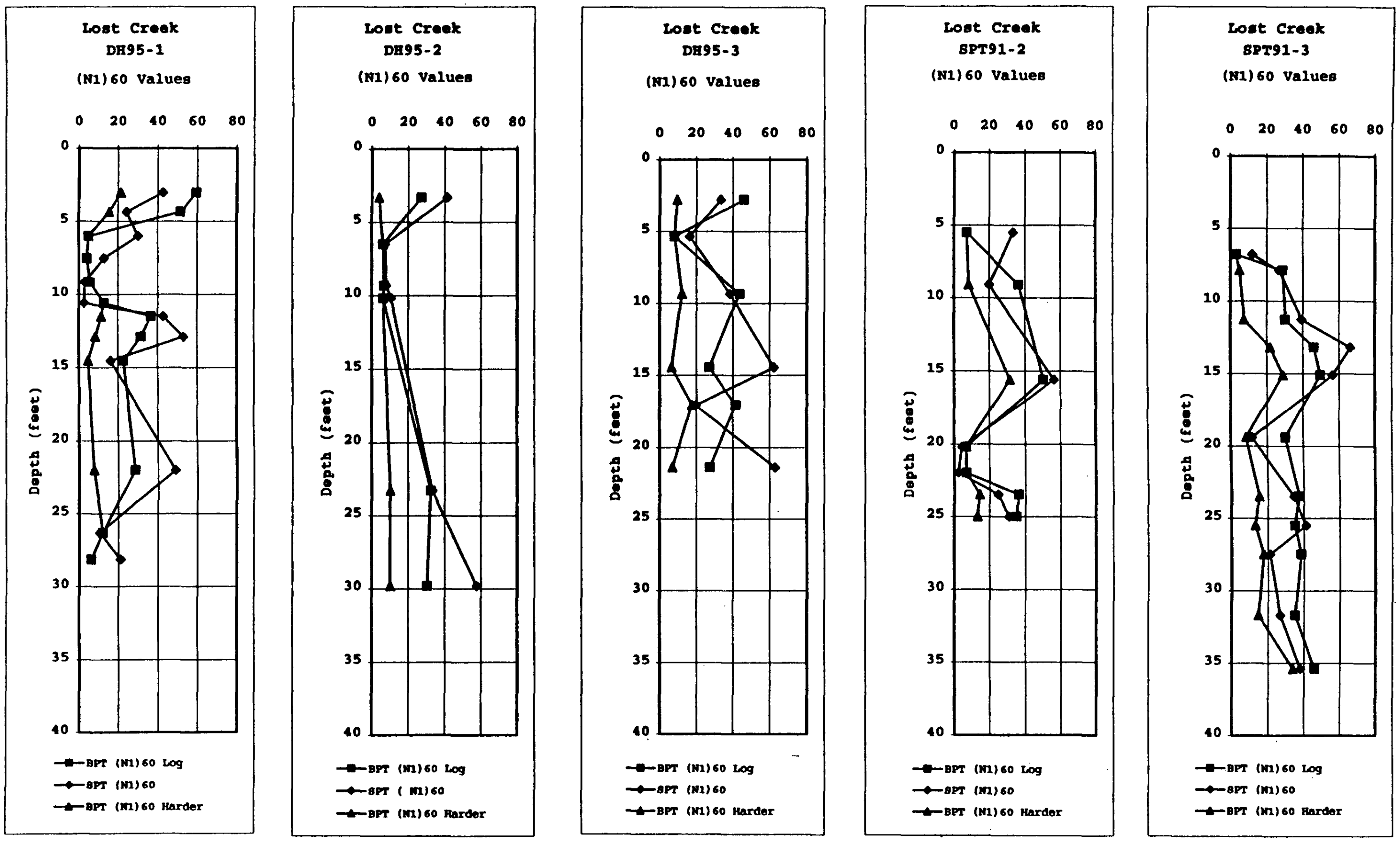


Figure 18. Lost Creek Dam Data

5.4 Recommendations for Further Research

If the BPT is going to be used in soils where there is no gradation information available, a method of determining where the Log correlation should be used instead of the Harder and Seed correlation is desirable. It is possible that there is a critical BPT value which indicates a sufficient percent gravel is present to change from one correlation technique to another.

If the percent gravel of the material being tested is not known, the following could result:

- If the Harder and Seed (1986) correlation is used, the predicted equivalent SPT values would be reasonable for the data that contained up to 25% gravel. However, for the data with more than 25% gravel it has been shown that the Harder and Seed (1986) correlation procedure is not a viable predictor equivalent SPT values.
- If the Log correlation is used, then the predicted equivalent SPT values would be reasonable in the data that contains more than 25% gravel. However, the Log predicted equivalent SPT values would not accurately predict the actual SPT results that would occur in soils containing a smaller percentage of gravel.

For the data set that is being analyzed in this study, the combination of the control and test groups, a speculated critical NBC final at which to use the Log correlation would be approximately 35. This is based on the linear trendlines fit to the data for entire database and for each site, although they are admittedly extremely poor correlations. According to the trendlines for all the data combined, and for 3 of the 6 sites, the NBC final value is approximately 35 when there is 25% gravel in the sample.

A possible method that could be used to determine a critical BPT value is outlined as follows:

- Collect the data and as much information as possible about the geologic conditions at the site. The percent gravel would have to be known for the analysis
- Correct the BPT data to NBC final values.
- Break the data into two groups, 0% to 25% gravel, and over 25% gravel.
- Conduct hypothesis testing on the data using the hypothesis that for one group of data the blow count is less than 35, and the other group of data the blow count is greater than 35. A simple non-parametric test such as the Sign test could work for this process, or the *t*-test (not paired) may be applicable also.
- Normalize the data for overburden pressure using the Cn correction or a more appropriate method if it is available. Break the data up into groups based on some sort of grouping, possibly relating the NBC_{final} values (normalized for overburden) to an approximately relative density, eg, loose, medium, dense. Look at each of these groupings in relation to percent gravel and determine if there is a relationship.

It is very possible that there is not a critical BPT value. The values in table 5.1 are for all of the data in the test and control groups. The numbers in the table indicate that the data that contains more than 25% gravel result in slightly higher mean BPT blow count, however, a variance analysis would indicate the groups means are not significantly different.

Table 5.1 Statistics of All BPT $(N1)_{60}$ Data

	Mean	Standard Deviation	Median	25^{th} percentile	75^{th} percentile
All data	34	25	24	14	48
0-25%	33	24	24	14	48
26%+	35	26	25	14	48

The data was also looked at site specifically. Mormon Island Auxiliary Dam (MIAD) was chosen because it contains many data pairs in both the over and under 25% gravel groups, and the range of gravel is high. Table 5.2 summarizes the descriptive statistics for the MIAD data.

Table 5.2 Statistics of Mormon Island Auxiliary Dam $(N1)_{60}$ Data					
	Mean	Standard Deviation	Median	25^{th} percentile	75^{th} percentile
All data	38	26	29	17	66
0-25%	35	25	24	15	65
26%+	42	26	39	19	67

The differences between the mean and median were much greater those shown for the entire data set. This indicates that the hypothetical critical BPT value may be site specific.

CHAPTER 6

CONCLUSIONS

The SPT and BPT data collected for this study is from 6 dam sites in the Western United States. The data were adjusted in a manner that is typical for the geotechnical industry in order for the comparisons to be valid. The data were quite scattered and patterns, trends, and correlations were not easy to identify. However, with the use of the paired *t*-test, the data did allow the conclusion that there is a statistically significant division between the data that contains 0% to 25% gravel and that which contains more than 26% gravel. The results of this test indicate that when there is more than 25% gravel in a soil, the results of the SPT and BPT on the similar material are significantly different. This cannot be said for the data with less than 25% gravel.

The results of this project were dependent upon the reliability of the SPT and BPT testing procedures, the standard procedures for normalizing the test results for energy and equipment, and upon a standard correlation method developed by Harder and Seed (1986) that converts BPT results to equivalent SPT values. This correlation was developed in soils that contained 5% or less gravel. The results of the paired *t*-tests indicate not only that the SPT is significantly affected when there is 25% or more gravel in a soil, but also that this correlation is a viable method of predicting equivalent SPT values for material containing up to 25% gravel.

The data containing more than 25% gravel were analyzed to determine if a relationship exists between the two testing methods when there is this amount of gravel present. Trendlines were fit to the data, and the relationships were analyzed based on the results of the paired *t*-tests. A log based equation was determined to be the best fit. This shows that a relationship still exists between the two test methods when there is gravel in a soil, but it is different from the one that exists when the percentage gravel is lower. Based on this new relationship, an equivalent SPT value can be predicted from BPT results when there is more than 25% gravel present in the soil.

The hypothesis developed by the analysis of the test group that the SPT results are not dramatically influenced by grain size when a soil contains up to 25% gravels and a different relationship exists between the SPT and BPT beyond that point were applied to the control group for validation. The control group statistics were able to validate this theory.

The conclusions of this study are as follows:

- Gravel significantly impacts the results of the SPT when there is more than 25% gravel in a soil.
- The Harder and Seed correlation which was developed in soils with 0% to 5% gravel is a viable predictor of the SPT penetration resistance until the soil contains more than 25% gravel.
- A relationship exists between the SPT and BPT when there is more than 25% gravel in a soil and the BPT can be used to predict an equivalent SPT blow count.

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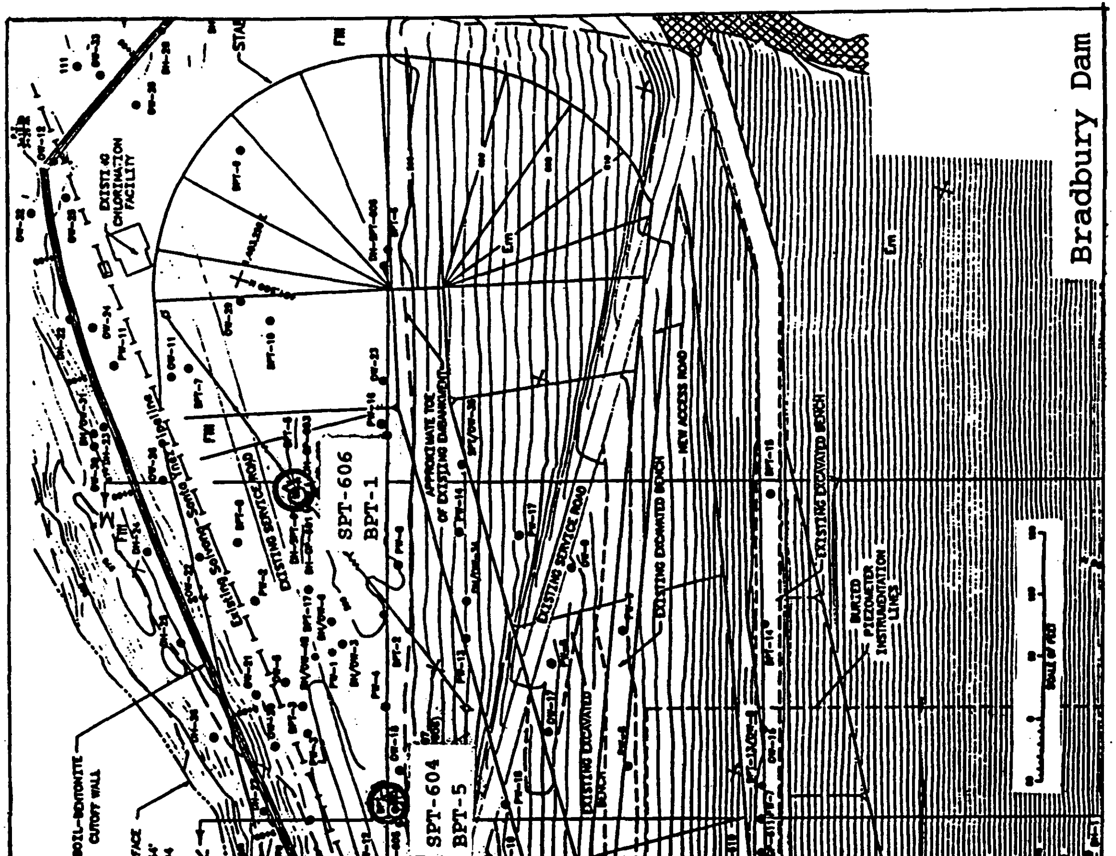
APPENDIX A

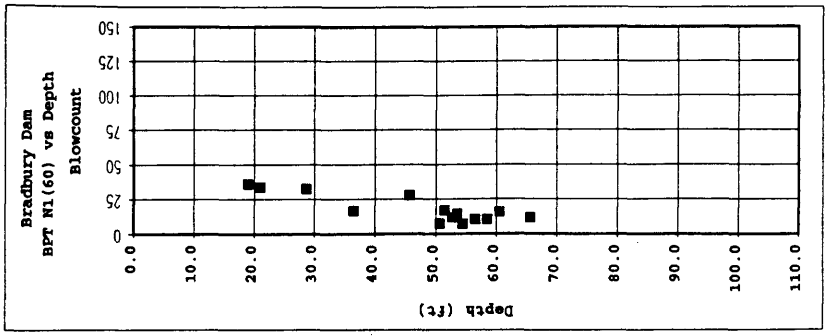
SITE DATA

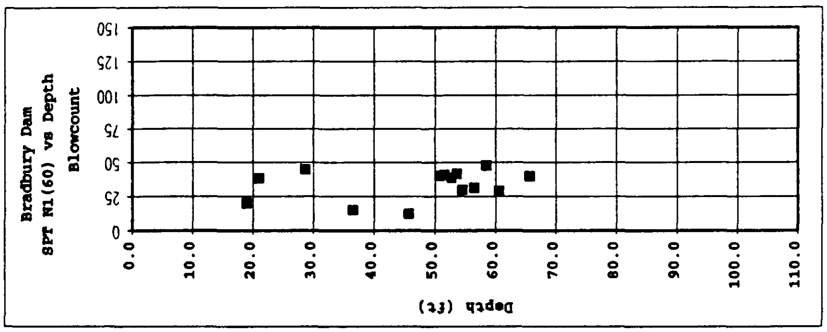
The SPT drill holes and the BPT holes with which they were paired and the pair identification numbers, the plan views of the sites, and depth versus N values are presented in this appendix. These three items are presented for each site, in alphabetical order. The tables with the paired holes are presented to show which were used for this study. The plan view are presented in order to show the locations of the SPT and BPT drill holes relative to each other. The paired drill holes are circled, with the BPT's enhanced with triangles and the SPT's enhanced with circles. Plan views of the Mormon Island Auxiliary Dam data are not available.

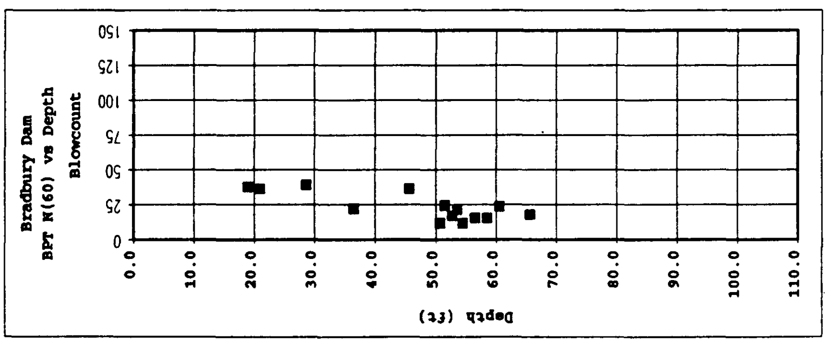
The charts following each of the plan views consists of all of the data for that site from the test and control group. These plots are the test depth versus SPT and BPT $(N1)_{60}$ and N_{60} values. These plots visually show how the overburden correction affects the data and how the SPT and BPT are similar or different.

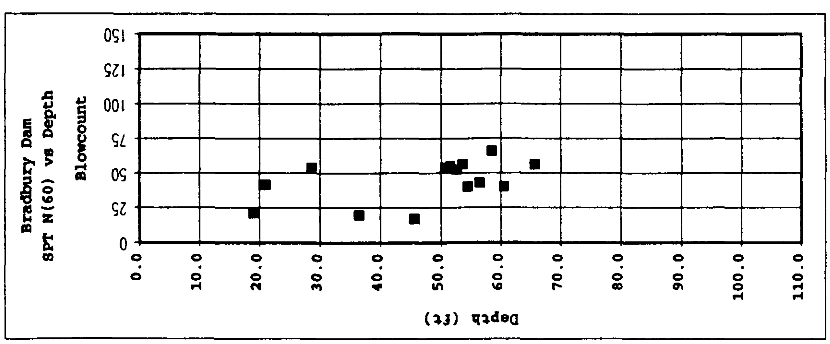
Bradbury Dam		
SPT Drill Hole	BPT Drill Hole	Pair ID
SPT-604	BPT-5	100-110
SPT-606	BPT-1	111-130


Bradbury Dam
SPT-606
BPT-1
SPT-604
BPT-5
STABILITY BERM

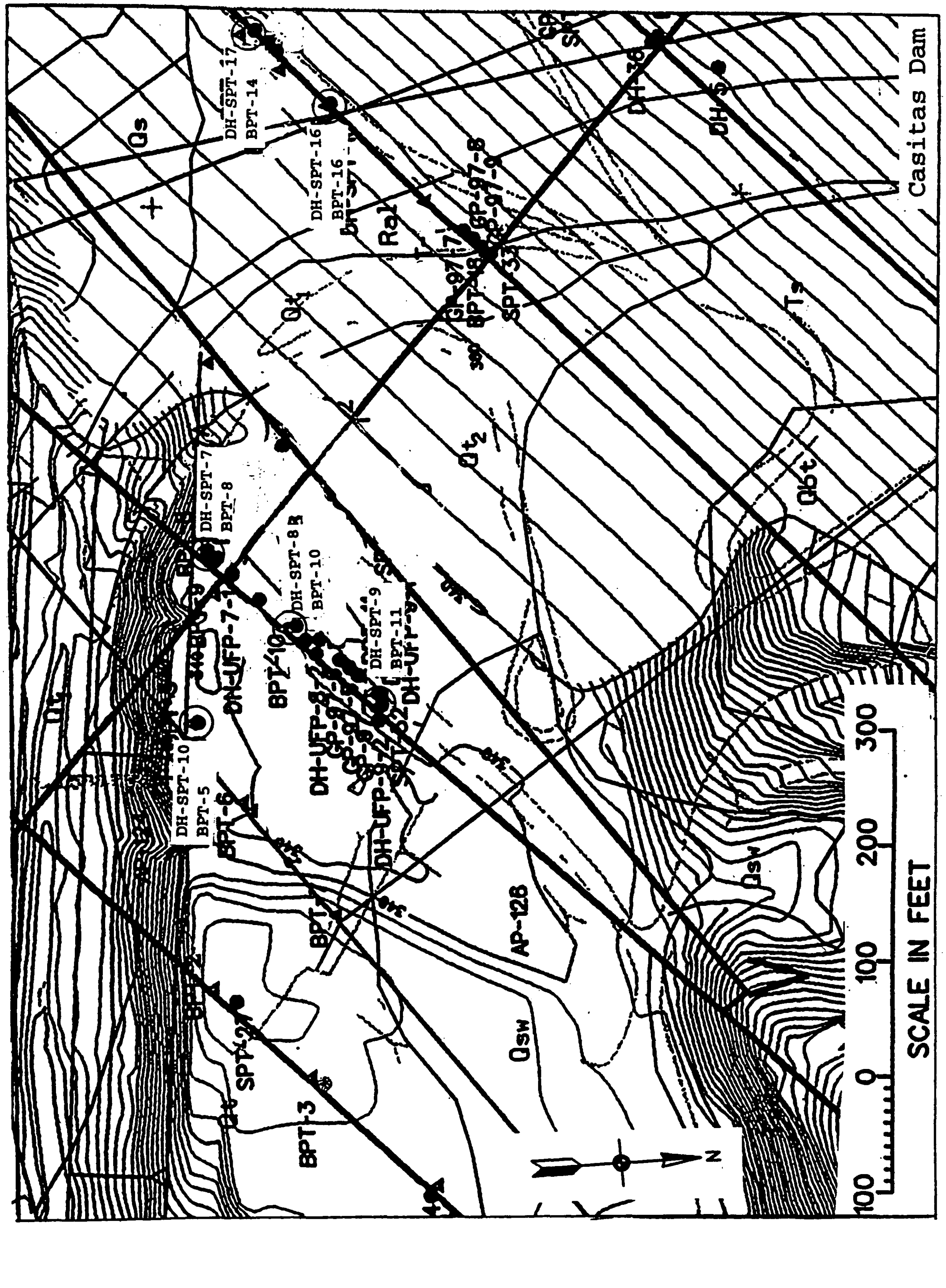

Bradbury Dam
SPT N1(60) vs Depth
Blowcount
0
25
50
75
100
125
150
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
Depth (ft)

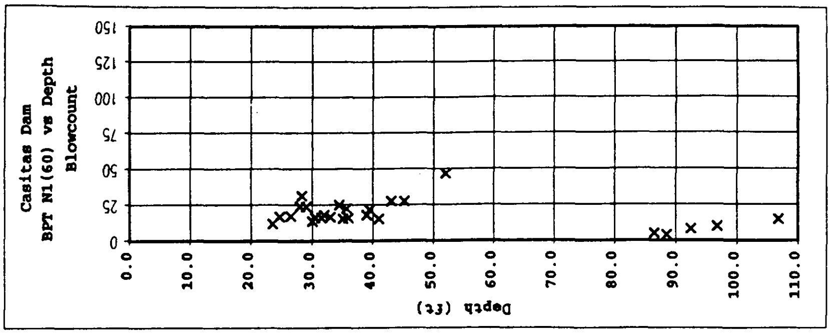

Bradbury Dam
SPT N1(60) vs Depth
Blowcount
0
25
50
75
100
125
150
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
Depth (ft)

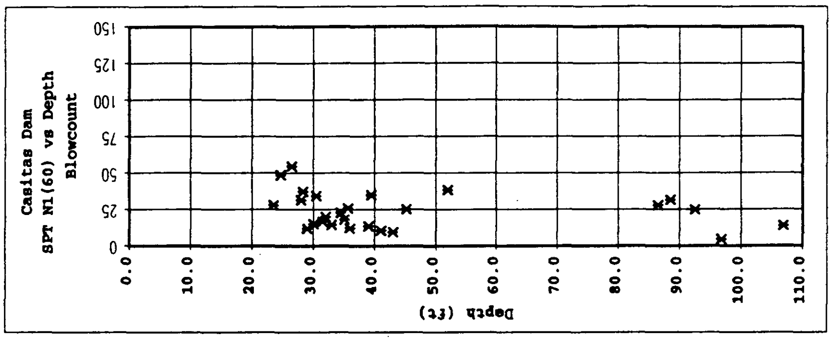

Bradbury Dam
SPT N(60) vs Depth
Blowcount
0
25
50
75
100
125
150
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
Depth (ft)

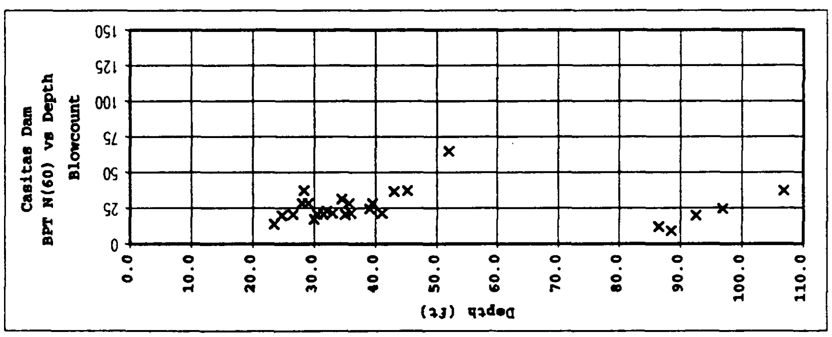

Bradbury Dam
SPT N(60) vs Depth
Blowcount
0
25
50
75
100
125
150
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
Depth (ft)

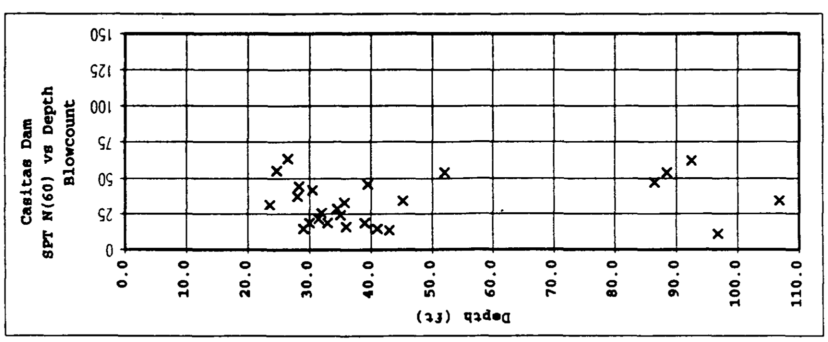
Casitas Dam		
SPT Drill Hole	BPT Drill Hole	Pair ID
DH-SPT-7	BPT-8	414-421
DH-SPT-8	BPT-10	422-432
DH-SPT-9	BPT-11	433-442
DH-SPT-10	BPT-5	401-413
DH-SPT-16	BPT-16	449-454
DH-SPT-17	BPT-14	443-448


Casitas Dam
SCALE IN FEET
100
0
100
200
300
N
Qs
Qt
Qsw
Ts
Qbt
Ral
AP-12B
BPT-3
DH-SPT-10
BPT-5
DH-SPT-7
BPT-8
DH-SPT-8
BPT-10
DH-SPT-9
BPT-11
DH-SPT-16
BPT-16
DH-SPT-17
BPT-14

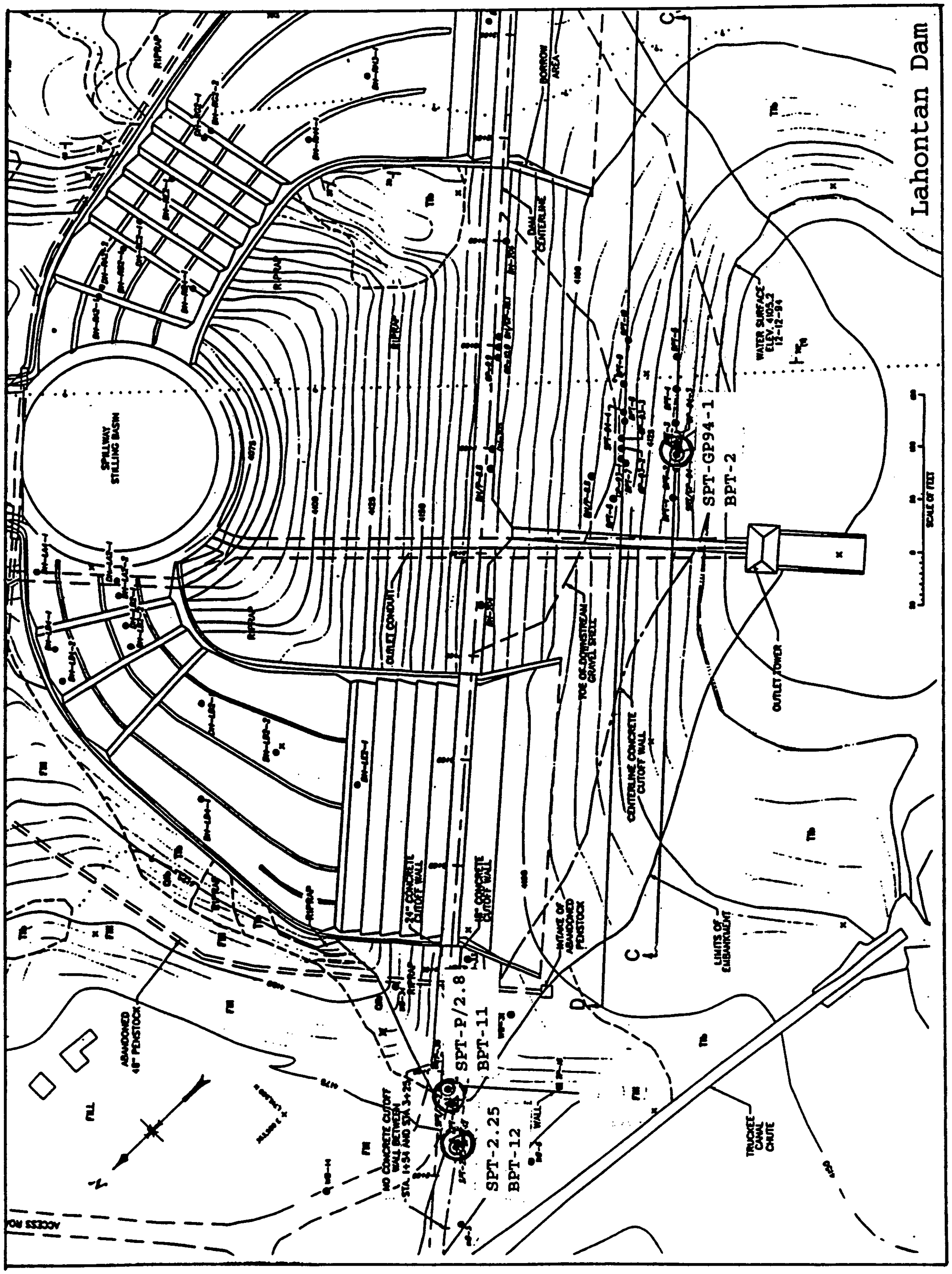

Casitas Dam
SPT N1(60) vs Depth
Blowcount
Depth (ft)

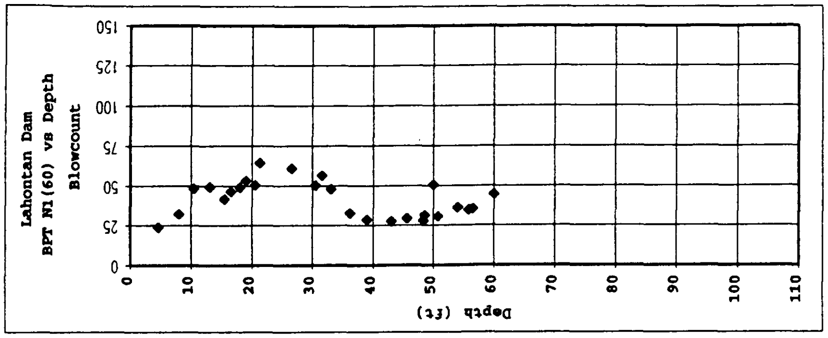

Casitas Dam
SPT N1(60) vs Depth
Blowcount
Depth (ft)

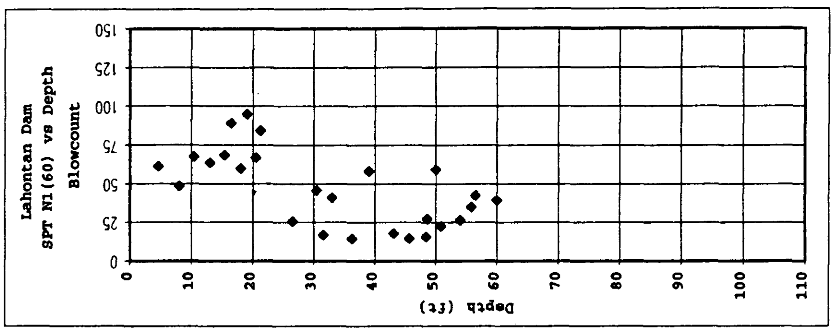

Casitas Dam
SPT N(60) vs Depth
Blowcount
Depth (ft)

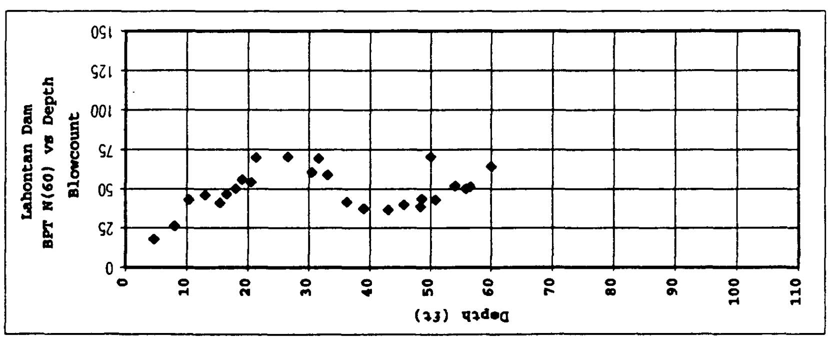

Casitas Dam
SPT N(60) vs Depth
Blowcount
Depth (ft)

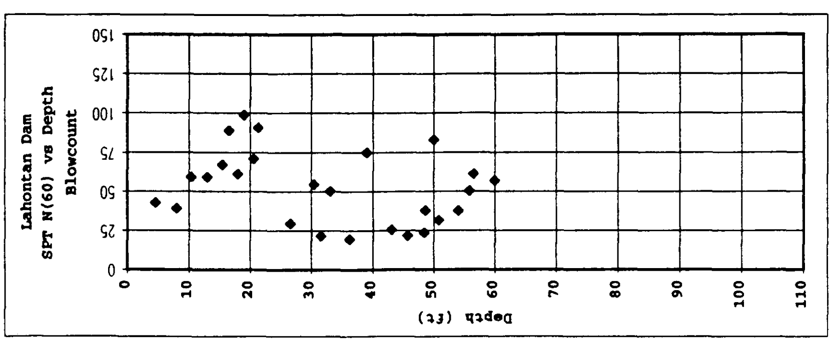
Lahontan Dam		
SPT Drill Hole	BPT Drill Hole	Pair ID
SPT-P/2.8	BPT-11	1-5
SPT-GP94-1	BPT-2	6-25
SPT-2.25	BPT-12	26-47


Lahontan Dam
SPT-GP94-1
BPT-2
SPT-P/2.8
BPT-11
SPT-2.25
BPT-12
SPILLWAY STILLING BASIN
OUTLET TOWER
TRUCKEE CANAL CHUTE

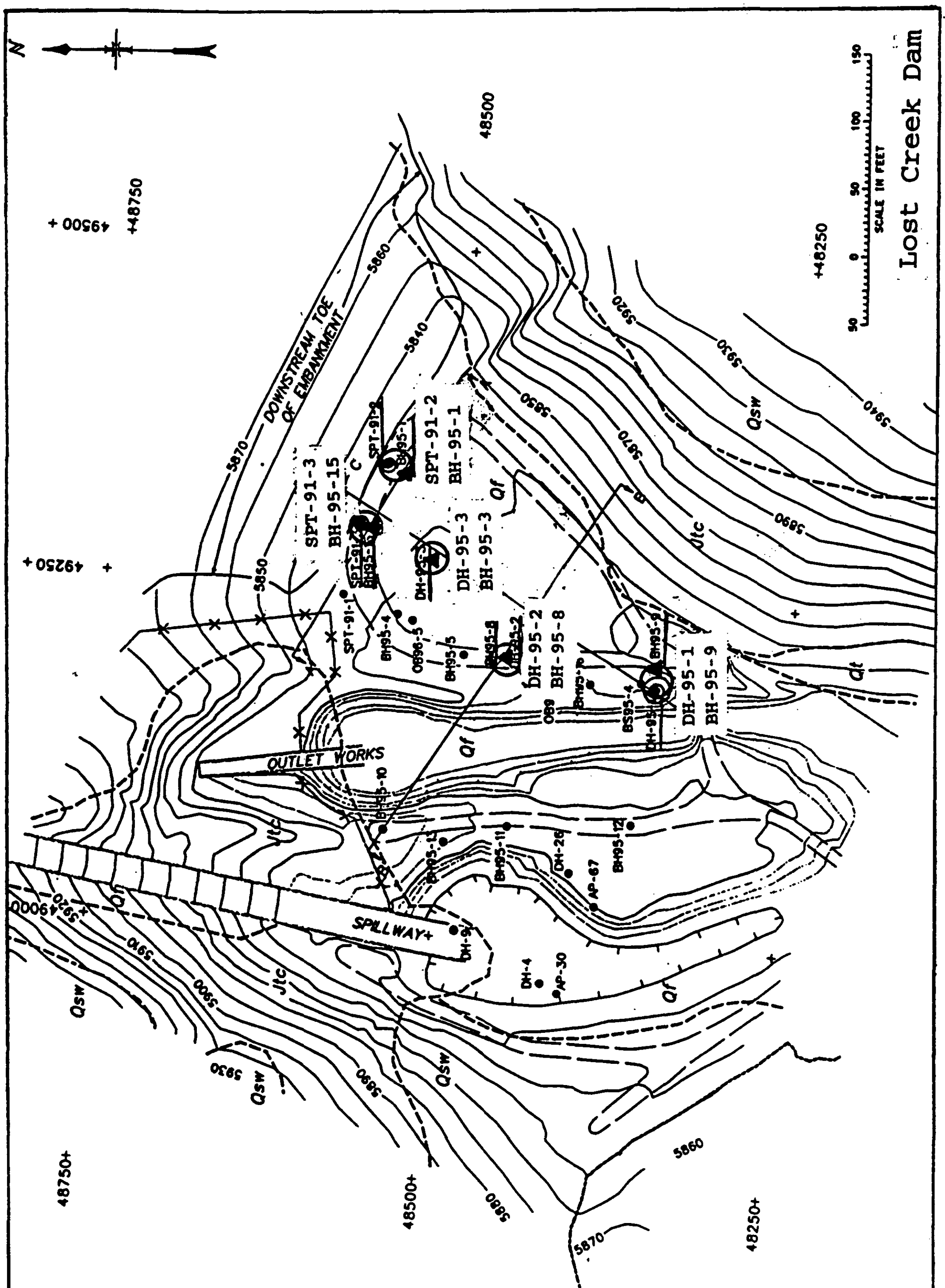

Lahontan Dam
BPT N1(60) vs Depth
Blowcount
Depth (ft)

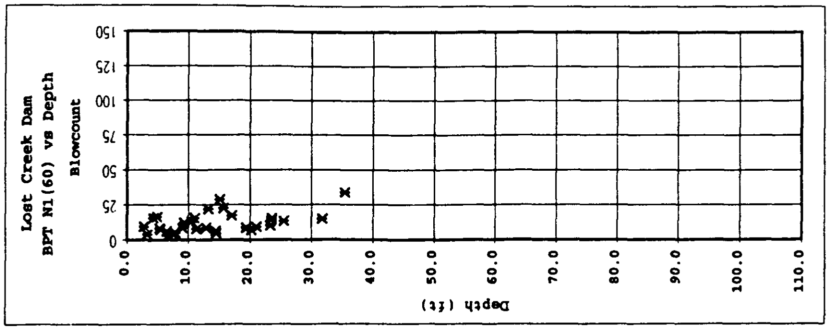

Lahontan Dam
SPT N1(60) vs Depth
Blowcount
Depth (ft)

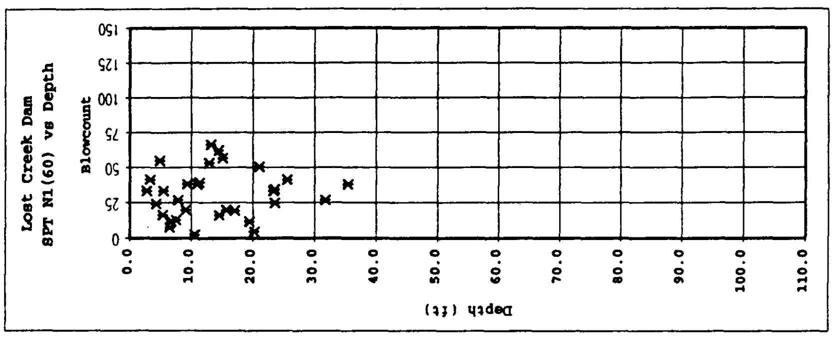

Lahontan Dam
BPT N(60) vs Depth
Blowcount
Depth (ft)

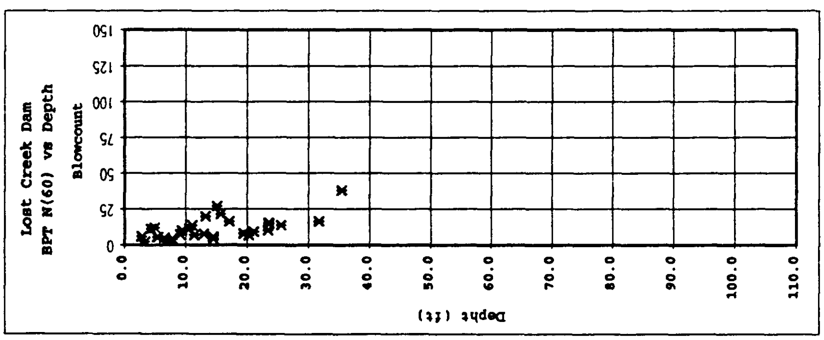

Lahontan Dam
SPT N(60) vs Depth
Blowcount
Depth (ft)

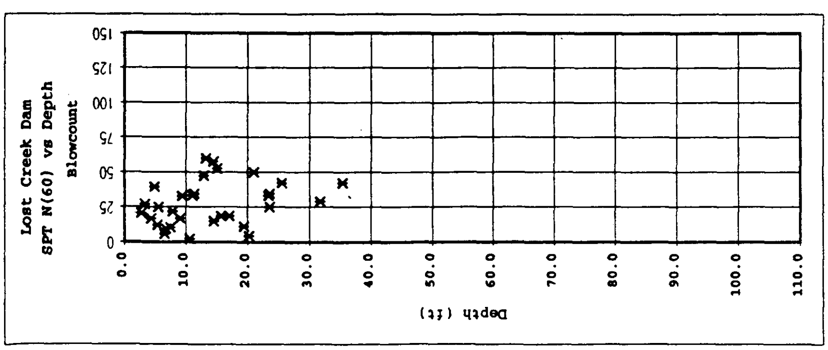
Lost Creek Dam		
SPT Drill Hole	BPT Drill Hole	Pair ID
DH-95-1	BH-95-9	557-569
DH-95-2	BH-95-8	547-556
DH-95-3	BH-95-3	500-506
SPT-91-2	BH-95-1	514-526
SPT-91-3	BH-95-15	527-542


Lost Creek Dam
SCALE IN FEET
DOWNSTREAM TOE OF EMBANKMENT
OUTLET WORKS
SPILLWAY
SPT-91-3
BH-95-15
SPT-91-2
BH-95-1
DH-95-3
BH-95-3
DH-95-2
BH-95-8
DH-95-1
BH-95-9

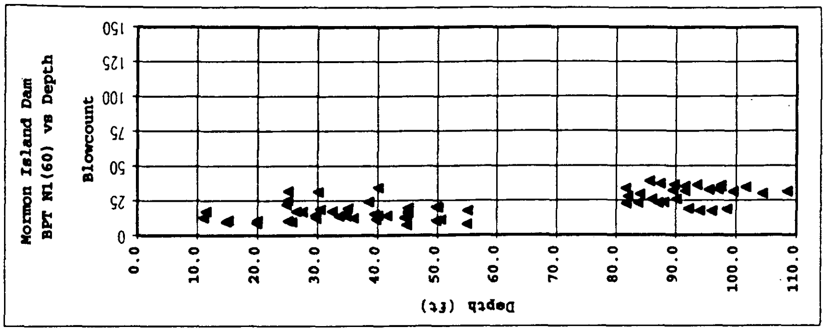

Lost Creek Dam
SPT N1(60) vs Depth
Blowcount
Depth (ft)

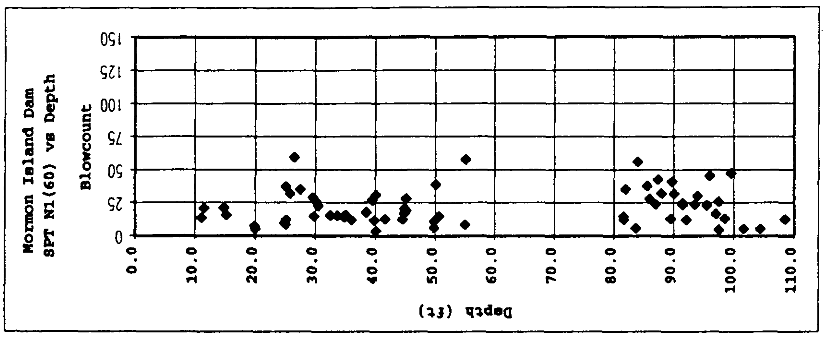

Lost Creek Dam
SPT N1(60) vs Depth
Blowcount
Depth (ft)

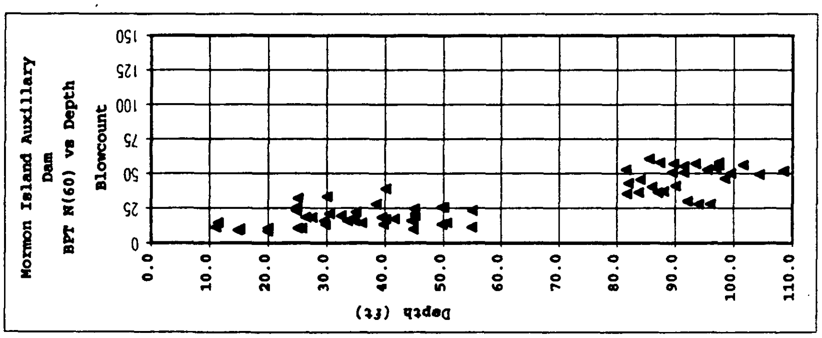

Lost Creek Dam
SPT N(60) vs Depth
Blowcount
Depth (ft)

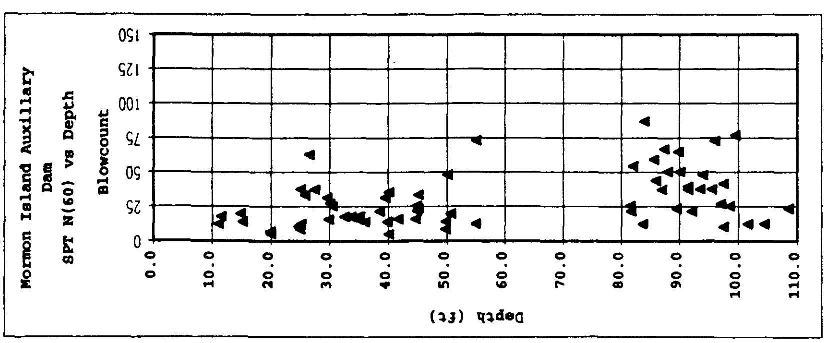

Lost Creek Dam
SPT N(60) vs Depth
Blowcount
Depth (ft)

Mormon Island Auxiliary Dam		
SPT Drill Hole	BPT Drill Hole	Pair ID
SPT-9101	UNCASED-91-01	200-207
SPT-9102	UNCASED-91-02	208-218
SPT-9104	UNCASED-91-04	219-230
SPT-9105	UNCASED-91-05	231-240
SPT-A73	POST-90-12	241-245
SPT-E35	POST-90-06	246-253
SPT/P-107I	PRE-90-18	254-261
SPT/P-123M	PRE-90-06	262-271
SPT P-36	BERM-91-07	272-276
SPT P-37	BERM-91-05	277-282
SPT P-39	BERM-91-01	283-285
SPT/P-55M	PRE-90-10	286-292
SPT/P-89K	PRE-90-16	293-300
SPT/P-71E	PRE-90-14	301-307
SPT/P-39I	PRE-90-08	308-315

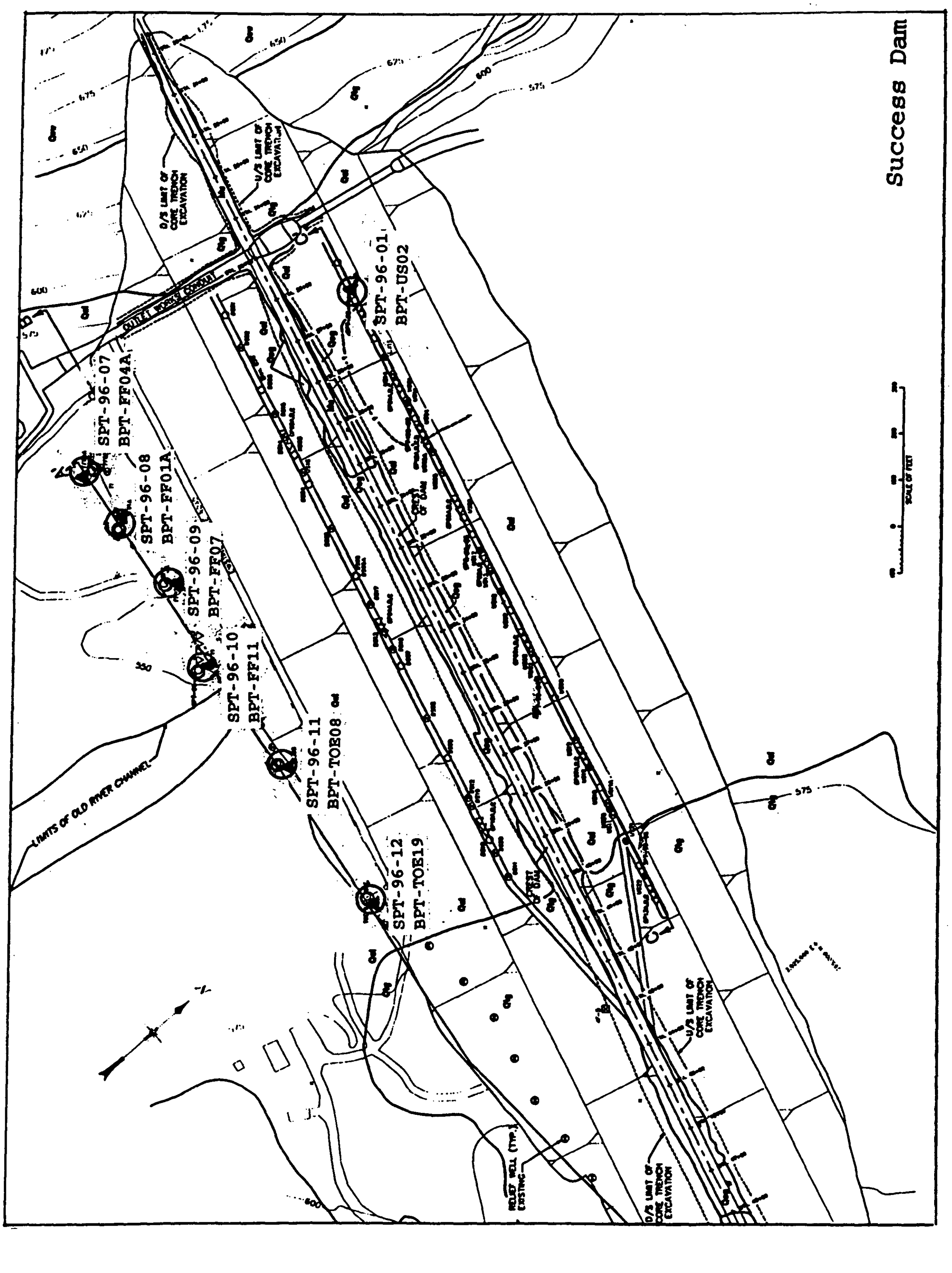

Mormon Island Dam
BPT N1(60) vs Depth
Blowcount
Depth (ft)

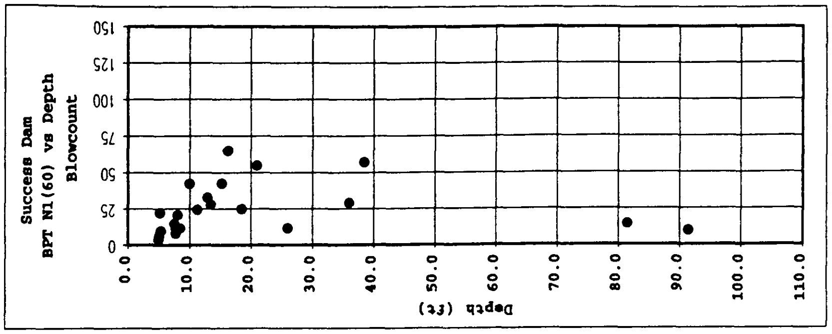

Mormon Island Dam
SPT N1(60) vs Depth
Blowcount
Depth (ft)

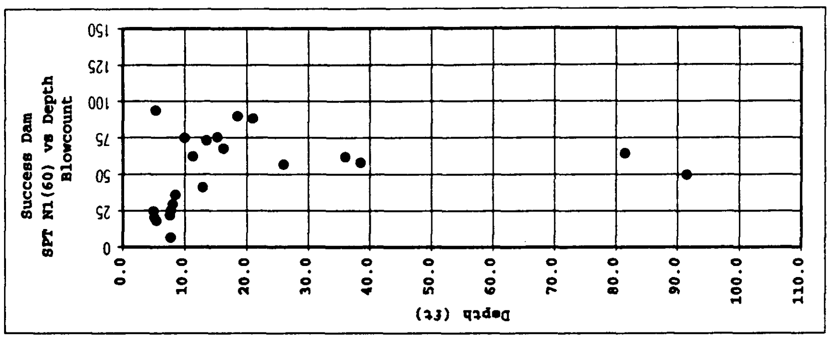

Mormon Island Auxiliary Dam
BPT N(60) vs Depth
Blowcount
Depth (ft)

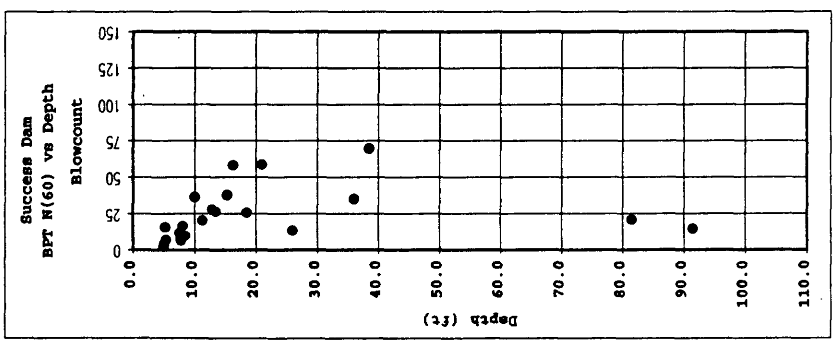

Mormon Island Auxiliary Dam
SPT N(60) vs Depth
Blowcount
Depth (ft)

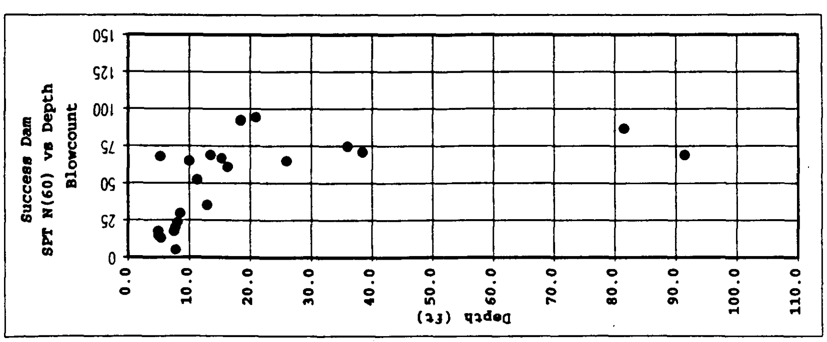
Success Dam		
SPT Drill Hole	BPT Drill Hole	Pair ID
SPT-96-01	US02	640-646
SPT-96-08	FF01A	635-639
SPT-96-09	FF07	631-634
SPT-96-07	FF04A	628-630
SPT-96-10	FF11	623-627
SPT-96-11	TOE08	618-622
SPT-96-12	TOE19	600-611
SPT-96-13	FF02	612-617


Success Dam
SPT-96-01
BPT-US02
SPT-96-07
BPT-FF04A
SPT-96-08
BPT-FF01A
SPT-96-09
BPT-FF07
SPT-96-10
BPT-FF11
SPT-96-11
BPT-TOE08
SPT-96-12
BPT-TOE19
LIMITS OF OLD RIVER CHANNEL


Success Dam
BPT N1(60) vs Depth
Blowcount
Depth (ft)
0
25
50
75
100
125
150
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0


Success Dam
SPT N1(60) vs Depth
Blowcount
Depth (ft)
0
25
50
75
100
125
150
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0


Success Dam
BPT N(60) vs Depth
Blowcount
Depth (ft)
0
25
50
75
100
125
150
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0


Success Dam
SPT N(60) vs Depth
Blowcount
Depth (ft)
0
25
50
75
100
125
150
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0

APPENDIX B

TEST AND CONTROL GROUP DATA

The spreadsheets contained in this appendix summarize the test and control group data. This data is also located on the disk located in the back pocket.

																Test Group Data														
SPT	SPT	SPT	nergy	Liner	SPT	. Eff.	Cn	Cn	Cn	SPT	%	%	%	D(50)	BPT	BPT	BP	BP	BPT	BPT	RIG	NBC	BPT	t. Eff.	Cn	Cn	Cn	BPT	Pair	Fixed
Lower	Lower	N	Corr	Corr	N60	Stress	R.D	R.D	R.D	(60)	ravel	Fines	Recov	(mm)	Lower	Lower	psi)	CORR	N(B)	(BC)	FACT.	INAL	(60)	Stress	R.D.	R.D.	R.D.	(60)	ID	Random
Depth	Elev.					(psf)	0.8	0.6	0.4						Depth	Elev		(psi)						(psf)	0.8	0.6	0.4		No.	Number
7.5	5821.5	12	1.00	1.14	10	915	1.24	1.24	1.24	13	0	13	80	0.22	8.0	5821.7	7	10	5	4	1.0	4	3	974.9	1.22	1.22	1.22	4	560	0.71692
20.2	5810.9	4	1.00	1.10	4	1854	1.02	1.02	1.02	4	0	86	0	0.02	20.0	5811.2	7	10	12	7	1.0	7	7	1892.3	1.02	1.02	1.02	7	521	0.23048
5.5	5825.6	27	1.00	1.23	25	692	1.35	1.35	1.35	34	0	62	66	0.05	6.0	5825.2	5	9	21	7	1.0	7	6	749.9	1.32	1.32	1.32	7	514	0.69490
19.9	354.9	4	1.58	1.10	7	1709	1.04	1.04	1.04	7	0	18	75	0.32	20.0	355.0	13	13	5	6	1.5	8	8	1727.4	1.04	1.04	1.04	9	309	0.57636
5.4	542.6	10	1.58	1.13	13	648	1.37	1.37	1.37	18	0	3	100	NA	5.0	543.0	11	11	22	9	1.0	9	7	600.0	1.40	1.40	1.40	10	631	0.67629
10.6	5818.4	2	1.00	1.10	2	1179	1.16	1.16	1.16	3	0	29	100	0.15	11.0	5818.7	10	14	23	11	1.0	11	11	1175.9	1.16	1.16	1.16	13	562	0.00697
86.5	308.3	35	1.08	1.25	47	11661	0.59	0.52	0.41	28	0	16	NA	0.15	86.0	308.8	13	13	24	12	1.0	12	12	11598.0	0.59	0.52	0.42	5	443	0.35363
4.9	5825.8	42	1.00	1.25	39	613	1.39	1.39	1.39	55	0	69	53	0.04	5.0	5826.2	10	14	35	16	1.0	16	12	634.1	1.38	1.38	1.38	17	507	0.56522
29.6	345.1	17	1.58	1.17	31	2658	0.92	0.90	0.87	29	0	20	6	NA	30.0	345.0	16	16	13	11	1.5	17	16	2702.9	0.91	0.89	0.86	14	247	0.76976
30.0	309.7	15	1.08	1.16	19	3749	0.83	0.79	0.73	15	0	74	NA	0.04	30.0	309.7	14	14	43	18	1.0	18	17	3748.5	0.83	0.79	0.73	14	424	0.75004
49.8	325.0	5	1.58	1.10	9	3790	0.83	0.79	0.73	6	0	45	100	0.09	50.0	325.0	19	19	20	19	1.5	29	26	3815.4	0.82	0.79	0.72	20	315	0.69455
28.0	311.7	28	1.08	1.24	37	3500	0.85	0.81	0.76	32	0	71	NA	0.02	28.0	311.7	16	16	61	32	1.0	32	28	3500.0	0.85	0.81	0.76	24	423	0.34657
83.7	342.9	7	1.58	1.11	12	9017	0.64	0.57	0.47	6	0	66	94	na	84.0	343.0	20	20	35	29	1.5	44	36	9072.0	0.64	0.57	0.47	23	220	0.91761
48.4	4126.3	13	1.58	1.15	24	5808	0.73	0.67	0.59	16	0	99	100	0.00	49.0	4126.0	15	19	68	47	1.0	47	39	5880.0	0.72	0.67	0.58	28	22	0.73897
36.3	4137.7	11	1.58	1.14	20	4356	0.79	0.75	0.68	15	0	43	87	0.09	37.0	4138.0	19	23	56	52	1.0	52	42	4440.0	0.79	0.74	0.67	33	39	0.84246
50.8	4123.9	17	1.58	1.17	31	6096	0.72	0.66	0.57	23	0	54	100	0.00	51.0	4124.0	16	20	77	54	1.0	54	43	6120.0	0.71	0.66	0.57	31	23	0.50581
48.6	4125.4	20	1.58	1.19	38	5832	0.73	0.67	0.59	27	0	97	127	0.00	50.0	4125.0	18	21	73	55	1.0	55	44	6000.0	0.72	0.67	0.58	31	44	0.45264
55.8	4118.9	26	1.58	1.23	50	6696	0.70	0.64	0.55	35	0	60	100	0.06	56.0	4119.0	17	21	92	66	1.0	66	50	6720.0	0.70	0.64	0.55	35	25	0.56308
56.5	4117.5	31	1.58	1.25	61	6780	0.69	0.64	0.54	42	0	88	133	0.01	57.0	4118.0	20	24	76	68	1.0	68	51	6840.0	0.69	0.63	0.54	36	47	0.66418
54.0	4120.0	20	1.58	1.19	38	6480	0.70	0.65	0.56	26	0	97	133	0.00	55.0	4120.0	20	24	77	69	1.0	69	52	6600.0	0.70	0.64	0.55	36	46	0.15475
31.6	4142.4	12	1.58	1.14	22	3792	0.83	0.79	0.73	17	0	72	0	0.03	33.0	4142.0	21	25	108	98	1.0	98	69	3960.0	0.81	0.78	0.71	57	37	0.25744
45.7	4129.0	12	1.58	1.14	22	5484	0.74	0.69	0.60	15	0	39	100	0.15	46.0	4129.0	18	22	57	49	1.0	49	40	5520.0	0.74	0.69	0.60	29	21	0.60044
5.0	542.0	13	1.58	1.15	18	600	1.40	1.40	1.40	25	1	33	80	NA	5.0	542.0	5	5	9	3	1.0	3	2	600.0	1.40	1.40	1.40	3	628	0.96974
33.0	307.0	15	1.08	1.16	19	4110	0.81	0.77	0.70	14	1	50	NA	0.07	33.0	306.8	16	16	42	23	1.0	23	21	4109.0	0.81	0.77	0.70	16	436	0.04214
96.8	298.1	9	1.08	1.12	11	12959	0.40	0.40	0.40	4	1	56	NA	0.06	97.0	298.1	19	19	37	27	1.0	27	25	12985.5	0.40	0.40	0.40	10	451	0.14408
25.0	349.5	5	1.58	1.10	9	2103	0.98	0.98	0.98	8	1	10	100	0.65	25.0	350.0	20	20	17	19	1.5	29	26	2131.3	0.98	0.98	0.97	25	287	0.55052
29.0	311.0	12	1.08	1.14	15	3625	0.84	0.80	0.74	12	1	63	NA	0.05	29.0	310.8	16	16	62	32	1.0	32	28	3625.0	0.84	0.80	0.74	24	434	0.41779
81.7	344.9	12	1.58	1.14	22	8870	0.64	0.56	0.47	12	1	20	87	0.30	82.0	345.0	20	20	34	28	1.5	42	35	8924.8	0.64	0.57	0.47	23	219	0.07527
104.4	322.2	7	1.58	1.11	12	10540	0.61	0.54	0.44	5	1	25	63	0.28	105.0	322.0	22	22	45	43	1.5	65	49	10617.6	0.61	0.54	0.43	30	228	0.01032
101.6	325.0	7	1.58	1.11	12	10334	0.61	0.54	0.44	5	1	31	100	0.20	102.0	325.0	22	22	59	51	1.5	77	56	10396.8	0.61	0.54	0.44	34	227	0.56004
43.1	4131.6	14	1.58	1.15	26	5172	0.75	0.70	0.62	18	2	93	100	0.00	43.0	4132.0	14	17	80	44	1.0	44	37	5160.0	0.75	0.70	0.62	28	20	0.17006
41.0	299.0	12	1.08	1.14	15	5070	0.76	0.71	0.63	10	2	37	NA	0.10	41.0	298.8	16	16	43	23	1.0	23	21	5069.0	0.76	0.71	0.63	15	440	0.39367
39.0	301.0	15	1.08	1.16	19	4830	0.77	0.72	0.64	14	2	29	NA	0.19	39.0	300.8	17	17	45	27	1.0	27	25	4829.0	0.77	0.72	0.64	18	439	0.39845
35.7	303.5	25	1.08	1.22	33	4430	0.79	0.75	0.67	26	2	15	NA	0.59	36.0	303.4	16	16	60	32	1.0	32	28	4467.0	0.79	0.74	0.67	22	406	0.02469
36.0	531.0	38	1.58	1.25	75	3758	0.83	0.79	0.73	62	2	45	100	NA	36.0	531.0	20	20	53	42	1.0	42	35	3758.4	0.83	0.79	0.73	29	610	0.53785
39.0	4135.0	38	1.58	1.25	75	4680	0.77	0.73	0.65	58	2	62	93	0.02	40.0	4135.0	17	21	53	45	1.0	45	37	4800.0	0.77	0.72	0.65	29	40	0.02572
38.5	528.5	36	1.58	1.25	71	3902	0.82	0.78	0.72	58	2	45	100	NA	39.0	528.0	25	25	109	99	1.0	99	70	3931.2	0.82	0.78	0.71	57	611	0.59580
88.5	306.3	40	1.08	1.25	54	11911	0.59	0.52	0.41	32	3	18	NA	0.33	88.0	306.8	13	13	15	9	1.0	9	9	11848.0	0.59	0.52	0.41	4	444	0.96509
54.9	319.6	7	1.58	1.11	12	4184	0.80	0.76	0.69	9	3	43	94	0.11	55.0	320.0	16	16	6	8	1.5	11	11	4219.3	0.80	0.76	0.69	8	292	0.96702
45.1	329.3	13	1.58	1.15	24	3441	0.85	0.82	0.76	19	3	54	63	0.06	46.0	329.0	20	20	11	15	1.5	23	21	3537.0	0.84	0.81	0.75	17	300	0.85640
24.8	350.0	6	1.58	1.11	10	2274	0.96	0.95	0.94	10	3	9	93	0.55	25.0	350.0	14	14	36	17	1.5	26	23	2299.0	0.96	0.95	0.93	22	256	0.81203
5.4	5828.1	14	1.00	1.15	12	668	1.36	1.36	1.36	16	4	33	47	0.11	4.0	5827.8	6	10	15	7	1.0	7	6	487.2	1.49	1.49	1.49	8	501	0.94919
32.0	307.7	20	1.08	1.19	26	3989	0.81	0.77	0.71	20	4	38	NA	0.10	32.0	307.7	16	16	48	25	1.0	25	23	3988.5	0.81	0.77	0.71	18	425	0.01156
43.0	297.0	11	1.08	1.14	13	5310	0.75	0.70	0.61	9	4	18	NA	0.32	43.0	296.8	18	18	72	44	1.0	44	37	5309.0	0.75	0.70	0.61	27	441	0.10418
81.6	345.4	20	1.08	1.19	26	8648	0.64	0.58	0.48	15	4	21	100	0.85	85.0	345.0	22	22	53	47	1.5	71	53	9145.6	0.63	0.57	0.47	34	272	0.86044
7.8	540.2	15	1.58	1.16	21	936	1.24	1.24	1.24	26	5	4	100	NA	8.0	540.0	11	11	19	9	1.0	9	7	960.0	1.23	1.23	1.23	8	632	0.19799
25.1	349.7	7	1.58	1.11	12	2071	0.99	0.99	0.98	12	5	11	100	0.80	25.0	350.0	12	12	10	7	1.5	11	11	2075.4	0.99	0.99	0.98	10	310	0.64417
7.8	545.2	4	1.58	1.10	5	761	1.31	1.31	1.31	7	5	2	75	NA	8.0	545.0	13	13	11	8	1.5	12	9	772.8	1.31	1.31	1.31	12	619	0.16912
91.5	543.5	35	1.58	1.25	69	5957	0.72	0.67	0.58	50	5	12	100	NA	92.0	543.0	9	9	74	10	1.5	15	15	5985.6	0.72	0.67	0.58	10	644	0.03754
41.6	333.1	9	1.58	1.12	16	3493	0.85	0.81	0.76	13	5	40	100	NA	42.0	333.0	17	17	13	12	1.5	18	17	3538.1	0.84	0.81	0.75	14	251	0.98206
30.5	308.7	31	1.08	1.25	42	3806	0.82	0.79	0.72	35	5	21	NA	0.40	31.0	308.4	16	16	41	22	1.0	22	21	3867.0	0.82	0.78	0.72	16	403	0.66874
89.5	337.1	13	1.58	1.15	24	9444	0.63	0.56	0.46	13	5	9	92	0.80	90.0	337.0	22	22	48	45	1.5	68	51	9513.6	0.63	0.56	0.46	32	221	0.00068
95.5	331.1	20	1.58	1.19	38	9885	0.62	0.55	0.45	23	5	32	100	0.20	96.0	331.0	22	22	52	47	1.5	71	53	9955.2	0.62	0.55	0.45	33	224	0.21824

																Test Group Data														
SPT Lower Depth	SPT Lower Elev.	SPT N	nergy Corr	Liner Corr	SPT N60	. Eff. Stress (psf)	Cn R.D 0.8	Cn R.D 0.6	Cn R.D 0.4	SPT (60)	% ravel	% Fines	% Recov	D(50) (mm)	BPT Lower Depth	BPT Lower Elev	BP psi)	BP CORR (psi)	BPT N(B)	BPT (BC)	RIG FACT.	NBC INAL	BPT (60)	t. Eff. Stress (psf)	Cn R.D. 0.8	Cn R.D. 0.6	Cn R.D. 0.4	BPT (60)	Pair ID No.	Fixed Random Number
26.5	4147.5	16	1.58	1.17	29	3180	0.87	0.84	0.79	26	5	25	73	0.32	27.0	4148.0	22	27	156	100	1.0	100	71	3240.0	0.87	0.84	0.79	61	35	0.46499
44.5	330.2	9	1.58	1.12	16	3695	0.83	0.80	0.74	13	6	32	33	NA	45.0	330.0	16	16	13	11	1.5	17	16	3746.9	0.83	0.79	0.73	13	252	0.58047
26.5	313.5	47	1.08	1.25	63	3313	0.86	0.83	0.78	55	6	46	NA	0.08	26.0	313.8	15	15	50	22	1.0	22	21	3250.0	0.86	0.84	0.78	17	433	0.29088
92.1	334.7	12	1.58	1.14	22	9257	0.63	0.57	0.46	12	6	40	63	0.10	93.0	335.0	19	19	26	23	1.5	35	30	9421.8	0.63	0.56	0.46	19	205	0.99315
15.2	359.2	8	1.58	1.12	14	1360	1.11	1.11	1.11	16	7	11	100	0.80	16.0	359.0	12	12	9	7	1.5	10	10	1449.0	1.09	1.09	1.09	11	294	0.51898
92.5	302.3	46	1.08	1.25	62	12411	0.40	0.40	0.40	25	7	19	NA	0.30	92.0	302.8	14	14	55	21	1.0	21	20	12348.0	0.40	0.40	0.40	8	446	0.52912
24.7	315.0	41	1.08	1.25	55	3088	0.88	0.85	0.80	49	7	48	NA	0.08	25.0	314.7	15	15	44	21	1.0	21	20	3125.0	0.87	0.85	0.80	17	422	0.88227
5.3	541.7	46	1.58	1.25	68	636	1.38	1.38	1.38	94	8	25	80	NA	5.0	542.0	15	15	50	22	1.0	22	16	600.0	1.40	1.40	1.40	22	612	0.37750
98.5	329.5	14	1.58	1.15	26	11181	0.60	0.53	0.42	14	8	51	93	0.08	116.0	330.0	20	20	50	40	1.5	60	47	13592.0	0.40	0.40	0.40	19	238	0.26754
8.0	4166.7	27	1.58	1.23	39	960	1.23	1.23	1.23	48	9	17	100	NA	8.0	4167.0	12	15	103	39	1.0	39	26	960.0	1.23	1.23	1.23	32	6	0.06502
5.1	544.9	11	1.58	1.14	15	612	1.39	1.39	1.39	21	10	7	50	NA	5.0	545.0	9	9	9	6	1.0	6	4	600.0	1.40	1.40	1.40	6	623	0.64632
50.6	324.1	11	1.58	1.14	20	4120	0.81	0.77	0.70	15	10	28	100	NA	51.0	324.0	16	16	11	10	1.5	15	15	4164.5	0.80	0.76	0.69	11	253	0.93477
7.6	542.4	13	1.58	1.15	18	912	1.25	1.25	1.25	22	10	7	38	NA	8.0	542.0	15	15	27	16	1.0	16	12	960.0	1.23	1.23	1.23	15	624	0.46415
32.5	342.2	10	1.58	1.13	18	2860	0.90	0.88	0.84	16	10	13	100	NA	33.0	342.0	17	17	18	14	1.5	21	20	2911.7	0.89	0.87	0.83	17	248	0.70559
19.0	4155.0	50	1.58	1.25	99	2280	0.96	0.95	0.94	95	11	23	93	0.40	20.0	4155.0	19	24	87	76	1.0	76	56	2400.0	0.95	0.93	0.91	53	32	0.78053
18.0	4156.7	31	1.58	1.25	61	2160	0.98	0.97	0.96	60	11	22	100	0.40	18.0	4157.0	18	22	88	66	1.0	66	50	2160.0	0.98	0.97	0.96	49	10	0.07761
97.5	329.1	6	1.58	1.11	10	10033	0.62	0.55	0.45	5	12	52	87	na	98.0	329.0	22	22	62	53	1.5	80	58	10102.4	0.62	0.55	0.44	36	225	0.91131
6.5	5822.9	7	1.00	1.11	6	804	1.29	1.29	1.29	8	13	21	67	1.04	6.0	5823.1	6	9	18	6	1.0	6	5	742.3	1.32	1.32	1.32	6	549	0.14272
20.0	355.2	3	1.58	1.10	5	1962	1.01	1.01	1.01	5	13	8	40	NA	20.0	355.0	10	10	14	7	1.5	11	11	1951.0	1.01	1.01	1.01	11	263	0.74823
45.7	534.3	14	1.08	1.15	17	4950	0.76	0.72	0.64	12	13	87	80	0.08	534.0	46.0	17	17	83	44	1.0	44	37	4971.6	0.76	0.71	0.63	28	120	0.62089
34.5	304.7	22	1.08	1.20	29	4286	0.80	0.75	0.68	23	14	16	NA	0.48	35.0	304.4	17	17	61	36	1.0	36	31	4347.0	0.79	0.75	0.68	25	405	0.71021
13.0	4161.7	30	1.58	1.25	59	1560	1.07	1.07	1.07	64	14	18	100	0.20	13.0	4162.0	17	21	79	59	1.0	59	46	1560.0	1.07	1.07	1.07	49	8	0.32123
33.1	4141.6	26	1.58	1.23	50	3972	0.81	0.78	0.71	41	14	18	93	0.65	33.0	4142.0	19	23	101	81	1.0	81	59	3960.0	0.81	0.78	0.71	48	16	0.22951
36.5	543.5	16	1.08	1.17	20	4282	0.80	0.75	0.68	15	15	85	80	0.40	544.0	36.0	17	17	40	24	1.0	24	22	4245.6	0.80	0.76	0.69	17	117	0.79298
29.8	345.0	9	1.58	1.12	16	2398	0.95	0.94	0.91	15	16	20	80	1.30	30.0	345.0	13	13	14	9	1.5	14	13	2423.4	0.94	0.93	0.91	12	311	0.98049
31.5	307.7	17	1.08	1.17	22	3926	0.82	0.78	0.71	17	16	14	NA	0.95	32.0	307.4	16	16	39	22	1.0	22	21	3987.0	0.81	0.77	0.71	16	404	0.19341
30.5	344.3	14	1.58	1.15	26	2727	0.91	0.89	0.86	23	16	18	100	NA	31.0	344.0	16	16	22	15	1.5	23	21	2772.5	0.91	0.89	0.85	19	242	0.73554
39.5	299.3	34	1.08	1.25	46	4884	0.77	0.72	0.64	35	16	20	NA	0.42	40.0	299.1	15	15	78	32	1.0	32	28	4945.5	0.76	0.72	0.64	22	416	0.64161
10.4	4164.3	30	1.58	1.25	59	1248	1.14	1.14	1.14	68	16	15	100	0.65	11.0	4164.0	17	21	70	54	1.0	54	43	1320.0	1.12	1.12	1.12	48	7	0.99622
30.5	4144.2	28	1.58	1.24	55	3660	0.83	0.80	0.74	46	17	17	100	0.75	31.0	4144.0	19	23	106	84	1.0	84	61	3720.0	0.83	0.79	0.73	50	15	0.22800
54.5	524.5	30	1.08	1.25	41	5536	0.74	0.69	0.60	30	17	83	80	1.20	525.0	54.0	13	13	25	12	1.0	12	12	5500.0	0.74	0.69	0.60	7	104	0.93359
23.5	315.7	24	1.08	1.21	31	2938	0.89	0.87	0.83	28	18	15	NA	1.60	24.0	315.4	14	14	27	14	1.0	14	14	3000.0	0.89	0.86	0.82	12	401	0.72536
36.0	338.8	8	1.58	1.12	14	3053	0.88	0.86	0.81	12	18	35	67	NA	36.0	339.0	12	12	22	10	1.5	15	15	3064.6	0.88	0.85	0.81	13	305	0.38682
49.8	324.7	8	1.58	1.12	14	3829	0.82	0.79	0.72	11	19	60	67	0.01	50.0	325.0	18	18	6	9	1.5	14	13	3871.3	0.82	0.78	0.72	10	291	0.33752
34.8	340.0	9	1.58	1.12	16	2746	0.91	0.89	0.85	14	19	17	80	1.40	35.0	340.0	14	14	17	11	1.5	17	16	2771.4	0.91	0.89	0.85	14	312	0.95548
11.3	535.7	27	1.58	1.23	53	1088	1.19	1.19	1.19	62	19	7	87	NA	11.0	536.0	16	16	41	22	1.0	22	21	1070.4	1.19	1.19	1.19	25	636	0.10754
35.1	339.4	10	1.58	1.13	18	2806	0.90	0.88	0.84	16	20	12	67	1.20	36.0	339.0	20	20	15	16	1.5	24	22	2896.9	0.89	0.87	0.83	19	289	0.99366
91.5	335.5	28	1.08	1.24	37	9377	0.63	0.56	0.46	24	20	11	67	5.00	94.0	336.0	22	22	49	45	1.5	68	51	9808.0	0.62	0.56	0.45	32	274	0.30896
8.5	558.5	21	1.58	1.20	30	1020	1.21	1.21	1.21	36	22	39	100	NA	9.0	558.0	16	16	16	13	1.0	13	10	1080.0	1.19	1.19	1.19	12	601	0.29413
33.6	341.2	10	1.58	1.13	18	2942	0.89	0.87	0.82	15	22	18	53	NA	34.0	341.0	16	16	12	11	1.5	17	16	2981.3	0.89	0.86	0.82	14	243	0.41101
40.1	335.1	3	1.58	1.10	5	3361	0.86	0.83	0.77	4	22	13	50	NA	40.0	335.0	16	16	15	12	1.5	18	17	3343.0	0.86	0.83	0.77	14	267	0.58461
39.5	335.3	17	1.58	1.17	31	3353	0.86	0.83	0.77	27	23	28	100	NA	40.0	335.0	16	16	17	13	1.5	20	19	3398.9	0.85	0.82	0.77	15	245	0.77698
6.8	5823.7	11	1.00	1.14	9	835	1.28	1.28	1.28	12	23	27	53	0.80	7.0	5823.7	6	9	4	3	1.0	3	2	861.0	1.27	1.27	1.27	3	527	0.15048
8.1	538.9	17	1.58	1.17	24	903	1.25	1.25	1.25	29	24	4	82	NA	8.0	539.0	14	14	66	23	1.0	23	17	897.6	1.25	1.25	1.25	21	613	0.65402
16.5	4157.5	45	1.58	1.25	89	1980	1.00	1.00	1.00	89	24	23	73	0.43	17.0	4158.0	18	22	76	60	1.0	60	47	2040.0	0.99	0.99	0.99	46	31	0.82573
55.0	320.2	37	1.58	1.25	73	4398	0.79	0.75	0.67	58	25	12	80	NA	55.0	320.0	16	16	25	17	1.5	26	23	4387.0	0.79	0.75	0.68	18	270	0.56469
106.8	288.1	26	1.08	1.23	34	13984	0.40	0.40	0.40	14	25	56	NA	0.06	107.0	288.1	18	18	74	45	1.0	45	37	13917.3	0.40	0.40	0.40	15	453	0.01250
28.3	310.5	33	1.08	1.25	45	3538	0.84	0.81	0.75	38	25	25	NA	0.29	29.0	310.1	18	18	74	45	1.0	45	37	3625.0	0.84	0.80	0.74	31	414	0.04226
14.5	5819.0	46	1.00	1.25	58	1505	1.08	1.08	1.08	62	26	6	74	1.31	13.0	5818.8	7	11	7	6	1.0	6	6	1455.6	1.09	1.09	1.09	6	504	0.31085
27.5	347.3	20	1.58	1.19	38	2518	0.93	0.92	0.89	35	26	17	80	NA	28.0	347.0	16	16	16	13	1.5	20	19	2563.7	0.93	0.91	0.88	17	241	0.95682
50.1	324.7	25	1.58	1.22	48	4035	0.81	0.77	0.70	39	26	19	73	NA	50.0	325.0	16	16	29	19	1.5	29	26	4039.0	0.81	0.77	0.70	20	307	0.42237
50.0	4070.4	42	1.58	1.25	83	6151	0.71	0.66	0.57	59	26	17	100	0.80	4070.0	50.0	13	16	683	100	1.0	100	71	6126.0	0.71	0.66	0.57	51	2	0.07082
4.6	4169.4	29	1.58	1.24	43	552	1.43	1.43	1.43	61	27	9	73	1.10	6.0	4169.0	11	14	70	25	1.0	25	18	720.0	1.33	1.33	1.33	24	26	0.94495
12.9	534.1	19	1.58	1.18	36	1180	1.16	1.16	1.16	41	27	7	31	NA	13.0	534.0	15	15	79	32	1.0	32	28	1185.6	1.16	1.16	1.16	33	614	0.03538

																Test Group Data														
SPT Lower Depth	SPT Lower Elev.	SPT N	nergy Corr	Liner Corr	SPT N60	. Eff. Stress (psf)	Cn R.D 0.8	Cn R.D 0.6	Cn R.D 0.4	SPT (60)	% ravel	% Fines	% Recov	D(50) (mm)	BPT Lower Depth	BPT Lower Elev	BP psi)	BP CORR (psi)	BPT N(B)	BPT (BC)	RIG FACT.	NBC INAL	BPT (60)	t. Eff. Stress (psf)	Cn R.D. 0.8	Cn R.D. 0.6	Cn R.D. 0.4	BPT (60)	Pair ID No.	Fixed Random Number
97.0	330.0	21	1.08	1.20	27	9782	0.62	0.56	0.45	17	27	27	73	0.50	100.0	330.0	23	23	51	48	1.5	72	54	10249.6	0.61	0.55	0.44	33	275	0.79015
26.0	541.0	33	1.58	1.25	65	3120	0.88	0.85	0.80	57	28	11	87	NA	26.0	541.0	16	16	19	14	1.0	14	14	3120.0	0.88	0.85	0.80	12	606	0.33066
81.5	553.5	44	1.58	1.25	87	5381	0.74	0.69	0.61	65	28	9	67	NA	82.0	553.0	10	10	106	15	1.5	23	21	5409.6	0.74	0.69	0.61	15	640	0.65701
13.5	553.5	35	1.58	1.25	69	1620	1.06	1.06	1.06	73	28	19	67	NA	14.0	553.0	21	21	34	30	1.0	30	27	1680.0	1.05	1.05	1.05	28	602	0.71419
21.0	546.0	48	1.58	1.25	95	2520	0.93	0.92	0.89	88	28	9	100	NA	21.0	546.0	24	24	97	81	1.0	81	59	2520.0	0.93	0.92	0.89	55	604	0.67188
21.3	4152.7	46	1.58	1.25	91	2556	0.93	0.91	0.88	84	28	17	87	1.00	22.0	4153.0	21	25	109	99	1.0	99	70	2640.0	0.92	0.90	0.87	64	33	0.59531
15.4	4159.3	34	1.58	1.25	67	1848	1.02	1.02	1.02	69	29	20	100	0.65	16.0	4159.0	17	21	62	51	1.0	51	41	1920.0	1.01	1.01	1.01	42	9	0.39987
58.5	520.5	49	1.08	1.25	66	5827	0.73	0.67	0.59	48	29	71	93	1.60	521.0	58.0	14	14	33	16	1.0	16	16	5790.4	0.73	0.67	0.59	11	106	0.80687
35.1	304.9	19	1.08	1.18	24	4362	0.79	0.75	0.68	18	29	25	NA	0.28	35.0	304.8	16	16	38	22	1.0	22	21	4349.0	0.79	0.75	0.68	15	437	0.93634
9.1	5822.0	19	1.00	1.18	17	1085	1.19	1.19	1.19	20	29	47	40	0.10	9.0	5822.2	8	12	19	9	1.0	9	7	1102.7	1.18	1.18	1.18	8	516	0.23861
52.7	526.3	39	1.08	1.25	53	5406	0.74	0.69	0.61	39	30	70	87	1.80	526.0	53.0	14	14	43	18	1.0	18	17	5427.4	0.74	0.69	0.61	12	103	0.96920
45.1	329.4	18	1.58	1.18	34	3502	0.85	0.81	0.76	28	30	30	47	0.40	46.0	329.0	20	20	10	14	1.5	21	20	3592.9	0.84	0.81	0.75	16	290	0.97167
16.3	530.7	31	1.58	1.25	61	1376	1.11	1.11	1.11	68	30	5	87	NA	16.0	531.0	19	19	159	80	1.0	80	58	1358.4	1.11	1.11	1.11	65	638	0.88413
20.5	4154.2	36	1.58	1.25	71	2460	0.94	0.93	0.90	67	31	16	100	1.00	21.0	4154.0	17	21	105	73	1.0	73	54	2520.0	0.93	0.92	0.89	51	11	0.80612
60.0	4060.4	29	1.58	1.24	57	6877	0.69	0.63	0.54	39	31	15	NR	0.80	4060.0	60.0	19	24	129	90	1.0	90	64	6852.0	0.69	0.63	0.54	45	4	0.31066
38.5	336.2	12	1.58	1.14	22	3278	0.86	0.83	0.78	18	31	16	80	NA	39.0	336.0	20	20	22	21	1.5	32	28	3329.3	0.86	0.83	0.78	24	250	0.04170
15.3	531.7	34	1.58	1.25	67	1318	1.12	1.12	1.12	75	31	8	93	NA	15.0	532.0	20	20	61	46	1.0	46	38	1300.8	1.13	1.13	1.13	43	615	0.32174
44.8	330.0	12	1.58	1.14	22	3666	0.83	0.80	0.74	17	32	15	100	2.00	45.0	330.0	11	11	8	7	1.5	10	10	3691.0	0.83	0.80	0.74	7	260	0.64305
44.8	330.0	14	1.58	1.15	26	3442	0.85	0.82	0.76	21	33	14	73	2.00	45.0	330.0	17	17	10	11	1.5	17	16	3467.4	0.85	0.82	0.76	13	314	0.41886
36.0	303.7	13	1.08	1.15	16	4469	0.79	0.74	0.67	12	33	14	NA	0.59	36.0	303.7	16	16	45	23	1.0	23	21	4468.5	0.79	0.74	0.67	16	427	0.78704
10.0	540.0	33	1.58	1.25	65	1200	1.15	1.15	1.15	75	33	14	60	NA	10.0	540.0	22	22	47	44	1.0	44	37	1200.0	1.15	1.15	1.15	42	625	0.39184
50.7	528.3	40	1.08	1.25	54	5260	0.75	0.70	0.62	40	34	66	87	2.40	528.0	51.0	13	13	25	12	1.0	12	12	5282.2	0.75	0.70	0.62	7	102	0.73672
19.4	5811.1	10	1.00	1.13	11	1802	1.03	1.03	1.03	12	35	7	20	3.00	20.0	5810.7	7	11	25	8	1.0	8	8	1839.6	1.02	1.02	1.02	8	534	0.52647
45.0	330.2	13	1.58	1.15	24	3702	0.83	0.80	0.73	19	35	14	60	NA	45.0	330.0	17	17	25	18	1.5	27	25	3691.0	0.83	0.80	0.74	20	268	0.43879
65.7	513.3	42	1.08	1.25	57	6349	0.71	0.65	0.56	40	37	63	80	3.00	513.0	66.0	15	15	35	19	1.0	19	18	6371.2	0.71	0.65	0.56	12	109	0.33569
51.5	528.5	41	1.08	1.25	55	5371	0.74	0.69	0.61	41	39	61	67	2.80	529.0	51.0	17	17	44	27	1.0	27	25	5334.6	0.75	0.70	0.61	17	123	0.21225
7.9	5822.6	24	1.00	1.21	22	961	1.23	1.23	1.23	27	40	20	100	2.36	8.0	5822.7	8	12	8	5	1.0	5	4	976.0	1.22	1.22	1.22	5	528	0.44170
39.8	335.0	8	1.58	1.12	14	3094	0.88	0.85	0.80	12	40	13	53	3.40	40.0	335.0	13	13	15	9	1.5	14	13	3119.4	0.88	0.85	0.80	11	313	0.78859
108.5	318.1	13	1.58	1.15	24	10842	0.60	0.54	0.43	13	40	22	40	0.50	109.0	318.0	22	22	50	46	1.5	69	52	10912.0	0.60	0.53	0.43	31	230	0.27467
14.5	5814.5	13	1.00	1.15	15	1458	1.09	1.09	1.09	16	41	14	60	2.36	15.0	5814.7	6	10	5	4	1.0	4	4	1458.3	1.09	1.09	1.09	5	565	0.73820
96.0	330.8	37	1.58	1.25	73	9544	0.63	0.56	0.46	46	41	22	33	1.20	97.0	331.0	19	19	24	21	1.5	32	28	9716.2	0.62	0.56	0.45	17	207	0.17215
87.4	339.9	34	1.58	1.25	67	9034	0.64	0.57	0.47	43	41	13	67	2.40	87.0	340.0	22	22	63	53	1.5	80	58	8980.2	0.64	0.57	0.47	37	211	0.10629
11.0	5820.4	27	1.00	1.23	33	1237	1.14	1.14	1.14	38	42	7	33	3.50	11.0	5820.6	11	16	23	14	1.0	14	14	1292.7	1.13	1.13	1.13	16	543	0.04317
3.3	5826.1	29	1.00	1.24	27	435	1.53	1.53	1.53	41	44	17	100	3.35	3.0	5826.1	5	9	5	3	1.0	3	2	393.0	1.58	1.58	1.58	4	548	0.83579
23.5	5807.6	21	1.00	1.20	25	2066	0.99	0.99	0.98	25	44	19	60	3.50	24.0	5807.2	11	15	26	15	1.0	15	15	2149.9	0.98	0.97	0.96	14	523	0.59963
13.2	5817.3	48	1.00	1.25	60	1398	1.11	1.11	1.11	66	44	8	40	3.70	13.0	5817.7	11	15	55	21	1.0	21	20	1383.4	1.11	1.11	1.11	22	531	0.84780
4.3	5824.7	19	1.00	1.18	17	551	1.43	1.43	1.43	24	45	20	73	3.46	5.0	5824.7	8	12	71	15	1.0	15	11	637.9	1.38	1.38	1.38	16	558	0.40370
18.5	548.5	47	1.58	1.25	93	2220	0.97	0.96	0.95	90	45	10	33	NA	19.0	548.0	19	19	39	29	1.0	29	26	2280.0	0.96	0.95	0.94	25	603	0.72157
19.0	561.0	17	1.08	1.17	22	2375	0.95	0.94	0.92	20	46	54	67	3.30	561.0	19.0	20	20	61	46	1.0	46	38	2375.0	0.95	0.94	0.92	36	111	0.51229
25.5	5805.0	34	1.00	1.25	43	2199	0.97	0.97	0.95	41	47	6	33	4.00	26.0	5804.7	11	16	22	14	1.0	14	14	2233.6	0.97	0.96	0.95	13	537	0.71515
23.5	5807.0	28	1.00	1.24	35	2062	0.99	0.99	0.98	34	48	8	53	4.20	24.0	5806.7	11	16	28	16	1.0	16	16	2096.4	0.99	0.98	0.98	15	536	0.74729
15.1	5815.4	42	1.00	1.25	53	1532	1.08	1.08	1.08	57	48	5	40	4.50	15.0	5815.7	11	16	71	30	1.0	30	27	1524.6	1.08	1.08	1.08	29	532	0.10627
12.9	5816.1	38	1.00	1.25	48	1343	1.12	1.12	1.12	53	48	4	93	4.43	14.0	5815.7	8	12	15	8	1.0	8	8	1387.7	1.11	1.11	1.11	9	564	0.11991
87.0	340.8	28	1.08	1.24	37	8880	0.64	0.58	0.47	24	48	10	60	3.00	89.0	341.0	20	20	35	29	1.5	44	36	9204.0	0.63	0.57	0.47	23	283	0.98627
56.5	522.5	32	1.08	1.25	43	5682	0.73	0.68	0.59	32	50	50	73	4.80	523.0	56.0	14	14	32	16	1.0	16	16	5645.2	0.73	0.68	0.60	11	105	0.50094
28.7	551.4	40	1.08	1.25	54	3628	0.84	0.80	0.74	45	50	50	100	4.75	551.0	29.0	17	17	95	48	1.0	48	39	3675.0	0.83	0.80	0.74	33	114	0.18776
45.2	294.5	26	1.08	1.23	34	5573	0.74	0.68	0.60	25	51	13	NA	5.00	45.0	294.7	18	18	74	45	1.0	45	37	5548.5	0.74	0.69	0.60	27	431	0.45140
52.0	287.7	40	1.08	1.25	54	6077	0.72	0.66	0.57	39	51	18	NA	5.00	52.0	287.7	20	20	154	91	1.0	91	65	5995.4	0.72	0.67	0.58	47	432	0.89973
23.3	5806.1	27	1.00	1.23	33	2008	1.00	1.00	1.00	33	53	7	53	5.30	23.0	5806.1	10	14	29	10	1.0	10	10	1950.2	1.01	1.01	1.01	10	554	0.79942
99.5	327.8	39	1.58	1.25	77	9925	0.62	0.55	0.45	48	53	27	47	7.00	99.0	328.0	21	21	50	44	1.5	66	50	9863.4	0.62	0.55	0.45	31	217	0.77493
60.6	519.4	30	1.08	1.25	41	6032	0.72	0.66	0.58	29	54	46	60	6.00	519.0	61.0	16	16	49	26	1.0	26	24	6060.6	0.72	0.66	0.57	16	127	0.58193
21.0	5809.7	40	1.00	1.25	50	1927	1.01	1.01	1.01	51	54	10	53	6.00	21.0	5810.2	7	10	26	9	1.0	9	9	1975.9	1.00	1.00	1.00	9	513	0.82323
25.1	349.3	20	1.58	1.19	38	2049	0.99	0.99	0.99	37	55	12	9	6.50	26.0	349.0	20	20	27	25	1.5	38	32	2145.0	0.98	0.97	0.97	32	296	0.96770
17.1	5816.3	16	1.00	1.17	19	1679	1.05	1.05	1.05	20	56	16	20	7.20	15.0	5816.8	11	15	29	17	1.0	17	16	1590.8	1.07	1.07	1.07	18	505	0.29937

																Test Group Data														
SPT	SPT	SPT	nergy	Liner	SPT	. Eff.	Cn	Cn	Cn	SPT	%	%	%	D(50)	BPT	BPT	BP	BP	BPT	BPT	RIG	NBC	BPT	t. Eff.	Cn	Cn	Cn	BPT	Pair	Fixed
Lower	Lower	N	Corr	Corr	N60	Stress	R.D	R.D	R.D	(60)	ravel	Fines	Recov	(mm)	Lower	Lower	psi)	CORR	N(B)	(BC)	FACT.	INAL	(60)	Stress	R.D.	R.D.	R.D.	(60)	ID	Random
Depth	Elev.					(psf)	0.8	0.6	0.4						Depth	Elev		(psi)						(psf)	0.8	0.6	0.4		No.	Number
40.1	334.3	19	1.58	1.18	36	3093	0.88	0.85	0.80	31	56	13	59	7.50	41.0	334.0	25	25	28	32	1.5	48	39	3189.0	0.87	0.84	0.79	34	299	0.91079
15.7	5815.7	16	1.00	1.17	19	1569	1.07	1.07	1.07	20	57	5	13	6.00	16.0	5815.6	12	17	43	23	1.0	23	21	1645.7	1.06	1.06	1.06	23	545	0.36155
30.1	344.3	15	1.58	1.16	27	2397	0.95	0.94	0.91	26	59	12	27	11.00	31.0	344.0	20	20	29	26	1.5	39	33	2493.0	0.94	0.92	0.90	31	297	0.66732
31.7	5798.8	24	1.00	1.21	29	2625	0.92	0.90	0.87	27	59	3	33	7.50	32.0	5798.7	12	17	29	17	1.0	17	16	2645.2	0.92	0.90	0.87	15	539	0.49818
35.4	5795.1	34	1.00	1.25	43	2878	0.90	0.87	0.83	38	61	4	33	9.50	36.0	5794.7	14	19	76	46	1.0	46	38	2919.6	0.89	0.87	0.83	34	541	0.37969
9.4	5824.0	35	1.00	1.25	33	1145	1.17	1.17	1.17	38	64	3	52	9.93	8.0	5823.8	8	12	41	13	1.0	13	10	977.8	1.22	1.22	1.22	12	503	0.03305
26.5	348.2	32	1.58	1.25	63	2443	0.94	0.93	0.90	60	64	12	40	NA	27.0	348.0	17	17	14	13	1.5	20	19	2494.1	0.94	0.92	0.90	17	246	0.07174
11.1	363.7	7	1.58	1.11	12	1320	1.12	1.12	1.12	14	66	12	33	NA	11.0	364.0	11	11	15	8	1.5	11	11	1324.6	1.12	1.12	1.12	13	301	0.12337
11.5	363.3	10	1.58	1.13	18	1125	1.17	1.17	1.17	21	66	12	38	10.00	12.0	363.0	16	16	10	10	1.5	15	15	1170.6	1.16	1.16	1.16	17	308	0.60128
21.0	559.0	31	1.08	1.25	42	2625	0.92	0.90	0.87	39	67	33	80	7.50	559.0	21.0	21	21	51	44	1.0	44	37	2625.0	0.92	0.90	0.87	34	112	0.01734
53.6	526.4	42	1.08	1.25	57	5523	0.74	0.69	0.60	42	68	32	67	13.00	526.0	54.0	16	16	43	23	1.0	23	21	5552.4	0.74	0.69	0.60	15	124	0.90551
2.8	5830.6	23	1.00	1.21	21	367	1.61	1.61	1.61	34	69	6	20	10.39	1.0	5830.8	7	11	14	8	1.0	8	6	131.0	1.60	1.60	1.60	9	500	0.25407
93.5	333.8	20	1.58	1.19	38	9483	0.63	0.56	0.46	24	72	9	60	17.00	93.0	334.0	22	22	61	52	1.5	78	57	9421.8	0.63	0.56	0.46	36	214	0.82047
14.8	360.0	11	1.58	1.14	20	1578	1.07	1.07	1.07	21	73	12	13	NA	15.0	360.0	10	10	11	6	1.5	9	9	1603.0	1.06	1.06	1.06	10	302	0.81447
25.8	349.0	18	1.58	1.18	34	2344	0.95	0.94	0.92	32	74	8	33	NA	26.0	349.0	10	10	13	7	1.5	11	11	2368.6	0.95	0.94	0.92	10	303	0.57617
88.0	338.8	26	1.58	1.23	50	8955	0.64	0.57	0.47	32	74	9	33	19.00	89.0	339.0	20	20	36	30	1.5	45	37	9127.4	0.63	0.57	0.47	24	203	0.83413
82.0	344.8	28	1.58	1.24	55	8513	0.65	0.59	0.48	35	74	10	67	6.00	83.0	345.0	21	21	40	36	1.5	54	43	8685.8	0.64	0.58	0.48	28	200	0.39282
34.8	340.0	10	1.58	1.13	18	2970	0.89	0.86	0.82	15	75	8	33	11.00	35.0	340.0	17	17	15	13	1.5	20	19	2995.0	0.89	0.86	0.82	16	258	0.10280
84.0	342.8	44	1.58	1.25	87	8661	0.64	0.58	0.48	56	75	11	53	19.00	85.0	343.0	21	21	43	39	1.5	59	46	8833.0	0.64	0.58	0.48	29	201	0.07659
90.1	336.7	26	1.58	1.23	50	9109	0.63	0.57	0.47	32	77	8	44	17.00	91.0	337.0	20	20	44	34	1.5	51	41	9274.6	0.63	0.57	0.46	26	204	0.89926
89.8	337.5	33	1.58	1.25	65	9211	0.63	0.57	0.47	41	77	5	53	15.00	89.0	338.0	22	22	61	52	1.5	78	57	9127.4	0.63	0.57	0.47	36	212	0.90509
85.6	341.7	30	1.58	1.25	59	8902	0.64	0.58	0.47	38	80	4	53	11.00	85.0	342.0	22	22	68	56	1.5	84	61	8833.0	0.64	0.58	0.48	39	210	0.05572
11.3	5819.2	28	1.00	1.24	35	1264	1.14	1.14	1.14	39	80	1	47	16.00	12.0	5818.7	9	13	10	7	1.0	7	7	1312.8	1.13	1.13	1.13	8	530	0.48023
91.5	335.8	21	1.58	1.20	40	9336	0.63	0.57	0.46	25	81	6	73	19.00	91.0	336.0	21	21	61	50	1.5	75	56	9274.6	0.63	0.57	0.46	35	213	0.09253
86.0	340.8	23	1.58	1.21	44	8808	0.64	0.58	0.48	28	84	6	67	21.00	87.0	341.0	21	21	37	33	1.5	50	40	8980.2	0.64	0.57	0.47	26	202	0.15445
94.0	332.8	25	1.58	1.22	48	9397	0.63	0.56	0.46	30	85	3	60	13.00	95.0	333.0	19	19	24	21	1.5	32	28	9569.0	0.63	0.56	0.46	18	206	0.93613
97.5	329.8	22	1.58	1.20	42	9778	0.62	0.56	0.45	26	90	3	53	25.00	97.0	330.0	21	21	62	51	1.5	77	56	9716.2	0.62	0.56	0.45	35	216	0.82706

															Control Group Data															
SPT Lower Depth	SPT Lower Elev.	SPT N	nergy Corr	Liner Corr	SPT N60	t. Eff. Stress (psf)	Cn R.D 0.8	Cn R.D 0.6	Cn R.D 0.4	SPT (60)	% ravel	% Fines	% Recov	D(50) (mm)	BPT Lower Depth	BPT Lower Elev	BP psi)	BP CORR (psi)	BPT N(B)	BPT (BC)	RIG FACT.	NBC INAL	BPT (60)	t. Eff. Stress (psf)	Cn R.D. 0.8	Cn R.D. 0.6	Cn R.D. 0.4	BPT (60)	Pair ID No.	Fixed Random Number
45.0	295.0	4	1.08	1.10	5	5550.0	0.74	0.69	0.60	3	0	34	NA	0.16	45.0	294.8	18.4	18.4	67	42	1.0	42	35	5549.0	0.74	0.69	0.60	26	442	0.19773
37.0	303.0	20	1.08	1.19	26	4590.0	0.78	0.74	0.66	19	0	35	NA	0.15	37.0	302.8	17.1	17.1	57	35	1.0	35	31	4589.0	0.78	0.74	0.66	24	438	0.34301
38.0	301.7	9	1.08	1.12	11	4708.5	0.77	0.73	0.65	7	0	16	NA	0.32	38.0	301.7	16.6	16.6	55	34	1.0	34	30	4708.5	0.77	0.73	0.65	23	428	0.37640
34.0	305.7	12	1.08	1.14	15	4228.5	0.80	0.76	0.69	11	0	54	NA	0.07	34.0	305.7	16.7	16.7	40	24	1.0	24	22	4228.5	0.80	0.76	0.69	17	426	0.70958
51.5	4122.5	17	1.58	1.17	31	6180.0	0.71	0.66	0.57	22	0	97	133	0.00	52.0	4123.0	18.2	22.2	67	55	1.0	55	44	6240.0	0.71	0.66	0.57	31	45	0.04157
53.6	4121.1	25	1.58	1.22	48	6432.0	0.70	0.65	0.56	34	0	91	100	0.02	54.0	4121.0	16.2	20.0	94	61	1.0	61	47	6480.0	0.70	0.65	0.56	33	24	0.18616
38.0	4136.7	20	1.58	1.19	38	4560.0	0.78	0.74	0.66	29	0	32	100	0.20	38.0	4137.0	15.9	19.6	61	46	1.0	46	38	4560.0	0.78	0.74	0.66	30	18	0.27349
40.5	4134.2	12	1.58	1.14	22	4860.0	0.77	0.72	0.64	16	0	81	100	0.02	41.0	4134.0	16.4	20.2	58	45	1.0	45	37	4920.0	0.76	0.72	0.64	29	19	0.35089
46.5	4127.5	38	1.58	1.25	75	5580.0	0.74	0.68	0.60	55	0	NA	47	NA	47.0	4128.0	18.7	22.8	70	60	1.0	60	47	5640.0	0.73	0.68	0.60	34	43	0.61388
28.5	538.5	11	1.58	1.14	20	3326.4	0.86	0.83	0.78	16	0	12	67	NA	29.0	538.0	16.0	16.0	29	19	1.0	19	18	3355.2	0.86	0.83	0.77	15	607	0.69597
99.5	327.1	6	1.58	1.11	10	10179.8	0.61	0.55	0.44	5	0	48	100	0.09	100.0	327.0	22.0	22.0	62	53	1.5	80	58	10249.6	0.61	0.55	0.44	36	226	0.37427
52.5	286.7	12	1.08	1.14	15	6084.1	0.72	0.66	0.57	10	1	48	NA	0.08	53.0	286.4	20.0	20.0	116	86	1.0	86	62	6032.8	0.72	0.66	0.58	45	411	0.24540
44.0	295.7	11	1.08	1.14	13	5428.5	0.74	0.69	0.61	9	1	26	NA	0.35	44.0	295.7	16.1	16.1	61	32	1.0	32	28	5428.5	0.74	0.69	0.61	21	430	0.43321
91.5	336.3	21	1.08	1.20	27	9300.7	0.63	0.57	0.46	17	1	39	67	0.10	94.0	336.0	20.0	20.0	34	28	1.5	42	35	9672.0	0.62	0.56	0.45	22	284	0.39658
31.0	309.0	12	1.08	1.14	15	3870.0	0.82	0.78	0.72	12	4	51	NA	0.07	31.0	308.8	15.4	15.4	33	18	1.0	18	17	3869.0	0.82	0.78	0.72	14	435	0.07527
5.6	547.4	4	1.58	1.10	5	634.6	1.38	1.38	1.38	7	4	38	100	NA	6.0	547.0	11.1	11.1	10	7	1.5	10	8	657.6	1.37	1.37	1.37	10	618	0.14258
29.8	345.0	9	1.58	1.12	16	2621.9	0.92	0.90	0.87	14	5	11	73	1.00	30.0	345.0	14.0	14.0	11	9	1.5	13	13	2647.0	0.92	0.90	0.87	11	257	0.82055
10.4	542.6	14	1.58	1.15	26	911.0	1.25	1.25	1.25	32	6	4	73	NA	10.0	543.0	14.6	14.6	20	13	1.5	20	19	888.0	1.26	1.26	1.26	23	620	0.05294
10.1	364.3	5	1.58	1.10	9	1004.8	1.21	1.21	1.21	11	7	9	80	0.90	11.0	364.0	14.0	14.0	10	9	1.5	13	13	1101.0	1.18	1.18	1.18	15	293	0.09732
10.2	5819.2	8	1.00	1.12	9	1117.6	1.18	1.18	1.18	11	7	38	63	0.12	10.0	5819.1	5.7	9.3	10	5	1.0	5	5	1068.0	1.19	1.19	1.19	6	551	0.48486
86.5	340.5	27	1.08	1.23	36	9008.8	0.64	0.57	0.47	23	8	13	87	1.40	89.0	341.0	23.0	23.0	51	48	1.5	72	54	9440.0	0.63	0.56	0.46	34	273	0.47772
93.6	333.0	19	1.58	1.18	36	9745.6	0.62	0.56	0.45	22	8	20	88	0.50	94.0	333.0	22.0	22.0	55	48	1.5	72	54	9808.0	0.62	0.56	0.45	33	223	0.56031
45.0	329.8	9	1.58	1.12	16	3679.8	0.83	0.80	0.74	13	9	25	33	NA	45.0	330.0	15.0	15.0	29	17	1.5	26	23	3691.0	0.83	0.80	0.74	19	306	0.28746
50.0	325.2	15	1.58	1.16	27	4050.2	0.81	0.77	0.70	22	9	33	87	NA	50.0	325.0	17.0	17.0	15	13	1.5	20	19	4039.0	0.81	0.77	0.70	14	269	0.99656
9.2	5819.9	3	1.00	1.10	2	1077.9	1.19	1.19	1.19	3	9	34	87	0.16	10.0	5819.7	6.4	10.1	14	6	1.0	6	5	1105.3	1.18	1.18	1.18	6	561	0.61873
7.7	539.3	13	1.58	1.15	18	880.3	1.26	1.26	1.26	22	9	68	80	NA	8.0	539.0	12.0	12.0	19	9	1.0	9	7	897.6	1.25	1.25	1.25	9	629	0.71833
22.0	5809.1	2	1.00	1.10	2	1962.7	1.01	1.01	1.01	2	10	23	67	0.20	21.0	5810.2	6.7	10.4	12	7	1.0	7	7	1952.9	1.01	1.01	1.01	7	522	0.13359
100.6	327.4	17	1.58	1.17	31	11335.4	0.59	0.53	0.42	19	11	39	100	0.18	119.0	327.0	21.0	21.0	72	54	1.5	81	59	13812.8	0.40	0.40	0.40	24	239	0.76011
36.6	338.2	16	1.58	1.17	29	3151.1	0.87	0.85	0.80	26	11	57	75	NA	37.0	338.0	15.0	15.0	14	11	1.5	17	16	3190.1	0.87	0.84	0.79	13	244	0.90003
9.3	5820.1	8	1.00	1.12	7	1055.4	1.20	1.20	1.20	8	11	2	47	1.99	9.0	5820.1	6.4	10.0	20	7	1.0	7	6	997.4	1.22	1.22	1.22	7	550	0.98360
16.6	358.6	4	1.58	1.10	7	1725.5	1.04	1.04	1.04	7	12	9	81	NA	16.0	359.0	10.0	10.0	13	7	1.5	11	11	1672.6	1.05	1.05	1.05	11	262	0.57833
91.5	335.1	11	1.58	1.14	20	9591.0	0.62	0.56	0.46	11	13	10	67	1.90	92.0	335.0	22.0	22.0	57	49	1.5	74	55	9660.8	0.62	0.56	0.45	34	322	0.03541
19.5	354.9	6	1.58	1.11	10	1659.1	1.05	1.05	1.05	11	14	8	70	1.40	20.0	355.0	14.0	14.0	10	9	1.5	13	13	1727.4	1.04	1.04	1.04	13	295	0.96338
26.3	5802.7	10	1.00	1.13	11	2280.7	0.96	0.95	0.94	11	14	6	53	0.53	27.0	5802.7	11.2	15.7	23	13	1.0	13	13	2296.9	0.96	0.95	0.93	12	568	0.55149
25.0	350.2	4	1.58	1.10	7	2310.2	0.96	0.95	0.93	6	15	12	80	NA	25.0	350.0	12.0	12.0	17	9	1.5	14	13	2299.0	0.96	0.95	0.93	13	264	0.60631
30.0	345.2	13	1.58	1.15	24	2658.2	0.92	0.90	0.87	21	15	10	87	NA	30.0	345.0	17.0	17.0	21	17	1.5	26	23	2647.0	0.92	0.90	0.87	21	265	0.98304
35.5	4139.2	21	1.58	1.20	40	4260.0	0.80	0.76	0.69	32	17	17	100	0.72	36.0	4139.0	16.7	20.5	75	56	1.0	56	44	4320.0	0.79	0.75	0.68	35	17	0.11863
10.9	363.6	11	1.58	1.14	20	1122.0	1.18	1.18	1.18	23	18	14	73	1.10	11.0	364.0	15.0	15.0	7	8	1.5	12	12	1156.9	1.17	1.17	1.17	14	286	0.83969
9.3	537.7	29	1.58	1.24	43	972.5	1.22	1.22	1.22	52	19	7	53	NA	9.0	538.0	14.0	14.0	45	18	1.0	18	13	955.2	1.23	1.23	1.23	16	635	0.34402
104.0	323.3	19	1.58	1.18	36	10256.1	0.61	0.55	0.44	22	19	30	100	0.20	104.0	323.0	22.0	22.0	53	47	1.5	71	53	10231.4	0.61	0.55	0.44	32	218	0.42221
106.5	320.1	9	1.58	1.12	16	10695.0	0.60	0.54	0.43	9	19	37	67	0.16	107.0	320.0	23.0	23.0	51	48	1.5	72	54	10764.8	0.60	0.54	0.43	32	229	0.78717
6.0	5823.0	25	1.00	1.22	23	742.2	1.32	1.32	1.32	30	19	23	73	0.23	7.0	5822.7	6.1	9.7	11	5	1.0	5	4	866.1	1.26	1.26	1.26	5	559	0.05419
40.0	299.7	7	1.08	1.11	8	4948.5	0.76	0.72	0.64	5	20	30	NA	0.20	40.0	299.7	14.9	14.9	39	20	1.0	20	19	4948.5	0.76	0.72	0.64	14	429	0.73395
28.5	310.7	25	1.08	1.22	33	3562.5	0.84	0.81	0.75	28	21	10	NA	0.48	29.0	310.4	14.5	14.5	52	20	1.0	20	19	3625.0	0.84	0.80	0.74	15	402	0.95077
6.0	561.0	22	1.58	1.20	31	720.0	1.33	1.33	1.33	42	22	13	80	NA	2.0	561.0	11.0	11.0	14	8	1.0	8	6	720.0	1.33	1.33	1.33	8	600	0.90799
28.1	5800.9	19	1.00	1.18	22	2406.3	0.95	0.93	0.91	21	23	7	NA	NA	29.0	5800.7	8.7	12.8	10	7	1.0	7	7	2434.1	0.94	0.93	0.91	6	569	0.90351
33.5	533.5	41	1.58	1.25	81	3614.4	0.84	0.80	0.74	68	24	13	100	NA	34.0	533.0	20.0	20.0	56	44	1.0	44	37	3643.2	0.84	0.80	0.74	31	609	0.44845
35.5	339.2	10	1.58	1.13	18	3068.9	0.88	0.85	0.81	15	25	16	87	NA	36.0	339.0	20.0	20.0	24	23	1.5	35	30	3120.5	0.88	0.85	0.80	26	249	0.72951
35.0	340.2	19	1.58	1.18	36	3006.2	0.88	0.86	0.82	31	26	8	53	NA	35.0	340.0	17.0	17.0	16	14	1.5	21	20	2995.0	0.89	0.86	0.82	17	266	0.64400
13.8	533.2	19	1.58	1.18	36	1231.7	1.15	1.15	1.15	41	30	5	30	NA	14.0	533.0	18.0	18.0	49	33	1.0	33	29	1243.2	1.14	1.14	1.14	33	637	0.24161
30.3	308.5	38	1.08	1.25	51	3780.0	0.83	0.79	0.73	42	33	17	NA	1.50	31.0	308.1	17.3	17.3	60	36	1.0	36	31	3865.5	0.82	0.78	0.72	26	415	0.50278
45.5	293.7	50	1.08	1.25	68	5606.0	0.73	0.68	0.60	50	35	16	NA	0.70	46.0	293.4	19.1	19.1	132	88	1.0	88	63	5629.6	0.73	0.68	0.60	46	410	0.30642
30.0	344.8	46	1.58	1.25	91	2635.8	0.92	0.90	0.87	84	38	16	100	NA	30.0	345.0	13.0	13.0	22	11	1.5	17	16	2647.0	0.92	0.90	0.87	14	304	0.17028
104.0	324.8	39	1.08	1.25	53	11296.3	0.59	0.53	0.42	31	42	16	73	2.40	103.0	325.0	23.0	23.0	57	53	1.5	80	58	11156.8	0.60	0.53	0.42	35	281	0.07290
39.9	334.9	10	1.58	1.13	18	3324.9	0.86	0.83	0.78	15	44	13	44	3.00	40.0	335.0	15.0	15.0	14	11	1.5	17	16	3343.0	0.86	0.83	0.77	13	259	0.63495
25.0	5806.1	26	1.00	1.23	32	2168.5	0.98	0.97	0.96	31	45	4.1	46	3.50	25.0	5806.2	10.9	15.4	22	14	1.0	14	14	2218.5	0.97	0.96	0.95	13	524	0.40886
21.4	5812.0	50	1.00	1.25	63	1942.1	1.01	1.01	1.01	63	47	20	40	3.52	20.0	5811.8	6.3	10.0	12	7	1.0	7	7	1893.8	1.02	1.02	1.02	7	506	0.22341
14.9	359.9	9	1.58	1.12	16	1584.9	1.07	1.07	1.07	17	48	15	69	4.00	15.0	360.0	9.0	9.0	13	6	1.5	9	9	1603.0	1.06	1.06	1.06	10	255	0.15810
86.5	342.3	40	1.08	1.25	54	10008.3	0.62	0.55	0.45	33	50	14	53	4.75	86.0	342.0	24.0	24.0	72	66	1.5	99	70	9905.6	0.62	0.55	0.45	43	278	0.68982
27.5	5803.0	19	1.00	1.18	22	2336.5	0.95	0.94	0.93	21	51	5.9	47	4.80	28.0	5802.7	13.5	18.4	30	20	1.0	20	19	2370.8	0.95	0.94	0.92	18	538	0.88051

														Control Group Data																
SPT Lower Depth	SPT Lower Elev.	SPT N	nergy Corr	Liner Corr	SPT N60	t. Eff. Stress (psf)	Cn R.D 0.8	Cn R.D 0.6	Cn R.D 0.4	SPT (60)	% ravel	% Fines	% Recov	D(50) (mm)	BPT Lower Depth	BPT Lower Elev	BP psi)	BP CORR (psi)	BPT N(B)	BPT (BC)	RIG FACT.	NBC INAL	BPT (60)	t. Eff. Stress (psf)	Cn R.D. 0.8	Cn R.D. 0.6	Cn R.D. 0.4	BPT (60)	Pair ID No.	Fixed Random Number
3.0	5826.0	29	1.00	1.24	27	396.9	1.57	1.57	1.57	43	51	13	60	5.03	4.0	5825.7	9.5	13.7	100	20	1.0	20	15	524.0	1.46	1.46	1.46	21	557	0.97551
15.6	5815.5	42	1.00	1.25	53	1543.9	1.08	1.08	1.08	56	53	7.9	40	6.00	16.0	5815.2	13.5	18.3	51	34	1.0	34	30	1621.9	1.06	1.06	1.06	32	519	0.37304
96.5	331.3	43	1.08	1.25	58	9768.7	0.62	0.56	0.45	36	55	14	100	6.50	99.0	331.0	20.0	20.0	44	34	1.5	51	41	10140.0	0.61	0.55	0.44	25	285	0.79902
62.5	517.5	43	1.08	1.25	58	6169.5	0.71	0.66	0.57	41	56	44	67	6.00	518.0	62.0	16.0	16.0	57	30	1.0	30	27	6133.2	0.71	0.66	0.57	18	128	0.79802
35.1	339.3	10	1.58	1.13	18	2744.8	0.91	0.89	0.85	16	57	11	40	7.00	36.0	339.0	22.0	22.0	30	30	1.5	45	37	2841.0	0.90	0.88	0.84	34	298	0.12010
11.5	5817.5	30	1.00	1.25	38	1243.8	1.14	1.14	1.14	43	59	5	40	9.50	12.0	5817.7	9.7	13.9	25	10	1.0	10	10	1246.5	1.14	1.14	1.14	12	563	0.80071
11.2	363.6	6	1.58	1.11	10	1327.3	1.12	1.12	1.12	12	61	14	50	8.00	11.0	364.0	12.0	12.0	9	7	1.5	10	10	1324.6	1.12	1.12	1.12	11	254	0.93562
40.7	539.3	36	1.08	1.25	49	4586.8	0.78	0.74	0.66	38	65	35	73	9.53	539.0	41.0	16.0	16.0	48	25	1.0	25	23	4608.6	0.78	0.73	0.66	17	119	0.92896
22.0	5807.0	39	1.00	1.25	49	1985.7	1.00	1.00	1.00	49	67	6	NA	NA	23.0	5806.7	9.1	13.2	12	8	1.0	8	8	2022.5	1.00	1.00	0.99	8	567	0.40757
30.1	344.4	7	1.58	1.11	12	2458.3	0.94	0.93	0.90	11	70	7	40	13.00	31.0	344.0	22.0	22.0	24	26	1.5	39	33	2548.9	0.93	0.91	0.89	31	288	0.91501
95.5	331.8	31	1.58	1.25	61	9630.5	0.62	0.56	0.46	38	72	14	60	22.00	95.0	332.0	22.0	22.0	60	52	1.5	78	57	9569.0	0.63	0.56	0.46	36	215	0.80049
29.8	5799.6	49	1.00	1.25	61	2454.1	0.94	0.93	0.90	58	100	0	7	24.90	30.0	5799.1	9.1	13.2	30	11	1.0	11	11	2430.4	0.94	0.93	0.91	10	556	0.73348

APPENDIX C

ANOVA RESULTS

The ANOVA results are presented along with the data grouped as described in section 3.2.3.

Anova: Single Factor
SPT N160 VALUES
SUMMARY

Groups	Count	Sum	Average	Variance
0 TO 20	91	2258.1	24.81431	373.645588
21 TO 35	40	1690.85	42.27128	607.626889
36 TO 50	22	828.526	37.66027	337.70213
51 TO 65	15	521.424	34.76159	128.388803
66+	20	624.129	31.20646	100.568737

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9704.5	4	2426.135	6.51712422	6.333E-05	2.42102
Within Groups	68126	183	372.2707			
Total	77830	187				

Anova: Single Factor
BPT N160 VALUES
SUMMARY

Groups	Count	Sum	Average	Variance
0 TO 20	91	2008.89	22.07566	182.716774
21 TO 35	40	991.669	24.79172	286.365547
36 TO 50	22	400.401	18.20002	100.986683
51 TO 65	15	355.651	23.71004	120.13435
66+	20	462.019	23.10096	112.987429

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	661.74	4	165.4344	0.90204355	0.4639529	2.42102
Within Groups	33562	183	183.3996			
Total	34224	187				

SPT (N1) 60

0 TO 20	21 TO 35	36 TO 50	51 TO 65	66+
12.79496	35.93761	40.0933	25.31521	13.81505
4.494617	15.4776	41.15404	38.69071	20.97695
33.58106	4.022006	26.82743	33.223	38.57142
7.264603	26.95974	12.02436	47.63461	41.80527
18.3588	11.96954	12.61622	29.08273	33.50458
2.55098	29.49458	16.30604	50.52372	23.57517
27.84169	89.12545	45.72593	37.33291	21.09863
54.82021	57.68939	42.71553	19.59421	31.94658
28.90426	13.77043	38.05426	31.18638	32.12265
14.89453	37.54463	41.47758	19.96869	35.46623
6.31245	62.26703	24.81769	26.03902	15.42418
31.65126	35.09464	66.32971	26.85474	55.98421
5.792217	39.04091	24.21047	38.10242	31.95816
15.89401	59.21647	89.96386	38.3539	41.21905
14.8029	61.30306	20.1923	59.52153	37.85758
22.53352	41.20409	41.30617		39.41876
27.27707	16.84846	34.34767		24.99578
35.04978	57.03529	56.56837		28.13856
42.44914	64.57653	53.10763		30.29534
26.42838	73.32623	23.93837		25.95506
17.08851	88.44986	31.58303		
14.908	84.40451	45.16599		
24.77477	68.65274			
14.39569	47.99677			
4.370112	18.2065			
8.473815	20.02325			
11.87704	39.07093			
12.47838	28.31897			
5.357285	67.98801			
5.410436	66.81871			
17.9605	39.35188			
10.49057	18.0353			
13.56106	75.46589			
25.94845	17.30369			
62.10961	20.88036			
58.15485	11.97099			
58.18072	75.19668			
31.61723	40.40142			
8.502739	11.63543			
19.29117	18.77561			
9.833153				
16.47165				
19.9105				
9.40353				
14.95271				
25.50344				
12.08554				
6.833245				
49.82419				
13.00292				
34.50355				
13.27756				
23.28328				
25.64818				
12.73548				
54.53733				
12.28279				
15.74367				
24.84				
48.58974				
93.90887				

BPT (N1) 60

0 TO 20	21 TO 35	36 TO 50	51 TO 65	66+
3.991531	11.75661	11.81936	27.49982	12.67542
6.875653	13.80592	17.11602	46.69572	17.06435
7.284662	14.30222	4.924211	10.20051	33.8184
8.82182	15.25889	11.32422	31.12664	14.69982
9.826686	3.156433	31.2547	15.81138	9.45198
12.83644	20.84059	4.677081	9.214903	35.96731
4.977002	46.40606	17.42804	31.62615	9.770598
16.53212	17.52684	37.05051	17.52495	9.737673
14.31589	14.93941	15.59088	34.15459	23.68527
13.70903	31.24569	3.931584	22.65153	27.70693
20.2811	6.321642	14.30029	31.20154	15.99011
23.98513	16.93704	21.97024	14.82158	29.32076
23.1026	19.8582	15.55304	33.92242	25.99196
27.9632	50.54889	24.89845	12.08846	36.31149
32.91145	23.87369	36.08967	17.1104	38.93986
30.77556	32.84273	13.2451		7.616872
31.40028	32.92123	15.29879		35.02928
34.92444	11.70435	29.01096		25.64321
35.55103	14.56218	8.578791		17.50804
36.34322	28.23293	23.0027		35.08986
56.56319	55.06968	10.6042		
29.44048	64.47273	32.73168		
3.492329	41.65649			
16.43189	10.50503			
9.842587	15.48147			
25.15723	8.287077			
23.73396	11.9546			
22.57962	15.95419			
29.91086	65.11849			
34.38433	50.69448			
27.61194	44.52306			
15.20368	24.0321			
17.75838	42.86299			
22.29245	7.282751			
29.26815	13.05551			
28.7217	15.92979			
57.21366	42.33509			
3.773172	7.374829			
7.775932	8.421832			
17.04129	19.61494			
22.26057				
8.219631				
17.85048				
27.37714				
33.51097				
8.163822				
10.4028				
11.98516				
9.790546				
14.00519				
16.16918				
32.01718				
32.66898				
61.19293				
12.68635				
17.24327				
18.95826				
10.82784				
7.926258				
16.79944				
22.41921				

13.50321				
48.41114				
20.62944				
15.11129				
22.034				
15.64062				
94.94359				
59.82761				
4.681347				
7.534957				
5.241946				
12.47787				
22.72188				
63.51874				
40.99465				
15.2026				
14.94455				
16.76563				
22.76129				
35.1147				
67.61401				
45.68782				
29.83995				
28.03944				
12.08367				
11.11246				
14.2138				
62.33036				
15.75094				
23.55022				

18.67303				
32.33006				
6.174323				
11.19692				
14.71963				
17.24468				
53.1016				
49.09126				
35.76453				
6.315538				
10.67093				
27.92177				
24.75443				
49.40319				
48.08661				
16.84178				
12.43304				
15.98738				
18.64812				
21.62218				
48.35597				
50.47356				
7.227333				
11.87544				
12.54234				
10.4546				
14.18393				
24.5839				
19.40038				
31.72579				

APPENDIX D

PAIRED *t*-TEST RESULTS

The paired *t*-test results for the test and control group are presented.

TEST DATA

t-Test: Paired Two Sample for Means
0% gravel (N1)60 values

	Variable	Variable 2
Mean	21.1679	21.9278
Variance	177.61	178.917
Observations	22	22
Pearson Correlation	0.17546	
Hypothesized Mean D	0	
df	21	
t Stat	-0.2079	
P(T<=t) one-tail	0.41865	
t Critical one-tail	1.72074	
P(T<=t) two-tail	0.83731	
t Critical two-tail	2.07961	

t-Test: Paired Two Sample for Means
0-5% gravel (N1)60 values

	Variable	Variable 2
Mean	20.9848	21.8559
Variance	218.321	175.317
Observations	54	54
Pearson Correlation	0.21832	
Hypothesized Mean D	0	
df	53	
t Stat	-0.3646	
P(T<=t) one-tail	0.35842	
t Critical one-tail	1.67412	
P(T<=t) two-tail	0.71685	
t Critical two-tail	2.00575	

t-Test: Paired Two Sample for Means
0-20% gravel (N1)60 values

	Variable	Variable 2
Mean	24.8143	22.0757
Variance	373.646	182.717
Observations	91	91
Pearson Correlation	0.41908	
Hypothesized Mean D	0	
df	90	
t Stat	1.42236	
P(T<=t) one-tail	0.07919	
t Critical one-tail	1.66196	
P(T<=t) two-tail	0.15838	
t Critical two-tail	1.98667	

t-Test: Paired Two Sample for Means
21-35% gravel (N1)60 values

	Variable	Variable 2
Mean	42.2713	24.7917
Variance	607.627	286.366
Observations	40	40
Pearson Correlation	0.67529	
Hypothesized Mean D	0	
df	39	
t Stat	6.07992	
P(T<=t) one-tail	2E-07	
t Critical one-tail	1.68488	
P(T<=t) two-tail	4E-07	
t Critical two-tail	2.02269	

t-Test: Paired Two Sample for Means
36-50% gravel (N1)60 values

	Variable	Variable 2
Mean	37.6603	18.2
Variance	337.702	100.987
Observations	22	22
Pearson Correlation	0.17134	
Hypothesized Mean D	0	
df	21	
t Stat	4.71096	
P(T<=t) one-tail	5.9E-05	
t Critical one-tail	1.72074	
P(T<=t) two-tail	0.00012	
t Critical two-tail	2.07961	

t-Test: Paired Two Sample for Means
51-65% gravel (N1)60 values

	Variable	Variable 2
Mean	34.7616	23.71
Variance	128.389	120.134
Observations	15	15
Pearson Correlation	-0.0497	
Hypothesized Mean D	0	
df	14	
t Stat	2.65004	
P(T<=t) one-tail	0.00951	
t Critical one-tail	1.76131	
P(T<=t) two-tail	0.01903	
t Critical two-tail	2.14479	

t-Test: Paired Two Sample for Means
26-90% gravel (N1)6values

	Variable	Variable 2
Mean	38.4246	23.2241
Variance	350.788	189.542
Observations	87	87
Pearson Correlation	0.44691	
Hypothesized Mean D	0	
df	86	
t Stat	8.05445	
P(T<=t) one-tail	2.1E-12	
t Critical one-tail	1.66277	
P(T<=t) two-tail	4.1E-12	
t Critical two-tail	1.98793	

t-Test: Paired Two Sample for Means
66+% gravel (N1)60 values

	Variable	Variable 2
Mean	31.2065	23.101
Variance	100.569	112.987
Observations	20	20
Pearson Correlation	0.24077	
Hypothesized Mean D	0	
df	19	
t Stat	2.846	
P(T<=t) one-tail	0.00517	
t Critical one-tail	1.72913	
P(T<=t) two-tail	0.01033	
t Critical two-tail	2.09302	

t-Test: Paired Two Sample for Means
0-25% gravel (N1)60 values

	Variable	ariable 2
Mean	25.5455	21.7636
Variance	399.095	178.236
Observations	101	101
Pearson Correlation	0.44376	
Hypothesized Mean D	0	
df	100	
t Stat	2.05936	
P(T<=t) one-tail	0.02103	
t Critical one-tail	1.66023	
P(T<=t) two-tail	0.04206	
t Critical two-tail	1.98397	

t-Test: Paired Two Sample for Means
0-30% gravel (N1)60 values

	Variable	ariable 2
Mean	29.6093	22.7036
Variance	495.301	209.619
Observations	120	120
Pearson Correlation	0.48498	
Hypothesized Mean D	0	
df	119	
t Stat	3.819	
P(T<=t) one-tail	0.00011	
t Critical one-tail	1.65776	
P(T<=t) two-tail	0.00021	
t Critical two-tail	1.9801	

TEST DATA WITH 26%+ GRAVEL

t-Test: Paired Two Sample for Means
N(POWER) vs SPT N60

	Variable	ariable 2
Mean	44.1141	40.2934
Variance	439.551	105.849
Observations	87	87
Pearson Correlation	0.50228	
Hypothesized Mean D	0	
df	86	
t Stat	1.96559	
P(T<=t) one-tail	0.02629	
t Critical one-tail	1.66277	
P(T<=t) two-tail	0.05257	
t Critical two-tail	1.98793	

t-Test: Paired Two Sample for Means
N1(POWER) vs SPT N160

	Variable	ariable 2
Mean	38.4246	34.666
Variance	350.788	76.2979
Observations	87	87
Pearson Correlation	0.49814	
Hypothesized Mean D	0	
df	86	
t Stat	2.15723	
P(T<=t) one-tail	0.01689	
t Critical one-tail	1.66277	
P(T<=t) two-tail	0.03378	
t Critical two-tail	1.98793	

t-Test: Paired Two Sample for Means
N(LOG) vs SPT N60

	Variable	ariable 2
Mean	44.1141	44.1151
Variance	439.551	107.028
Observations	87	87
Pearson Correlation	0.49344	
Hypothesized Mean D	0	
df	86	
t Stat	-0.0005	
P(T<=t) one-tail	0.49979	
t Critical one-tail	1.66277	
P(T<=t) two-tail	0.99959	
t Critical two-tail	1.98793	

t-Test: Paired Two Sample for Means
N1(LOG) vs SPT N160

	Variable	ariable 2
Mean	38.4246	37.9999
Variance	350.788	86.1522
Observations	87	87
Pearson Correlation	0.47583	
Hypothesized Mean D	0	
df	86	
t Stat	0.24042	
P(T<=t) one-tail	0.40529	
t Critical one-tail	1.66277	
P(T<=t) two-tail	0.81057	
t Critical two-tail	1.98793	

t-Test: Paired Two Sample for Means
N(LINE) vs SPT N60

	Variable	ariable 2
Mean	44.1141	33.4151
Variance	439.551	621.449
Observations	87	87
Pearson Correlation	0.49717	
Hypothesized Mean D	0	
df	86	
t Stat	4.2892	
P(T<=t) one-tail	2.3E-05	
t Critical one-tail	1.66277	
P(T<=t) two-tail	4.7E-05	
t Critical two-tail	1.98793	

t-Test: Paired Two Sample for Means
N1(LINE) vs SPT N160

	Variable	ariable 2
Mean	38.4246	27.1537
Variance	350.788	357.543
Observations	87	87
Pearson Correlation	0.43502	
Hypothesized Mean D	0	
df	86	
t Stat	5.25506	
P(T<=t) one-tail	5.3E-07	
t Critical one-tail	1.66277	
P(T<=t) two-tail	1.1E-06	
t Critical two-tail	1.98793	

t-Test: Paired Two Sample for Means
N(QUAD) vs SPT N60

	Variable	ariable 2
Mean	44.1141	40.2578
Variance	439.551	324.631
Observations	87	87
Pearson Correlation	0.44627	
Hypothesized Mean D	0	
df	86	
t Stat	1.7406	
P(T<=t) one-tail	0.04266	
t Critical one-tail	1.66277	
P(T<=t) two-tail	0.08533	
t Critical two-tail	1.98793	

t-Test: Paired Two Sample for Means
N1(QUAD) vs SPT N160

	Variable	ariable 2
Mean	38.4246	33.7221
Variance	350.788	208.922
Observations	87	87
Pearson Correlation	0.41855	
Hypothesized Mean D	0	
df	86	
t Stat	2.40325	
P(T<=t) one-tail	0.0092	
t Critical one-tail	1.66277	
P(T<=t) two-tail	0.0184	
t Critical two-tail	1.98793	

CONTROL GROUP

t-Test: Paired Two Sample for Means
N1(60) - all control data
t-Test: Paired Two Sample for Means

	Variable	ariable 2
Mean	25.1958	20.8101
Variance	303.83	114.916
Observations	72	72
Pearson Correlation	0.12028	
Hypothesized Mean D	0	
df	71	
t Stat	1.9248	
P(T<=t) one-tail	0.02913	
t Critical one-tail	1.6666	
P(T<=t) two-tail	0.05826	
t Critical two-tail	1.99394	

t-Test: Paired Two Sample for Means
Log and Harder Correlated - (N1)60 -
t-Test: Paired Two Sample for Means

	Variable	ariable 2
Mean	25.1958	26.1065
Variance	303.83	163.063
Observations	72	72
Pearson Correlation	0.40907	
Hypothesized Mean D	0	
df	71	
t Stat	-0.4579	
P(T<=t) one-tail	0.32421	
t Critical one-tail	1.6666	
P(T<=t) two-tail	0.64843	
t Critical two-tail	1.99394	

t-Test: Paired Two Sample for Means
Log and Harder Correlated - (N1)60 - 26%+ 1
t-Test: Paired Two Sample for Means

	Variable	ariable 2
Mean	37.5066	37.9529
Variance	307.838	66.5414
Observations	24	24
Pearson Correlation	-0.0853	
Hypothesized Mean D	0	
df	23	
t Stat	-0.1095	
P(T<=t) one-tail	0.45688	
t Critical one-tail	1.71387	
P(T<=t) two-tail	0.91377	
t Critical two-tail	2.06865	

t-Test: Paired Two Sample for Means
(N1)60 26%+ Harder Correlated - cont
t-Test: Paired Two Sample for Means

	Variable	ariable 2
Mean	37.5066	22.0639
Variance	307.838	135.114
Observations	24	24
Pearson Correlation	-0.097	
Hypothesized Mean D	0	
df	23	
t Stat	3.44402	
P(T<=t) one-tail	0.0011	
t Critical one-tail	1.71387	
P(T<=t) two-tail	0.00221	
t Critical two-tail	2.06865	

t-Test: Paired Two Sample for Means
Harder Correlated - (N1)60 control data 0-25%
t-Test: Paired Two Sample for Means

	Variable	ariable 2
Mean	19.0404	20.1832
Variance	192.247	106.273
Observations	48	48
Pearson Correlation	0.22258	
Hypothesized Mean D	0	
df	47	
t Stat	-0.5166	
P(T<=t) one-tail	0.30392	
t Critical one-tail	1.67793	
P(T<=t) two-tail	0.60784	
t Critical two-tail	2.01174	