EVALUATION OF CORRELATIONS BETWEEN SPT N AND UNDRAINED SHEAR STRENGTH FOR FINE GRAINED SOILS OF SRI LANKAN GEOLOGICAL CONDITIONS

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Degree of Master of Engineering

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Thesis submitted in partial fulfillment of the requirements for the degree Master of Engineering in Foundation Engineering and Earth Retaining Systems

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Statement of Authentication

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Abstract

Undrained shear strength is one of the essential parameters in most of the applications of geotechnical engineering. Unconsolidated undrained (UU) triaxial test is the most commonly practiced method of determining the undrained shear strength which takes a considerable time and effort to produce its results, since the sampling stage. Such correlations seldom exist pertinent to Sri Lankan soils. Hence, it is important to have reliable correlations between easily executable, commonly used test results and undrained shear strength of Sri Lankan soils to easily and promptly predict the soil structure interaction phenomenon, especially in local geotechnical engineering applications.

Thus, in this study, an attempt has been made to correlate the standard penetration test (SPT) with experimentally determined unconsolidated undrained triaxial test parameters, and the undrained shear strength estimated from the field vane shear test data. This analysis consists of three main stages, namely analysis of the available correlations, analysis of the available data set based on the soil and sampling properties to develop a correlation and the analysis on a set of reliable data with a defined deviation factor.

A correlation between SPT N_{60} and undrained shear strength has been proposed for Sri Lankan silty soils. Further, possible analysis methods for developing correlations for other different soil types have also been addressed. In addition, existing drawbacks and difficulties associated with developing such correlations related to Sri Lankan context are also described.

***Key words**: Undrained Shear Strength, Standard Penetration Test, Fine grained Soils, Correlations, Sri Lanka*

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01. INTRODUCTION

1.1 Background

Continuous growth of the construction field parallel with the rapid economic growth, industrialization and urban development have created a massive demand for lands especially in suburbs of major cities in the entire world. Most of the lands with ideal subsurface conditions for large scale constructions have already been used causing an exponential increase of value of the limited unused lands over the past few decades. Considering the above facts, many alternatives have been considered by the experts to improve the weak subsurface conditions to cater for the superstructure loads. In such situations, design of suitable ground improvement methodologies necessarily involves quite a comprehensive review of the entire subsoil conditions. Such studies require costly, sophisticated as well as time consuming procedures which might not be the healthiest approach in terms of project budget.

As a result of that, the requirement of having comprehensive and accurate data on subsurface condition has become more important than ever for a safe, and cost-effective option. Further, it helps to deliver more technically sound and cost effective geotechnical designs while confronting unfavorable ground conditions such as, weak and highly compressible thick soil layers, high ground water table, highly variable soil profiles. Complex architectural designs, massive structural loads which sometimes involve dynamic components and tight safety factors, also play a vital impact on the geotechnical design. This emphasize the importance of thorough geotechnical study that includes geotechnical investigation, interpretation, parameter identification and geotechnical designing to match up with the design requirements and limitations in a cost effective manner.

1.2 Role of the Correlations in Geotechnical Engineering

Strength parameters of subsurface soil layers play a key role in determining bearing capacities, loading rates, settlements, stability of slopes or cuts in civil engineering designing works of buildings, dams, earth fills, highways and many more.

A combination of in-situ testing and laboratory testing of samples collected at the time of site investigation is considered as the ideal way for determining design parameters in geotechnical studies. At times, it becomes impossible to collect subsurface samples at required quantities and conditions, (especially in collecting undisturbed samples for laboratory testing due to many constrains such as site condition and facilities, type of equipment used, skills of the investigation crew and etc. In such occasions, all the decision making have to be done based on the in-situ test results obtained.

In addition, important laboratory tests like consolidated undrained, consolidated drained, unconsolidated undrained triaxial tests, oedometer consolidation tests and permeability tests consume longer time periods to give a result and sometimes needs to repeat the tests as well. Further, the time period required is also depend on the number of samples to be tested and the frequency of testing. On the other hand, the need of highly sensitive and expensive equipment and instruments, skill requirements of the testing staff, high maintenance cost of the instruments make the above tests more and more expensive.

But when it comes to the execution of the project with tight time schedules, all parties including the client, the designer and the contractor expect to get the geotechnical study completed with the shortest possible time with the minimum possible cost. In such cases the correlations become really handy specially in the preliminary studies where the soil strength parameters can be determined with basic results and data such as standard penetration test N (SPT N), field vane shear test (FVST) results, index properties, grain size distribution, classification, sampling depth, over burden. This will definitely reduce the time and cost of the initial stage and would certainly give a clear picture of what to expect and to perform in the secondary or detailed stage.

Further, these correlations can be used beyond the estimation of soil parameters for preliminary studies. They can be used for the comparison already available laboratory test results against the field tests, and to determine soil parameters to use for designing works. These approaches give reliable results, when use with accurate data, good judgment, previous experiences and set of reliable correlations.

1.3 Importance of having Reliable Correlations

Referring a chart or a correlation based on the available in-situ and laboratory test results is the general practice followed to determine the unavailable parameters required for designs. Though this sounds simple, this has to be done by an expert who has a sound knowledge on the behavior and properties of soil of considered and the applicability of the correlation for that specific soil type. Failure to fulfil any of the above could mislead the complete design and ended up with a catastrophe.

Thus, having an accurate, reliable correlation sets developed and verified for the considered geological formations (i.e. residual, colluvium, alluvial, aeoline and lacustrine) could be really useful to avoid foresaid constrains and reduce the time and cost spend over the geotechnical studies.

1.4 In-situ and Laboratory Tests

There are number of correlations have been reported in the literature which link undrained shear strength determined using in situ tests and laboratory tests. In this research a few of those correlations have been studied to investigate their applicability to local soils, considering the factors such as local availability of relevant data, cost, simplicity and dime consumption.

Standard penetration test (SPT) is the most widely used in-situ test performed to investigate subsurface conditions in both local and international contexts for decades. There are many correlations developed between SPT N value and undrained shear strength of fine grained soils by previous researchers (Terzaghi & Peck 1967, Stroud 1974, Stroud & Butler 1975, Sowers 1979, Hara et al 1974, Sivikaya & Togrol 2007, Décourt 1990 and etc) are analyzed here for local data sets.

Field vane shear test (FVST) is another reasonably popular, less time consuming & economical subsurface investigation test used to determine undrained cohesion of very soft to soft, fine grained deposits. Available test results of FVST also are used here for the establishment of correlations between SPT N and undrained shear strength of fine grained soils encountered in Sri Lanka.

In addition, basic soil properties derived from soil classification tests (i.e. Atterberg limits (index properties, particle size distribution (sieve and hydrometer analysis) and other available information pertinent to the soil sample such as sampling depth, overburden pressure, soil texture are also accounted for when developing correlations between the SPT N value and undrained shear strength of local soils.

1.5 Problem Statement

As discussed in the previous sections, having reliable, accurate and proven indirect methods to estimate undrained shear strength of local fine grained soils using readily available data would provide a definite advantage in foundation and geotechnical designing works. Availability of such correlations may simplify the preliminary design stage of the project, will reduce the cost to be incurred and time consumption for early planning, lessen the amount of new information to be collected and can even be used for final design purposes based on the degree of accuracy.

Having said that, there are a lot of grey areas in the developed correlations still to be sorted out.

- Lack of statistical analysis on the correlations,
- Overlooking the geographical variations with analysis limited to certain regions,
- Lack of clear defining of field SPT N and corrected SPT N values in correlations and standards followed in both in-situ and laboratory tests,
- Confusions on terms and wording such as unconfined compressive strength and undrained shear strength (Reid & Taylor, 2010) can be considered as some of the main concerns of them.

Further, British standard (2010) states that "if an empirical relationship is used in the analysis, it shall be clearly established that it is relevant for the prevailing ground condition". Which elaborates the high risk of applying the numerous correlations available to estimate the unknown parameters of soils defined for various foreign soil types geological conditions.

It is important to notice that no detailed studies have been conducted up to date to scrutinize the reliability and accuracy of the available correlations developed to estimate undrained shear strength of fine grained soils for Sri Lankan geological conditions. The inherent geological formation, associated mineralogy, weathering pattern, degree of decomposition and etc. of Sri Lankan soils can differ from the soils of which the properties were considered in developing those original correlations.

Hence, it is essential to verify these available derived correlations for regional foreign conditions, which may not applicable for the local conditions or may needed to be modified accordingly.

1.6 Scope of the Research

The scope of this research is to present a reliable and verified correlation between SPT results and undrained shear strength, considering the impact of index properties and other basic property tests for fine grained soils of Sri Lankan geological conditions. In view of that the available pertinent correlations will be studied in detail with incorporating available local field and laboratory data. Those correlations will then be modified to enhance the accuracy to make more reliable predictions with regard to local soils. Possibility of developing new correlations will also be investigated depending on the requirements.

1.7 Objectives

The main objectives of this research are to

- Carry out an extensive literature survey to find the available correlations for standard penetration tests results and undrained shear strength of fine grained soils.
- Collecting and analyzing the available local field and laboratory tests results against the aforesaid, available correlations and check their validity for Sri Lankan geological conditions
- If it deviates from the available correlations, new accurate or conservative correlations to be defined under this.

02. APPRAISAL OF STUDIES ON CORRELATIONS BETWEEN STANDARD PENETRATION TEST AND UNDRAINED SHEAR STRENGTH OF FINE GRAINED SOILS.

2.1 Introduction

An extensive literature review on the study area is presented under this chapter. Formation of soil, standard penetration test and available correlations for undrained shear strength of fine grained soils developed against the respective SPT N results, index properties and other basic laboratory test results are covered here.

2.2 Fine Grained Soils

2.2.1 Formation of Soil

Formation of soil is a direct output of the disintegration process of rock / mineral in to smaller particles by contacting with either water, air or living organisms, called weathering. The occurrence of weathering can be either physically, chemically or biologically. (Efretuei, 2016)

Physical Weathering – In here, the breaking down process of rock particle occurs without any changes to its molecular structure includes to this category, where water and air acts as the agents of physical weathering. Heavy down fall of rain, windblown or water flow across the rock surface, can facilitate the disintegration of rock which eventually becomes soil.

Chemical Weathering – In here, weathering occurs with changes of mineral composition due to the chemical reactions within rocks such as hydration (dissolution of rock mineral due to the reactions of hydrogen ions with metallic ions in rock materials), carbonation (carbonic acid forms by dissolving carbon dioxide in air and living organisms with water to react with rock material), oxidation (oxygen from air reacts with the rock material to form ion oxides.

Biological Weathering – In here, the biological organisms facilitate the disintegration of rock. Trees, animals and microorganisms play a major role in this process.

Further, the factor such as climate, topography, parental rock, time and living organism are directly effects to the soil formation process. (Efretuei, 2016)

2.2.2 Soil Categories

Soil deposits can be subdivided in to two broad categories as residual soil and transported soil based on their process responsible for the formation. The type of soil available at a certain location depends on the global position, geologic history, climate, and topography. (McCarthy, 2014)

Residual Soil – In here, soil forms with the weathered rock at the location of origin. residual soils consist with a wide size range and the composition depend on the degree of weathering.

Transported Soil – In here, soil forms with materials have been moved from the place of origin. This material movement could be caused by one or a combination of many methods given below. gravity transported (Colluvial), water transported (Alluvial), wind transported (Aeolian) and glacier transported (Glacial)

In Sri Lanka, most of the soil found belongs to residual soil category while alluvial deposits are mostly found in flood plains and along the valleys also some colluvial deposits in central part of the hill area and little aeolian deposits.

2.2.3 Classification of Soils

Several soil classifications methods / standards are practiced in the fields of geotechnical and civil engineering and based on the requirement and availability of required testing facilities the most suitable and available method / standard is utilized.

The classification proposed by the American society of testing and materials (ASTM), subdivided the soils in to two main categories as coarse grained soils and fine grained soils. Soils passing through 75 µm (No 200) sieve belong to fine grained category and retains fell in to coarse grained soils. Further, based on the grain sizes the coarse grained soils are further subdivided in to categories as sand, gravel, cobbles and boulders while fine grained soils are subdivided in to two categories as silts and clays based on their plasticity. (ASTM D2487)

Hence the classification of fine grained soils (soils passing through No 200 sieve) is done based on the Atterberg limit, (liquid limit and plasticity Index). In here, fine grained soils with liquid limit above 50% is called as high plastic material and fined grained soils with liquid limit equal or less than 50% is called as low plastic material. Also the positioning of the test results on the plasticity chart (shown in *Figure 2-1*) defines whether the soil is a clay (above the A line) or a silt (below the A line). Accordingly, there are four categories as high plastic clay (CH / fat clay), low plastic clay (CL / lean clay), elastic silt (MH) and silt (MH) are used for the classification of fine grained soils.

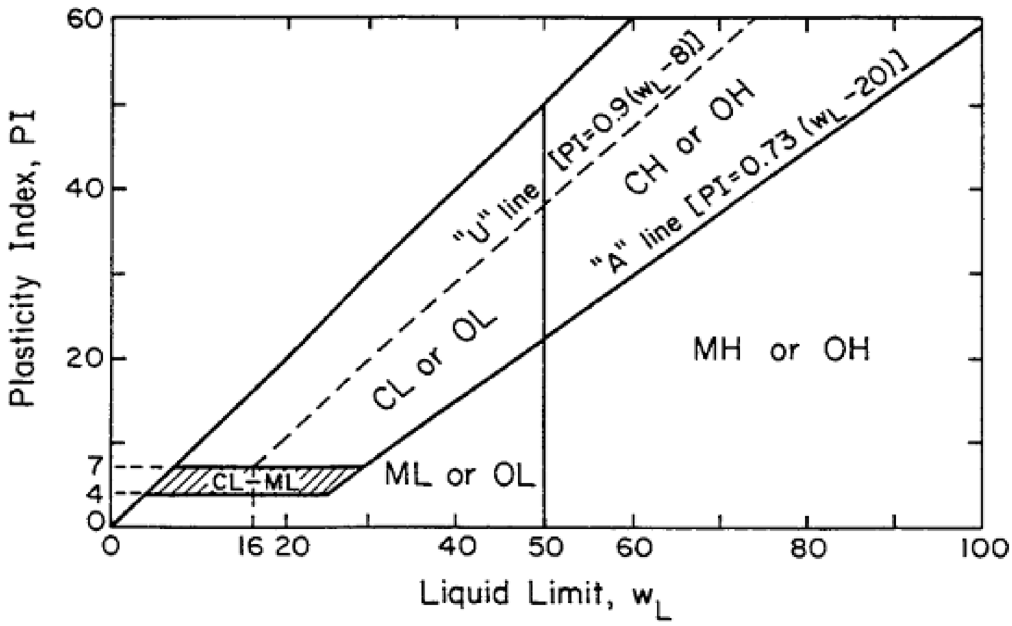

Figure 2-1: Plasticity Chart (USCS Classification),
Source: ASTM

2.3 Shear Strength

The shear strength of a soil mass can be defined as the resistance per unit area that can afford by a soil mass against its failure, can be defined as the shear strength, which generally analyzed in two criteria as drained shear strength and undrained shear strength. The rate of loading and the soil type (permeability of soil) mainly decides the what criteria to be used for the analysis.

Further the drained shear strength can be described as the strength of a soil mass that there when the loading is done slowly enough to (Duncan, 2014)

2.3.1 Undrained Strength

The undrained shear strength of a soil mass can be defined as the mobilized shearing resistance generates prior to any dissipation of shearing induced pore water pressure takes place. (Terzaghi, 1948). Undrained shear strength often comes across with construction problems relate to fine grained soils which is referred as undrained case as well as short term case (Louis, 2013)

2.4 Standard Penetration Test (SPT)

The SPT is the most popular and widely used, in-situ test in geotechnical related soil investigation works. It is said that SPT is used in more than 90% of boring in preliminary investigation stage (Mori, 1979). Simplicity, low cost, applicability on many soil conditions and possibility of acquiring samples can be identified as the main reasons for its popularity. General arrangement for SPT is shown in *Figure 2-1*.

Even though SPT was initially introduced and developed for determining static and dynamic properties of coarse grained soils with its ability to be performed on a wide range of soils from soft to hard clay and loose to dense sand, SPT became popular on studying fine grained soils as well. Hence many correlations were developed relates to SPT and soil parameters on both coarse and fine grained soils even with no general agreement on the use of SPT values on cohesive soils" (British standard, 2007)

Variations of the SPT results were observed with time and questions were aroused on the validity of the SPT and results obtained by using the correlations relates to SPT as well as on the correlations (Clayton, 1995). Several factors such as energy correction, methods of drilling, instruments and accessories, their dimensions, bore size, procedures and ect, were identified as the influencing factors of the validity of test (Schmertmann and Palacios, 1979). Considering above, the standardization of SPT test was done and a number of coefficients, factors and equations were developed to address the issues on the validity of the SPT.

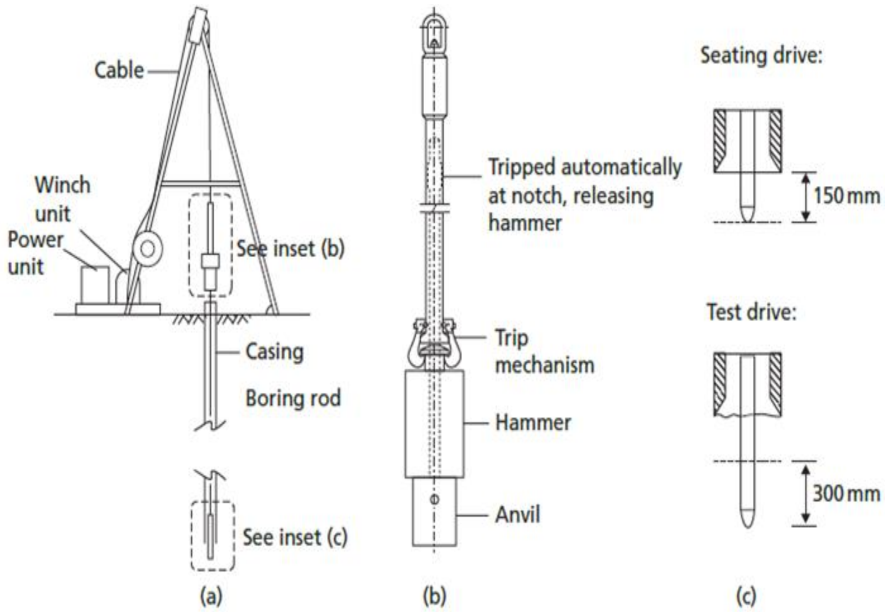

Figure 1-2: The SPT Test: (a) General Arrangement, (b) UK Standard Hammer System, (c) Test Procedure
Source: Craig (1974)

2.4.1 SPT Hammer Types

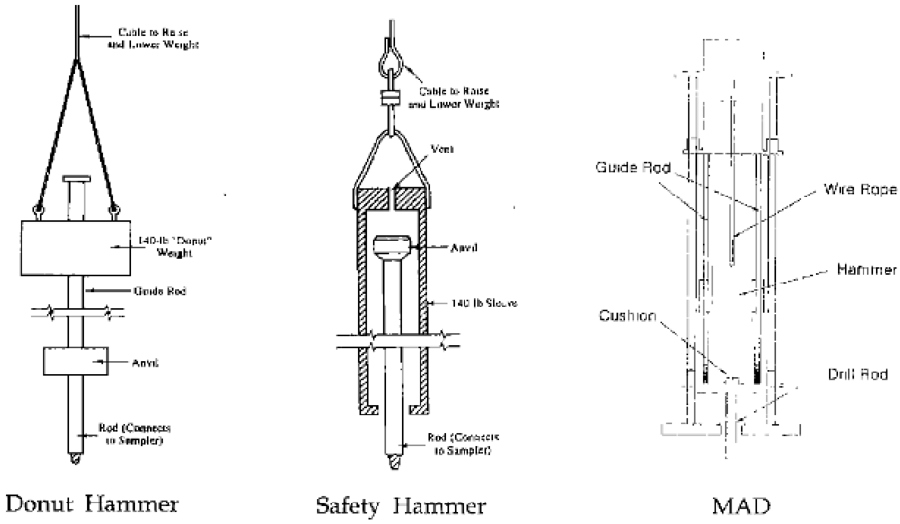

Figure 2-3: Types of SPT Hammers.
Source: Shin-Whan (2000)

There are several SPT hammer types (please refer the *Figure 2-3*) are used for geotechnical investigation works such as old standard, pin weight, Donut and safety hammer which are further sub divided as per their different hammer drop systems which can be identified as rope cathead, trip, semi-automatic and automatic (An, Shin-Whan, 2000).

Further based on the country, hammer type and their drop system the energy ratio varies between 45 to 100 as tabulated in the *Table 2-1*. (Bowles, 1997).

Table 2-1: Average Energy Ratio based on SPT Hammer and Drop Type.

Hammer for η_1					Remarks
	Average energy ratio E_r				
	Donut		Safety		
Country	R-P	Trip	R-P	Trip/Auto	R-P = Rope-pulley or cathead $\eta_1 = \mathbf{E}_r/\mathbf{E}_{rb} = E_r/70$ For U.S. trip/auto $w/\mathbf{E}_r = 80$ $\eta_1 = 80/70 = 1.14$
United States/ North America	45	—	70–80	80–100	
Japan	67	78	—	—	
United Kingdom	—	—	50	60	
China	50	60	—	—	

Source : Bowles (1997)

2.5 SPT related correlations to determine Undrained Shear Strength

2.5.1 Relationship proposed by Strouds 1974

The correlation proposed by Strouds (1974) can be considered as one of the most popular relationship of SPT N and C_u (Balachandran et al, 2017). After recognizing the requirement of mass strength of the ground which considers the weakening effects of the discontinuities for an engineering design, Stroud proposed the said simple correlation between mass undrained shear strength, C_u and SPT N value in his paper "The standard penetration test in insensitive clays and soft rocks", (1974).

$$C_u = f_1 \,.\, N_{60} \qquad (\textit{Equation 1})$$

where f_1 varies with the plasticity index, PI.

This relationship was presented based on a close relationship observed of SPT N values and mass undrained shear strength values on London clay obtained by Marsland (1971,1972) using deep in-situ plate loading tests in thirteen sites. A set of graphs including above *(Figure 2-4)* data and data from thirty-one other sites in United Kingdom of undrained shear strength, SPT N and depth was presented and these revealed the inversely proportional relationship between the Plasticity Index *(Figure 2-5)* and f_1 values were defined based on the Plasticity Index of the soils as

$$C_u = 4.2 \,.\, N_{60} \qquad \text{for PI>30} \qquad (\textit{Equation 2})$$

$$C_u = 4 - 5 \,.\, N_{60} \qquad \text{for 20<PI<30} \qquad (\textit{Equation 3})$$

$$C_u = 6 - 7 \,.\, N_{60} \qquad \text{for PI<20.} \qquad (\textit{Equation 4})$$

(Strouds, 1974)

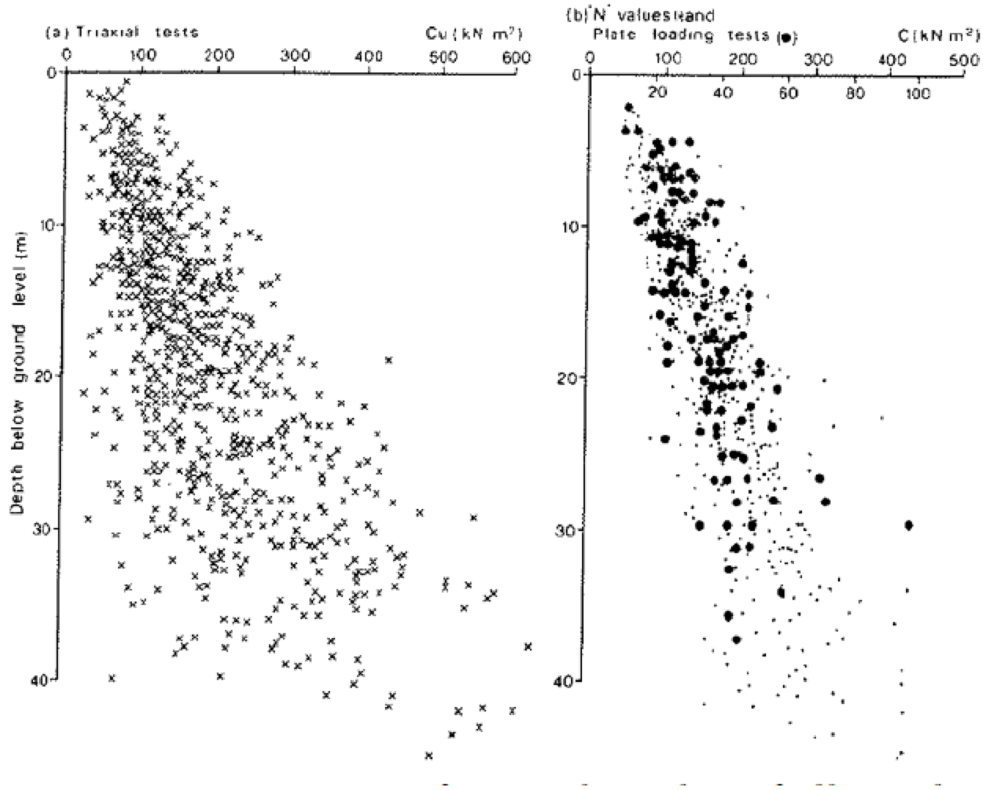

Figure 2-4: Comparison of London clay, Graph 1: undrained triaxial shear strength results against depth and Graph 2: all N values with all and with mass shear strength estimated from deep loading testing against depth, after Stroud (1974)
Source: White et al (2019)

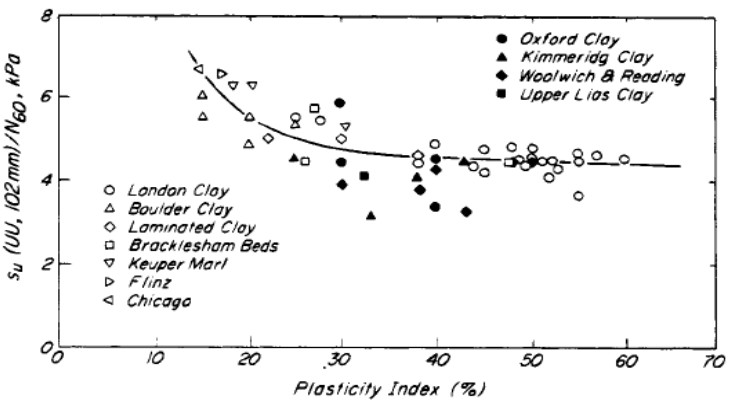

Figure 2-5: Relationship between plasticity index and ratio of undrained shear strength to SPT N_{60} for several clay types.
Source: Stroud (1974)

Further studies were carried on by Stroud and Butler, (1975) f_1 values were plotted against the PI of glacial depos-its, *(Figure 2-5)* insensitive clays and soft rocks and the specified f_1 values were modified with respect to plasticity limit as C_U (kPa) = 4.5 N for PI>30% and C_U (kPa) = 8N for low plasticity clay (PI =15%). Considerable scattering of C_u/SPT N values can be observed in test data with close to 10% higher and 20% lower than the estimated result (Bentley, 2016).

2.5.2 Relationship proposed by Terzaghi & Peck 1967

After many attempts to find a general relationship between C_u and SPT N_{60} for all clay types, one of the most frequently used equation was revealed by Terzaghi and Peck, 1967. (Browns & Hettiarachchi, 2008)

$$C_u = 0.06\, Pa\, .\, N_{60} \qquad (\textit{Equation 5})$$

Where, P_a : atmospheric pressure.

This relationship was developed by using several unconfined compression (UC) test results and the proposed correlation is given as follows as well (Balachandran et al, 2017).

$$C_u = 6.25\, .\, N_{field} \qquad (\textit{Equation 6})$$

Table 2-2: Approximated values for undrained shear strength for fine grained soils with respect to SPT N and consistency.

SPT-N	Consistency	Undrained shear strength S_u (kPa)		
		Tschebotarioff (1973)	Parcher and Means (1968)	Terzaghi and Peck (1967)
<2	Very soft	15	<12	<12.5
2~4	Soft	15~30	12~25	12.5~25
4~8	Medium	30~60	25~50	25~50
8~15	Stiff	60~120	50~100	50~100
15~30	Very stiff	120	100~200	100~200
>30	Hard	>225	>200	>200

Source : Sivrikaya & Togrol (2006)

Further, approximated values of unconfined shear strength for fine grained soils based on SPT N value and consistency were tabulated as given in the *Table 2-2*, with the values proposed by Tschebotarioff (1973), Parcher and Means (1968) which are very much coincide with the values proposed by Terzaghi and Peck (1967), (Sivrikaya & Togrol, 2006)

2.5.3 Relationship Proposed by Sowers, 1979

Sowers (1979) presented a correlation between undrained shear strength and SPT N value with respect to the plasticity of fine grained soils. In here he has considered three categories in fined grained soils based on their plasticity as low plastic clays (SC-ML), medium plastic clays (CL) and high plastic clay (CH) (Balachandran et al, 2017).

$C_u = 3.63 \,.\, N$ for low plasticity clay, (*Equation 7)*

$C_u = 7.25 \,.\, N$ for medium plasticity clay, (*Equation 8)*

$C_u = 12.0 \,.\, N$ for high plasticity clay. (*Equation 9)*

It can be further demonstrated in *Figure2-6.*

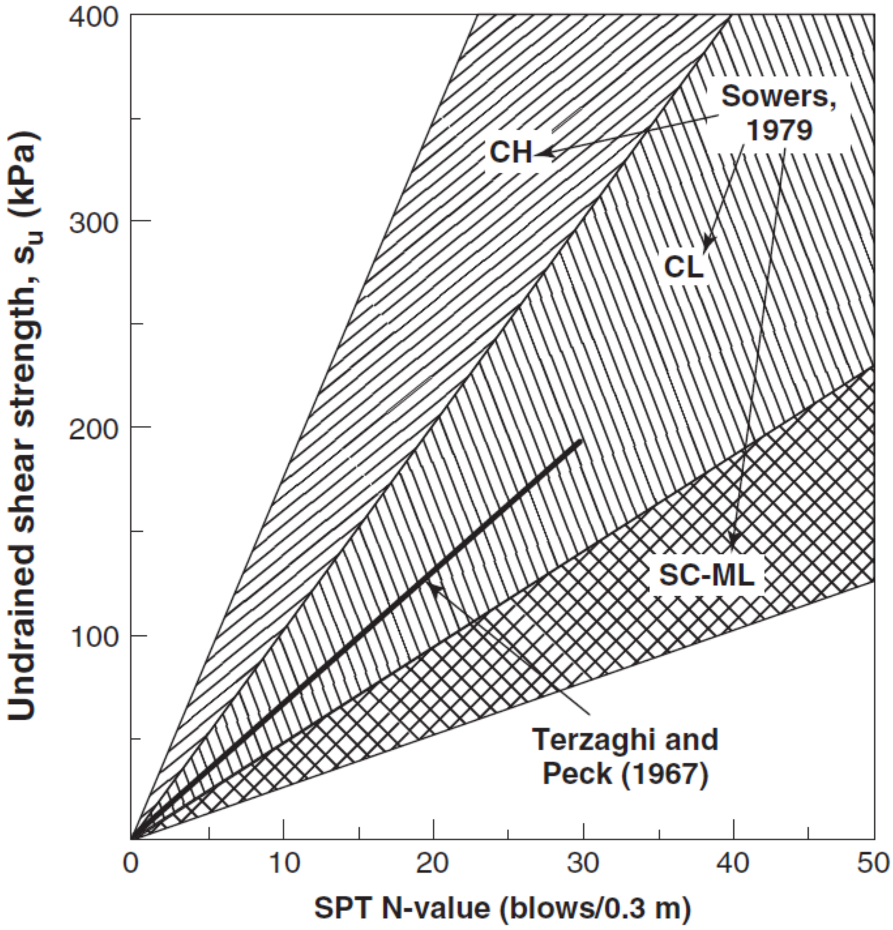

Figure 2-6: Correlation between undrained shear strength and SPT N (Sowers, 1979)

Source: Briaud (2013)

2.5.4 Relationship proposed by Hara A., Ohta T., Niwa M., Tanaka S. and Banno T. (1974)

This correlation developed by Hara et al, (1974) was based on a database for cohesive soils of same geology. (Brown & Hettiarachchi, 2008).

Most soils in this data set was within the void ratio between 1.0 to 2.0 while Over Consolidation Ratio values of the data set were within 1.0 to 3.0. (Vardanega & Bolton, 2011)

$$\frac{C_u}{P_a} = 0.29\, N_{60}^{0.72} \qquad \textit{(Equation 10)}$$

Pa – Atmospheric Pressure

2.5.5 Relationship proposed by Sivikaya & Togrol (2007)

Table 2-3: Types of soils analyzed and respective number of tests results taken for the analysis.

Soil type	Number of data (n)		
	UC	UU	FV
Highly plastic clay (CH)	113	80	13
Low plastic clay (CL)	72	67	11
Clay	185	147	24
Fine-grained soil	226	190	62

Source: Sivikaya & Togrol (2007)

A comprehensive analysis on the applicability and developing correlations between undrained shear strength against SPT N values has been done by Sivikaya & Togrol (2007). In here a data set with a large number of sample data from sites at various parts of Turkey was used and test results of unconfined compressive strength, unconsolidated undrained triaxial and field vane shear tests were separately analyzed. Further this study was done on four major divisions in fine grained soils as high plastic clay, low plastic clay, clay and fine grained soil and the number of test results taken for the analysis is given in the *Table 2-3* and results were analyzed in *Table 2-4* (Sivikaya & Togrol, 2007).

Results of the researches of Sivikaya & Togrol (2007) shows the increase of *f1* with the increase of Plasticity even with very much scattered point distribution, ***(Error!***

Reference source not found.) which agrees and reconfirms their results of study in 2002 and Sowers (1979) while opposes with the findings of Strouds (1974).

Table 2-4: Result analysis and summary

Results of the analysis perfomed for relations between SPT-N and S_u

Soil type	S_u kPa UC	S_u kPa UU	$S_u^*(\mu S_u)$ kPa FV
CH	$4.85N_{field}$, $r=0.83$, $s=\pm80$ $6.82N_{60}$, $r=0.80$, $s=\pm86$	$5.90N_{field}$, $r=0.80$, $s=\pm39$ $8.76N_{60}$, $r=0.80$, $s=\pm39$	$6.17N_{field}$, $r=0.86$, $s=\pm10$ $8.27N_{60}$, $r=0.87$, $s=\pm10$
CL	$3.35N_{field}$, $r=0.76$, $s=\pm64$ $4.93N_{60}$, $r=0.73$, $s=\pm68$	$3.97N_{field}$, $r=0.75$, $s=\pm21$ $5.82N_{60}$, $r=0.75$, $s=\pm21$	$3.58N_{field}$, $r=0.82$, $s=\pm6$ $4.88N_{60}$, $r=0.83$, $s=\pm5$
Clay	$4.33N_{field}$, $r=0.82$, $s=\pm82$ $6.19N_{60}$, $r=0.77$, $s=\pm85$	$5.13N_{field}$, $r=0.76$, $s=\pm36$ $7.57N_{60}$, $r=0.76$, $s=\pm36$	$4.97N_{field}$, $r=0.73$, $s=\pm12$ $6.72N_{60}$, $r=0.75$, $s=\pm11$
Fine-grained soil	$4.32N_{field}$, $r=0.80$, $s=\pm78$ $6.18N_{60}$, $r=0.78$, $s=\pm81$	$4.68N_{field}$, $r=0.72$, $s=\pm35$ $6.97N_{60}$, $r=0.71$, $s=\pm35$	$4.18N_{field}$, $r=0.76$, $s=\pm10$ $5.77N_{60}$, $r=0.79$, $s=\pm10$

Source : Sivikaya & Togrol (2007)

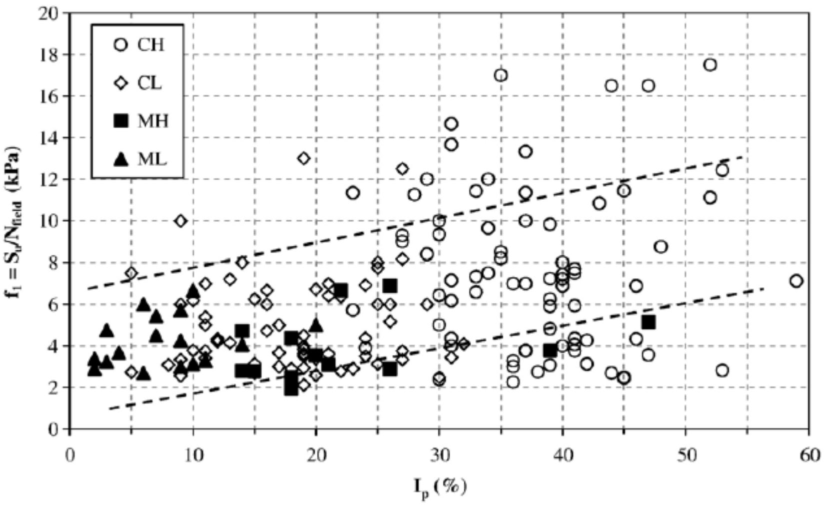

Figure 2-7 : Variation of f1 (S_u/N_{feild}) and Ip by UU Tests

Source: Sivrikaya & Togrol (2007)

Unlike in past studies on the subject, the analysis of data from a statistical point of view can be considered as one of the main highlights of this study. Also his statement on the importance of using the current correlations with correcting to the field SPT N value for better results and designs is very important.

Balachandrant et al (2017) states that the studies of Sivrikaya & Togrol (2007) reveal the correlation between SPT N and undrained shear strength only as a medium significance one it can only be used at preliminary stage designs relates to soil type.

The correlations developed for undrained shear strength and both SPT N_{field} and SPT N_{60} are given below with respect to soil types.

$C_u = 5.50 \,.\, N_{field}$	for CH	*(Equation 11)*
$C_u = 7.80 \,.\, N_{60}$	for CH	*(Equation 12)*
$C_u = 3.70 \,.\, N_{field}$	for CL	*(Equation 13)*
$C_u = 5.35 \,.\, N_{60}$	for CL	*(Equation 14)*
$C_u = 4.75 \,.\, N_{field}$	for Clays	*(Equation 15)*
$C_u = 6.90 \,.\, N_{60}$	for Clays	*(Equation 16)*
$C_u = 4.45 \,.\, N_{field}$	for fine grained soils	*(Equation 17)*
$C_u = 6.35 \,.\, N_{60}$	for fine grained soils	*(Equation 18)*

2.5.6 Relationship proposed by Décourt (1990)

Based on the analysis conducted on S. Paulo clays, Décourt (1990) proposed a correlation between SPT N and undrained shear strength. This relationship provides the undrained shear strength values almost twice as the relationship presented by Stroud (1974). Further no statistical details were provided for this analysis by Décourt (Sivrikaya & Togrol, 2007).

For Clay, $C_u = 12.5 \,.\, N_{field}$ *(Equation 19)*

$C_u = 15 \,.\, N_{60}$ *(Equation 20)*

2.4.7 Relationship proposed by Joseph E. Bowles

In the book "Foundation Analysis and Design", Joseph E. Bowles has presented a relationship between unconfined compressive strength & SPT corrected N_{70} values.

$$q_u = k \,.\, \mathrm{N} \qquad \textit{(Equation 21)}$$

Where the value of "*k*" is site dependent, with *k=12* has generally been used.

The values proposed by Joseph E. Bowels for unconfined compressive strength against SPT N'_{70} (Consistency of saturated cohesive soils) are shown on the *Table 2-5.*

Table 2-5: Consistency of saturated cohesive soils

Consistency of saturated cohesive soils*

Consistency			N'_{70}	q_u, kPa	Remarks
Very soft	NC	Young clay	0–2	< 25	Squishes between fingers when squeezed
Soft	NC	Young clay	3–5	25 – 50	Very easily deformed by squeezing
Medium	NC	Young clay	6–9	50 – 100	? ?
Stiff	Increasing OCR	Aged/cemented	10–16	100 – 200	Hard to deform by hand squeezing
Very stiff	Increasing OCR	Aged/cemented	17–30	200 – 400	Very hard to deform by hand squeezing
Hard	Increasing OCR	Aged/cemented	>30	> 400	Nearly impossible to deform by hand

* Blow counts and OCR division are for a guide—in clay "exceptions to the rule" are very common.

Source: Foundation Analysis and Design", Joseph E. Bowles (1997)

2.4.8 Other Available correlations available between Standard Penetration Test Results and Unconfined Compressive Strength of Fine grained soils.

Table 2-6: Consistency of Saturated Cohesive Soils

Author	Soil Type	Correlation / Unconfined Compressive Strength (kPa)
Sanglerat (1972)	Clay Silty Clay	25 N 20 N
Nixon (1982)	Clay	24 N
Sivrikaya & Togrol (2002)	High plastic clay (CH) Low plastic clay (CL) Fined grained soil	9.7 N_f / 13.63 N_{60} 6.7 N_f / 9.85 N_{60} 8.64 N_f / 12.36 N_{60}
Hettiarachchi & Brown (2009)	Fined grained soil	4.1 N_{60}

3. METHODOLOGY

3.1 Stage 1: Literature Review

An extended literature review was carried out to study the correlations developed over the past researchers, between the SPT N values and the undrained shear strength of fine grained soils. The governing properties of the fine grained soils that influence the correlations between the SPT N values and the undrained shear strength were studied and a set of commonly used in-situ and laboratory tests in Sri Lanka were selected to carry out the research.

The aforesaid commonly used, in-situ and laboratory tests can be tabulated as follows.

In-situ tests

- Standard penetration test (SPT)
- Field vane shear test (FVT)

Laboratory tests

- Natural moisture content.
- Atteberg limits test.
- Sieve analysis test.
- Hydrometer analysis test.
- Unconsolidated undrained triaxial test

3.2 Stage 2: Data Collection

Data extracted from major expressway, irrigation & drainage projects conducted in Sri Lanka in recent past are used for the analysis of this research which include test results of samples collected over 103 boreholes that were conducted at both in-situ and in laboratories. Most of the available test results that were used for this analysis were pertinent to samples collected from alluvial formations on flood plains and valleys in the Western and North Western provinces of Sri Lanka.

Available geotechnical investigation reports, including borehole logs were studied and the available unconsolidated undrained triaxial tests results, field vane shear test results and other information with relevant to the study were sorted.

Then, the depth of sampling/testing, respective field SPT N value, depth to the ground water table, visual description of the sample, laboratory test results of natural moisture content, Atteberg limits test, sieve analysis test, hydrometer analysis test and undrained cohesion values obtained for the sampled by conducting undrained triaxial tests of collected samples were extracted, please refer *Appendix I.*

3.3 Stage 3: Data Preparation

The collected data in stage 2 was tabulated using computer application, Microsoft Excel 2016. The data was arranged borehole wise for the ease of reference and analysis.

Then, the field SPT N values were corrected for SPT N_{70} to use in the analysis,

$$N'_{70} = C_N \,.\, N \,.\, \eta_1 . \eta_2 \,.\, \eta_3 \,.\, \eta_4 \qquad \textit{(Equation 22)}$$

N_{70} – Adjusted N to the standard, using E_{rb} (70)
C_N - Adjustment for effective overburden pressure P'_o
$= \left(\frac{95.76}{P\prime o}\right)^{1/2}$
η_1 - Correction for Hammer
η_2 - Correction for Rod length
η_3 - Correction for Sampler
η_4 - Correction for borehole diameter (Bowles, 1997)

Correction for SPT N_{60} was done as follows,

$$N_{60} = \frac{E_H \,.C_B.C_S \,.C_R \,.N}{0.6} \qquad \textit{(Equation 23)}$$

N_{60} - Adjusted N_{60} value
E_H - Hammer Efficiency
C_B - Borehole Diameter Correction
C_S - Sampler Correction
C_R - Rod Length Correction (Skempton, 1986)

Donut type hammers have been used to conduct all the SPT tests and 55% efficiency value was used for the corrections, based on the information provided by geotechnical investigation contractor.

Unified soil classification system (USCS) was used to categorize the research area by subdividing the fine grained soils to 4 categories as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) & low plastic silt (ML). Samples with 50% or more of material is finer than 75µm, (No 200 sieve) along with below plasticity chart was used for the USCS classification.

3.4 Stage 4: Data Analysis

Tabulated data in stage 3 was analyzed to verify an existing correlation between SPT N value and undrained cohesion of fine grained soil or develop a correlation varying several parameters, such as soil classification, liquid limit, plastic limit, plastic index, fines content, clay content, sampling depth and USCS classification.

In addition, the available FVST results were also used to develop a reliable, verified correlation between SPT N value and undrained cohesion.

3.5 Stage 5: Discussion and Recommendations.

Thesis was drafted based on the process followed in above four stages and reliability of the output and its limitations, possible reasons for the achieved results, possible areas of development for any future analysis were discussed in details.

4. ANALYSIS AND RESULTS

4.1 Analyze the possibility of applying the available correlations for Sri Lankan Conditions

Considering the literature collected, the available correlations between Undrained shear strength and SPT N values can be categorized mainly in to three divisions, based on the SPT N value used for the analysis as follows.

a) SPT N_{70}' V undrained shear strength
b) SPT N_{60} V undrained shear strength
c) SPT N_{field} V undrained shear strength

Hence it was decided to analyze the applicability of available correlation to Sri Lankan geological conditions based on aforesaid three divisions.

Soil samples of which more than 50 % percent by weight passing the No 200 sieve (75µm) were considered for the analysis to full fill the requirement of fine grained soils and *R squared* (R^2) was used for the statistical measures and find the line of best fit from the considered regression model.

4.1.1 Analysis on available correlations between "SPT N'_{70} and C_u"

Only one correlation between SPT N'_{70} and undrained shear strength, (C_u) was studies under the literature review, section 2 in this research and the details and the analysis on correlation proposed by Joseph E. Bowles are presented below.

4.1.1.1 Relationship proposed by Joseph E. Bowles (1996)

In here a table containing the SPT N'_{70} values and their respective unconfined compressive strength values is given and considering that a linear equation (q_u = k N'_{70}) was generated between undrained shear strength and SPT N'_{70} after converting the unconfined compressive strength values to Undrained Shear Strength values using the conversion $q_u/2 = C_u$, given in the same reference.

$$C_u = 6.4771\ N'_{70} \qquad \textit{(Equation 24)}$$

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear tests were plotted against the undrained shear strength values determined with aforesaid correlation proposed by Joseph E. Bowles as shown in Appendix II, section 1.1 and 1.2 respectively.

4.1.1.1.1 Results on analysis of relationship proposed by Joseph E. Bowles, 1996

Table 4-1: Results on analysis of relationship proposed by Joseph E. Bowles

	Analysis	No of Data sets	Correlation	R^2 Value
1.	C_u (Triaxial) and C_u (Energy by Bowles)	168	y = 0.1797x + 39.487	0.0150
2.	C_u (FVST) and C_u (Energy by Bowles)	76	y = 1.8319x + 23.989	0.0452

4.1.2 Analysis on available correlations between "SPT N60 and Cu"

Five correlation between SPT N_{60} and undrained shear strength, (C_u) was studies under the literature review, section 2 in this research and the details and the analysis on correlation proposed by Strouds (1974), Hara A. et al (1974), Sivikaya & Togrol (2007), Décourt (1990) and Terzaghi & Peck (1967) are presented below.

4.1.2.1 Relationship proposed by Strouds, (1974)

Relationship proposed by Strouds (1974) subdivided in to three categories based on the Plasticity Index variation as follows.

$$C_u = 4.2\,.\,N_{60} \quad \text{for PI>30} \quad (\textit{Equation 2})$$

$$C_u = 4 - 5\,.\,N_{60} \quad \text{for 20<PI<30} \quad (\textit{Equation 3})$$

$$C_u = 6 - 7\,.\,N_{60} \quad \text{for PI<20.} \quad (\textit{Equation 4})$$

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlations based on the plasticity index classification proposed by Strouds (1974) as shown in Appendix II, section 2.1 and 2.2 respectively.

4.1.2.1.1 Results on analysis of relationship proposed by Strouds (1974)

Table 4-2: Results on analysis of relationship proposed by Strouds (1974)

	Analysis	No of Data sets	Correlation	R^2 Value
1.	Cu (Triaxial) and Cu (Energy by Strouds) (PI<20%)	39	y = 0.5029x + 10.757	0.3701
2.	Cu (Triaxial) and Cu (Energy by Strouds) (20%<PI<30%)	66	y = 0.1998x + 12.429	0.1963
3.	Cu (Triaxial) and Cu (Energy by Strouds) (PI>30%)	35	y = -0.0097x + 21.91	0.0002
4.	Cu (FVST) and Cu (Energy by Strouds) (PI<20%)	15	y = 0.0198x + 15.785	0.0005
5.	Cu (FVST) and Cu (Energy by Strouds) (20%<PI<30%)	32	y = 0.0257x + 14.521	0.0018
6.	Cu (FVST) and Cu (Energy by Strouds) (PI>30%)	15	y = 0.1151x + 13.179	0.0388

4.1.2.2 Relationship proposed by Hara A et al., (1974)

Hara A et al. (1974) proposed a correlation between undrained shear strength and SPT N_{60} given below.

$$\frac{C_u}{P_a} = 0.29\ N_{60}^{0.72} \qquad \textit{(Equation 10)}$$

P_a – Atmospheric Pressure (~101kN/m^2)

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlation proposed by Hara A et al. (1974) as shown in Appendix II, section 3.1 and 3.2 respectively.

4.1.2.2.1 Results on analysis of relationship proposed by Hera A, et al.

Table 4-3: Results on analysis of relationship proposed by Hera A, et al.

	Analysis	No of Data sets	Correlation	R^2 Value
1.	Cu (Triaxial) and Cu (Energy by Hera A, et al.)	168	y = 0.6016x + 62.705	0.1239
2.	Cu (FVST) and Cu (Energy by Hera A, et al.)	76	y = 0.2703x + 57.686	0.0161

4.1.2.3 Relationship proposed by Sivikaya & Togrol, (2007)

Sivikaya & Togrol (2007) proposed correlations, categorized in four divisions as high plastic clays (CH), low plastic clays (CL), clays and fine grained soils, between undrained shear strength and SPT N_{60} are given below,

$\mathrm{C}_u = 7.80 \, . \mathrm{N}_{60}$ for CH *(Equation 12)*

$\mathrm{C}_u = 5.35 \, . \, \mathrm{N}_{60}$ for CL *(Equation 14)*

$\mathrm{C}_u = 6.90 \, . \, \mathrm{N}_{60}$ for Clays *(Equation 16)*

$\mathrm{C}_u = 6.35 \, . \, \mathrm{N}_{60}$ for fine grained soils *(Equation 18)*

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlations based on the soil classifications proposed by Sivikaya & Togrol, (2007) as shown in Appendix II, section 4.1 and 4.2 respectively.

4.1.2.3.1 Results on analysis of relationship proposed by Sivikaya & Togrol (2007)

Table 4-4 : Results on analysis of relationship proposed by Sivikaya & Togrol, (2007).

	Analysis	**No of Data sets**	**Correlation**	**R^2 Value**
1.	C_u (Triaxial) and C_u (Energy / N_{60}) by Sivikaya & Togrol (CH)	46	y = 0.0332x + 38.756	0.0009
2.	C_u (Triaxial) and C_u (Energy / N_{60}) by Sivikaya & Togrol (CL)	46	y = 0.3373x + 9.8612	0.2154
3.	C_u (Triaxial) and C_u (Energy / N_{60}) by Sivikaya & Togrol (Clay)	92	y = 0.2864x + 21.498	0.0835
4.	C_u (Triaxial) and C_u (Energy / N_{60}) by Sivikaya & Togrol (FG)	168	y = 0.2804x + 20.169	0.1114
5.	C_u (FVST) and Cu (Energy / N_{60}) by Sivikaya & Togrol (CH)	24	y = 0.0278x + 30.111	0.0006
6.	C_u (FVST) and C_u (Energy / N_{60}) by Sivikaya & Togrol (CL)	25	y = 0.1011x + 11.885	0.0207
7.	C_u (FVST) and C_u (Energy / N_{60}) by Sivikaya & Togrol (Clay)	49	y = 0.0624x + 21.297	0.0038
8.	C_u (FVST) and C_u (Energy / N_{60}) by Sivikaya & Togrol (FG)	76	y = 0.0931x + 18.209	0.0115

4.1.2.4 Relationship proposed by Décourt (1990)

Décourt (1990) proposed a correlation between undrained shear strength and SPT N_{60} as given below.

$$C_u = 15 \,.\, N_{60} \qquad \textit{(Equation 20)}$$

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlation proposed by Décourt, (1990) as shown in Appendix II, section 5.1 and 5.2 respectively.

4.1.2.4.3 Results on analysis of relationship proposed by Décourt, (1990)

Table 4-5: Results on analysis of relationship proposed by Décourt, (1990).

	Analysis	**No of Data sets**	**Correlation**	**R^2 Value**
1.	C_u (Triaxial) and C_u (Energy) by Décourt, 1990	168	y = 0.6623x + 47.643	0.1114
2.	C_u (FVST) and C_u (Energy) by Décourt, 1990	76	y = 0.2198x + 43.014	0.0115

4.1.2.5 Relationship proposed by Terzaghi & Peck, (1967)

Terzaghi & Peck, (1967) proposed a correlation between undrained shear strength and SPT N_{60} as given below.

$$C_u = 0.06\, Pa \,.\, N_{60} \qquad \textit{(Equation 5)}$$

P_a – Atmospheric Pressure (~101kN/m^2)

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlation proposed by Terzaghi & Peck, (1967) as shown in Appendix II, section 6.1 and 6.2 respectively.

4.1.2.5.1 Results on analysis of relationship proposed by Terzaghi & Peck, (1967)

Table 4-6: Results on analysis of relationship proposed by Terzaghi & Peck, (1967).

	Analysis	No of Data sets	Correlation	R^2 Value
1.	C_u (Triaxial) and C_u (Energy) by Terzaghi & Peck, 1967	168	y = 0.2649x + 19.057	0.1114
2.	C_u (FVST) and C_u (Energy) by Terzaghi & Peck, 1967	76	y = 0.0879x + 17.206	0.0115

4.1.3 Analysis on available correlations between "SPT N_{field} and C_u"

Four correlation between SPT N_{field} and Undrained Shear Strength, (C_u) was studies under the literature review, section 2 in this research and the details and the analysis on correlation proposed by Terzaghi & Peck (1967), Sowers (1979), Sivikaya & Togrol (2007) and Décourt (1990) are presented below.

4.1.3.1 Relationship proposed by Terzaghi & Peck (1967)

Terzaghi & Peck (1967) proposed a correlation between undrained shear strength and SPT N_{field} as given below.

$$C_u = 6.25 \,.\, N_{field} \qquad (Equation\ 6)$$

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlation proposed by Terzaghi & Peck (1967) as shown in Appendix II, section 7.1 and 7.2 respectively.

4.1.3.1.3 Results on analysis of relationship proposed by Terzaghi & Peck (1967)

Table 4-7: Results on analysis of relationship proposed by Terzaghi & Peck (1967).

	Analysis	No of Data sets	Correlation	R^2 Value
1.	C_u (Triaxial) and C_u (Energy/ N_f) by Terzaghi & Peck, 1967	168	y = 0.2829x + 22.89	0.0900
2.	C_u (FVST) and C_u (Energy / N_f) by Terzaghi & Peck, 1967	76	y = 0.0961x + 21.638	0.009

4.1.3.2 Relationship proposed by Sowers (1979)

Relationship proposed between undrained shear strength and SPT N_{field} by Sowers (1979) subdivided in to three categories based on the plasticity of the clay variation as low plasticity clay (SC-ML), medium plasticity clay (CL) and high plasticity clay (CH) given below.

$$C_u = 3.63 . N \text{ for low plasticity clay,} \quad \text{(Equation 7)}$$

$$C_u = 7.25 . N \text{ for medium plasticity clay,} \quad \text{(Equation 8)}$$

$$C_u = 12.0 . N \text{ for high plasticity clay.} \quad \text{(Equation 9)}$$

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlations based on the plasticity proposed by Sowers, (1979). Only the analysis of categories medium plasticity clay (CL) and high plasticity clay (CH) soils is shown in in Appendix II, section 8.1 and 8.2 respectively since the unavailability of data on low plasticity clay (SC-ML) soils.

4.1.3.2.1 Results on analysis of relationship proposed by Sowers, (1979)

Table 4-8: Results on analysis of relationship proposed by Sowers, (1979).

	Analysis	No of Data sets	Correlation	R^2 Value
1.	C_u (Triaxial) and C_u (Energy/ N_f) for CH by by Sowers, 1979	46	y = 0.0694x + 67.596	0.0012
2.	C_u (Triaxial) and C_u (Energy/ N_f) for CL by by Sowers, 1979	46	y = 0.5075x + 14.795	0.1950
3.	C_u (FVST) and C_u (Energy / N_f) for CH by Sowers, 1979	24	y = 0.0013x + 55.968	$4x10^{-7}$
4.	C_u (FVST) and C_u (Energy / N_f) for CL by Sowers, 1979	25	y = 0.1498x + 19.326	0.0188

4.1.3.3 Relationship proposed by Sivikaya & Togrol, (2007)

Sivikaya & Togrol (2007) proposed correlations, categorized in four divisions as high plastic clays (CH), low plastic clays (CL), clays and fine grained soils, between undrained shear strength and SPT N_{field} are given below,

$$C_u = 5.50 \, . \, N_{field} \quad \text{for CH} \quad \textit{(Equation 11)}$$

$$C_u = 3.70 \, . \, N_{field} \quad \text{for CL} \quad \textit{(Equation 13)}$$

$$C_u = 4.75 \, . \, N_{field} \quad \text{for Clays} \quad \textit{(Equation 15)}$$

$$C_u = 4.45 \, . \, N_{field} \quad \text{for fine grained soils} \quad \textit{(Equation 17)}$$

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlations based on the soil classifications proposed by Sivikaya & Togrol, (2007) as shown in Appendix II, section 9.1 and 9.2 respectively.

4.1.3.3.1 Results on analysis of relationship proposed by Sivikaya & Togrol (2007)

Table 4-9: Results on analysis of relationship proposed by Sivikaya & Togrol, 2007.

	Analysis	No of Data sets	Correlation	R^2 Value
1.	C_u (Triaxial) and C_u (Energy / N_{field}) by Sivikaya & Togrol (CH)	46	y = 0.0318x + 30.982	0.0012
2.	C_u (Triaxial) and C_u (Energy / N_{field}) by Sivikaya & Togrol (CL)	46	y = 0.259x + 7.5507	0.1950
3.	C_u (Triaxial) and C_u (Energy / N_{field}) by Sivikaya & Togrol (Clay)	92	y = 0.223x + 16.66	0.0789
4.	C_u (Triaxial) and C_u (Energy / N_{field}) by Sivikaya & Togrol (FG)	168	y = 0.2014x + 16.298	0.0900
5.	C_u (FVST) and C_u (Energy / N_{field}) by Sivikaya & Togrol (CH)	24	y = 0.0006x + 25.652	4×10^{-7}
6.	C_u (FVST) and C_u (Energy / N_{field}) by Sivikaya & Togrol (CL)	25	y = 0.0764x + 9.8627	0.0188
7.	C_u (FVST) and C_u (Energy / N_{field}) by Sivikaya & Togrol (Clay)	49	y = 0.036x + 17.692	0.0019
8.	C_u (FVST) and C_u (Energy / N_{field}) by Sivikaya & Togrol (FG)	76	y = 0.0684x + 15.406	0.0090

4.1.3.4 Relationship proposed by Décourt, (1990)

Décourt (1990) proposed a correlation between undrained shear strength and SPT N_{field} as given below.

$$C_u = 12.5 \, . N_{field} \qquad \textit{(Equation 19)}$$

Available undrained shear strength data from both unconsolidated undrained triaxial tests and field vane shear test were plotted against the undrained shear strength values determined with aforesaid correlation proposed by Décourt (1990) as shown in Appendix II, section 10.1 and 10.2 respectively.

4.1.3.4.1 Results on analysis of relationship proposed by Décourt (1990)

Table 4-10: Results on analysis of relationship proposed by Décourt (1990).

	Analysis	No of Data sets	Correlation	R^2 Value
1.	C_u (Triaxial) and C_u (Energy / N_f) by Décourt, 1990	168	y = 0.6789x + 54.936	0.090
2.	C_u (FVST) and C_u (Energy / N_f) by Décourt, 1990	76	y = 0.2306x + 51.931	0.009

4.1.4 Overall Analysis on the Available Correlations

Considering above analysis in sections 4.1.1, 4.1.2 & 4.1.3, it can be concluded that there is not sufficient facts and evidences to validate any of the existing correlation with the available data, Hence the analysis changed its focus to stablish a new relationship between SPT N value (either for field or corrected) and undrained shear strength for fine grained soils.

4.2 Analysis using Undrained Shear Strength by Triaxial UU Tests

Since the available data set includes the undrained shear strength values determined with both unconsolidated undrained triaxial tests and field vane shear tests, it was decided to analyze them as two separate data sets under sections 4.2 and 4.3 respectively, to widen the analysis.

Further, the aforementioned analyses were subdivided in to several categories based on their liquid limits, plastic limits, plasticity limits, fines content, clay content, sampling depth and USCS classifications to further enhancement of the analysis.

4.2.1 Analysis on Fine Grained Soils, Complete Set.

As the initial step, it was decided to analyze Soil samples of which more than 50 % percent by weight passing the No 200 sieve (75μm) without any divisions. In here, the undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix III, section 1.1, 1.2 and 1.3 respectively.

4.2.1.1 Results on Fine Grained Soils (Complete Set)

Table 4-11: Results on Fine Grained Soils (Complete Set)

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Triaxial UU (Complete Set)	168	Y = 0.5062x + 26.632	0.013
2.	SPT N_{60} Vs C_u by Triaxial UU (Complete Set)	168	Y = 4.2035x + 18.601	0.1114
3.	SPT N_{field} Vs C_u by Triaxial UU (Complete Set)	168	Y = 1.9532x + 20.262	0.0858

4.2.2. Analysis based on the variation of Liquid Limit.

The effects of the variation of liquid limit (LL) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to four sub categories based on their liquid limits (LL) as LL<40%, 40%<LL<50%, 50%<LL<60% and LL>60% for this analysis.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix III, section 2.1, 2.2 and 2.3 respectively.

Further to get an overall idea on the effects of the liquid limit on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective liquid limits, as shown in the Appendix III section 2.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.2.2.1 Results of analysis based on the variation of Liquid Limit

Table 4-12: Results of analysis based on the liquid limit variation

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Triaxial UU (LL<40%)	20	$Y = 1.3983x + 16.547$	0.1791
2.	SPT N'_{70} Vs C_u by Triaxial UU (40%<LL<50%)	41	$Y = 1.8319x + 23.989$	0.0452
3.	SPT N'_{70} Vs C_u by Triaxial UU (50%<LL<60%)	51	$Y = 0.6222x + 30.542$	0.0052
4.	SPT N'_{70} Vs C_u by Triaxial UU (LL>60%)	28	$Y = -0.0509x + 30.53$	0.0003
5.	SPT N_{60} Vs C_u by Triaxial UU (LL<40%)	20	$y = 4.2922x + 14.123$	0.2115
6.	SPT N_{60} Vs C_u by Triaxial UU (40%<LL<50%)	41	$y = 13.539x - 0.0577$	0.4617
7.	SPT N_{60} Vs C_u by Triaxial UU (50%<LL<60%)	51	$y = 4.6276x + 16.78$	0.0927
8.	SPT N_{60} Vs C_u by Triaxial UU (LL>60%)	28	$y = 3.2212x + 20.485$	0.1254
9.	SPT N_{field} Vs C_u by Triaxial UU (LL<40%)	20	$Y = 2.1581x + 14.818$	0.2128
10.	SPT N_{field} Vs C_u by Triaxial UU (40%<LL<50%)	41	$Y = 7.1133x + 0.5159$	0.4431
11.	SPT N_{field} Vs C_u by Triaxial UU (50%<LL<60%)	51	$Y = 1.8226x + 20.567$	0.0481
12.	SPT N_{field} Vs C_u by Triaxial UU (LL>60%)	28	$Y = 1.7409x + 20.568$	0.1172
13.	Cu / SPT N'_{70} factor Vs LL	132	$Y = -0.0019x^2 + 0.205x + 0.9667$	0.0012
14.	Cu / SPT N_{60} factor Vs LL	132	$y = 13.011\ e^{-0.008x}$	0.0056
15.	Cu / SPT N_f factor Vs LL	132	$y = 18.581\ x^{-0.347}$	0.0046

4.2.3. Analysis based on the variation of Plastic Limit

The effects of the variation of plastic limit (PL) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to four sub categories based on their plastic limits (PL) as PL<20%, 20%<PL<30% and PL>30% for this analysis.

Undrained shear strength values of undisturbed fine grained soil samples, determined with Triaxial UU Tests were plotted against the SPT N'$_{70}$, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix III, section 3.1, 3.2 and 3.3 respectively.

Further to get an overall idea on the effects of the Plastic Limit on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'$_{70}$, SPT N_{60} and SPT N_{field}, were plotted against the respective plastic limits, as shown in the Appendix III section 3.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.2.3.1 Results of analysis based on the variation of Plastic Limit

Table 4-13: Results of analysis based on the plastic limit variation

	Analysis	**No of Data sets**	**Correlation**	**R^2 Value**
1.	SPT N'$_{70}$ Vs C_u by Triaxial UU (PL<20%)	30	Y = 0.8307x + 12.625	0.0844
2.	SPT N'$_{70}$ Vs C_u by Triaxial UU (20%<PL<30%)	68	Y = 1.869x + 18.56	0.1028
3.	SPT N'$_{70}$ Vs C_u by Triaxial UU (PL>30%)	42	Y = -0.2881x + 37.249	0.0027
4.	SPT N_{60} Vs C_u by Triaxial UU (PL<20%)	30	y = 2.5737x + 11.521	0.0961
5.	SPT N_{60} Vs C_u by Triaxial UU (20%<PL<30%)	68	y = 7.0548x + 13.037	0.2034
6.	SPT N_{60} Vs C_u by Triaxial UU (PL>30%)	42	y = 7.7462x + 13.655	0.2555
7.	SPT N_{field} Vs C_u by Triaxial UU (PL<20%)	30	Y = 1.2553x + 12.041	0.093
8.	SPT N_{field} Vs C_u by Triaxial UU (20%<PL<30%)	68	Y = 3.8039x + 12.807	0.2015
9.	SPT N_{field} Vs C_u by Triaxial UU (PL>30%)	42	Y = 4.0811x + 15.337	0.2056
10.	Cu / SPT N'$_{70}$ factor Vs PL	132	$y = 0.0012x^2 + 0.2014x - 0.1154$	0.0686
11.	Cu / SPT N_{60} factor Vs PL	132	$y = -0.036x^2 + 2.024x - 13.224$	0.0169
12.	Cu / SPT N_f factor Vs PL	132	$y = -0.0164x^2 + 0.9637x - 6.082$	0.0165

4.2.4. Analysis based on the variation of Plasticity Index

The effects of the variation of plasticity index (PI) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by Triaxial UU Tests is studied in this section. Available data set was categorized in to four sub categories based on their plasticity indexes as PI<20%, 20%<PI<30% and PI>30% for this analysis.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix III, section 4.1, 4.2 and 4.3 respectively.

Further to get an overall idea on the effects of the plasticity index on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective plasticity index, as shown in the Appendix III section 4.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.2.4.1. Results of analysis based on the variation of Plasticity Index

Table 4-14: Results of analysis based on the plasticity index variation.

	Analysis	**No of Data sets**	**Correlation**	**R^2 Value**
1.	SPT N'_{70} Vs C_u by Triaxial UU (PI<20%)	39	Y = 1.6742x + 28.184	0.0962
2.	SPT N'_{70} Vs C_u by Triaxial UU (20%<PI<30%)	66	Y = 2.0063x + 15.55	0.1131
3.	SPT N'_{70} Vs C_u by Triaxial UU (PI>30%)	35	Y = -0.6146x + 29.212	0.0491
4.	SPT N_{60} Vs C_u by Triaxial UU (PI<20%)	39	y = 7.9726x + 15.424	0.3701
5.	SPT N_{60} Vs C_u by Triaxial UU (20%<PI<30%)	66	y = 7.3756x + 10.78	0.1964
6.	SPT N_{60} Vs C_u by Triaxial UU (PI>30%)	35	y = -0.1206x + 24.63	0.0002
7.	SPT N_{field} Vs C_u by Triaxial UU (PI<20%)	39	Y = 4.1097x + 17.451	0.3372

8.	SPT N_{field} Vs C_u by Triaxial UU (20%<PI<30%)	66	Y = 3.8426x + 11.286	0.1798
9.	SPT N_{field} Vs C_u by Triaxial UU (PI>30%)	35	Y = -0.178x + 25.294	0.0014
10.	Cu / SPT N'_{70} factor Vs PI	133	$Y = 0.0237x^2 - 1.4666x + 27.131$	0.106
11.	Cu / SPT N_{60} factor Vs PI	133	$y = 90.383x^{-0.728}$	0.0464
12.	Cu / SPT N_f factor Vs PI	133	$y = 58.91x^{-0.786}$	0.0541

4.2.5. Analysis based on the variation Fines Content.

The effects of the variation of fines content (FC) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to four sub categories based on their fines content as FC>90%, 90%<FC<80%, 80%<FC<70%, 70%<FC<60% and 60%<FC<50% for this analysis.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix III, section 5.1, 5.2 and 5.3 respectively.

Further to get an overall idea on the effects of the fines content on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective fines content, as shown in the Appendix III section 5.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.2.5.1 Results of analysis based on the variation of Fines Content

Table 4-15: Results of analysis based on the fines content variation.

	Analysis	**No of Data sets**	**Correlation**	**R^2 Value**
1.	SPT N'_{70} Vs C_u by Triaxial UU (FC>90%)	17	Y = -0.7487x + 34.851	0.0692
2.	SPT N'_{70} Vs C_u by Triaxial UU (80%<FC<90%)	27	Y = 1.5218x + 18.753	0.0549

3.	SPT N'_{70} Vs C_u by Triaxial UU (70%<FC<80%)	31	Y = 1.333x + 20.379	0.1696
4.	SPT N'_{70} Vs C_u by Triaxial UU (60%<FC<70%)	37	Y = -0.2671x + 27.527	0.0073
5.	SPT N'_{70} Vs C_u by Triaxial UU (50%<FC<60%)	42	Y = 4.2918x - 1.8143	0.2644
6.	SPT N_{60} Vs C_u by Triaxial UU (FC>90%)	17	y = 1.7012x + 24.526	0.0284
7.	SPT N_{60} Vs C_u by Triaxial UU (80%<FC<90%)	27	y = 4.8763x + 17.078	0.0576
8.	SPT N_{60} Vs C_u by Triaxial UU (70%<FC<80%)	31	y = 3.0002x + 22.804	0.1108
9.	SPT N_{60} Vs C_u by Triaxial UU (60%<FC<70%)	37	y = 0.6768x + 23.767	0.0042
10.	SPT N_{60} Vs C_u by Triaxial UU (50%<FC<60%)	42	y = 13.279x - 2.6612	0.3803
11.	SPT N_{field} Vs C_u by Triaxial UU (FC>90%)	17	Y = 0.1739x + 28.931	0.001
12.	SPT N_{field} Vs C_u by Triaxial UU (80%<FC<90%)	27	Y = 2.9618x + 15.674	0.0707
13.	SPT N_{field} Vs C_u by Triaxial UU (70%<FC<80%)	31	Y = 1.6085x + 22.583	0.1274
14.	SPT N_{field} Vs C_u by Triaxial UU (60%<FC<70%)	37	Y = 0.1142x + 24.966	0.0005
15.	SPT N_{field} Vs C_u by Triaxial UU (50%<FC<60%)	42	y = 7.1881x - 3.6397	0.4085
16.	Cu /SPT N'_{70} factor Vs FC	154	$y = 0.0053x^2 - 0.7198x + 29.56$	0.0216
17.	Cu /SPT N_{60} factor Vs FC	154	$y = -0.0023x^2 + 0.3072x + 4.4262$	0.0013
18.	Cu /SPT N_f factor Vs FC	154	$y = 3.0048x^{0.0965}$	0.0003

4.2.6 Analysis based on the variation Clay Content.

The effects of the variation of clay content (CC) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to four sub categories based on their clay content as 50%<CC<70%, 40%<CC<50%, 30%<CC<40%, 20%<CC<30% and CC<20% for this analysis.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix III, section 6.1, 6.2 and 6.3 respectively.

Further to get an overall idea on the effects of the clay content on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective clay content, as shown in the Appendix III section 6.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.1.6.1 Results of analysis based on the variation of Clay Content

Table 4-16: Results of analysis based on the clay content variation.

	Analysis	**No of Data sets**	**Correlation**	**R^2 Value**
1.	SPT N'_{70} Vs C_u by Triaxial UU (50%<CC<70%)	7	Y = 0.9517x + 33.617	0.0094
2.	SPT N'_{70} Vs C_u by Triaxial UU (40%<CC<50%)	16	Y = 0.0708x + 35.298	$7x10^{-5}$
3.	SPT N'_{70} Vs C_u by Triaxial UU (30%<CC<40%)	40	Y = 0.3141x + 33.994	0.0047
4.	SPT N'_{70} Vs C_u by Triaxial UU (20%<CC<30%)	63	Y = 0.8801x + 18.968	0.0617
5.	SPT N'_{70} Vs C_u by Triaxial UU (CC<20%)	35	Y = 0.3842x + 23.508	0.0152
6.	SPT N_{60} Vs C_u by Triaxial UU (50%<CC<70%)	7	Y = 2.8459x + 28.261	0.0832
7.	SPT N_{60} Vs C_u by Triaxial UU (40%<CC<50%)	16	Y = 3.7476x + 25.415	0.0568
8.	SPT N_{60} Vs C_u by Triaxial UU (30%<CC<40%)	40	Y = 1.6343x + 31.162	0.0143
9.	SPT N_{60} Vs C_u by Triaxial UU (20%<CC<30%)	63	Y = 2.5307x + 18.716	0.0594
10.	SPT N_{60} Vs C_u by Triaxial UU (CC<20%)	35	Y = 0.3796x + 19.446	0.0012
11.	SPT N_{field} Vs C_u by Triaxial UU (50%<CC<70%)	7	Y = 1.8824x + 27.731	0.0776

12.	SPT N_{field} Vs C_u by Triaxial UU (40%<CC<50%)	16	Y = 1.8055x + 26.771	0.0398
13.	SPT N_{field} Vs C_u by Triaxial UU (30%<CC<40%)	40	Y = 0.924x + 30.881	0.018
14.	SPT N_{field} Vs C_u by Triaxial UU (20%<CC<30%)	63	Y = 1.2761x + 18.965	0.0585
15.	SPT N_{field} Vs C_u by Triaxial UU (CC<20%)	35	Y = 0.0873x + 19.904	0.0003
16.	Cu /SPT N'_{70} factor Vs CC	154	$y = 1.2262e^{0.0356x}$	0.1261
17.	Cu /SPT N_{60} factor Vs CC	154	Y = -0.0112x + 14.433	$8x10^{-5}$
18.	Cu /SPT N_f factor Vs CC	154	$Y = 1.3826x^{0.3685}$	0.0273

4.2.7 Analysis based on the variation Sampling Depth.

The effects of the variation of sampling depth (SD) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by Triaxial UU Tests is studied in this section. Available data set was categorized in to four sub categories based on their sampling depths as 0.3m, 1.3m, 2.3m, 3.3m, 4.3, 5.3 to 6.3m, 7.3 to 13.3m for this analysis.

Undrained shear strength values of undisturbed fine grained soil samples, determined with Triaxial UU Tests were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix III, section 7.1, 7.2 and 7.3 respectively.

Further to get an overall idea on the effects of the sampling depths on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective sampling depths, as shown in the Appendix III section 7.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.2.7.1 Results of analysis based on the variation of Sampling Depth

Table 4-17: Results of analysis based on the sampling depth variation.

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Triaxial UU (0.3m)	31	Y = 0.4188x + 20.539	0.0281
2.	SPT N'_{70} Vs C_u by Triaxial UU (1.3m)	63	Y 0.8628x + 23.296	0.0422
3.	SPT N'_{70} Vs C_u by Triaxial UU (2.3m)	36	Y 1.4143x + 15.536	0.0612
4.	SPT N'_{70} Vs C_u by Triaxial UU (3.3m)	8	Y = -0.2322x + 37.359	0.0006
5.	SPT N'_{70} Vs C_u by Triaxial UU (4.3m)	8	Y = 8.9584x + 4.862	0.4477
6.	SPT N'_{70} Vs C_u by Triaxial UU (5.3-6.3m)	11	Y = 5.0194x + 11.96	0.0464
7.	SPT N'_{70} Vs C_u by Triaxial UU (7.3-13.3m)	12	Y = 12.91x + 11.18	0.4255
8.	SPT N_{60} Vs C_u by Triaxial UU (0.3m)	31	y = 0.7934x + 23.35	0.0043
9.	SPT N_{60} Vs C_u by Triaxial UU (1.3m)	63	y = 2.9185x + 22.018	0.0632
10.	SPT N_{60} Vs C_u by Triaxial UU (2.3m)	36	y = 3.6004x + 13.601	0.1127
11.	SPT N_{60} Vs C_u by Triaxial UU (3.3m)	8	y = 1.3036x + 33.176	0.0068
12.	SPT N_{60} Vs C_u by Triaxial UU (4.3m)	8	y = 18.417x - 16.669	0.8170
13.	SPT N_{60} Vs C_u by Triaxial UU (5.3-6.3m)	11	y = 8.9491x + 3.3889	0.1449
14.	SPT N_{60} Vs C_u by Triaxial UU (7.3-13.3m)	12	y = 9.746x + 12.325	0.4137
15.	SPT N_{field} Vs C_u by Triaxial UU (0.3m)	31	Y = 0.3927x + 23.35	0.0043
16.	SPT N_{field} Vs C_u by Triaxial UU (1.3m)	63	Y = 1.4446x + 22.018	0.0632
17.	SPT N_{field} Vs C_u by Triaxial UU (2.3m)	36	Y = 2.0198x + 13.601	0.1127

18.	SPT N_{field} Vs C_u by Triaxial UU (3.3m)	8	$Y = 0.731x + 33.176$	0.0068
19.	SPT N_{field} Vs C_u by Triaxial UU (4.3m)	8	$Y = 11.548x – 16.669$	0.8170
20.	SPT N_{field} Vs C_u by Triaxial UU (5.3-6.3m)	11	$Y = 5.6111x + 3.3889$	0.1449
21.	SPT N_{field} Vs C_u by Triaxial UU (7.3-13.3m)	12	$Y = 6.1785x + 13.134$	0.4081
22.	Cu /SPT N'_{70} factor Vs SD	162	$y = -0.0156x^2 + 1.6384x + 2.555$	0.2239
23.	Cu /SPT N_{60} factor Vs SD	162	$y = -2.048\ln(x) + 15.104$	0.0181
24.	Cu /SPT N_f factor Vs SD	162	$y = 4.1405e^{0.0442x}$	0.0093

4.2.8. Analysis based on the Unified Soil Classification System (USCS)

The effects of the variation of soil type on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by triaxial UU tests is studied in this section. Unified soil classification system (USCS) is used for the classification of available fine grained soil samples and categorized in to four divisions as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) and low plastic silt (ML) for this analysis.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix III, section 8.1, 8.2 and 8.3 respectively, with aforesaid categories, categorized based on USCS.

4.2.8.1 Results of analysis based on the Unified Soil Classification System (USCS)

Table 4-18: Results of analysis based on the USCS.

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Triaxial UU (CH)	46	y = 0.2667x + 27.923	0.0044
2.	SPT N'_{70} Vs C_u by Triaxial UU (CL)	46	y = 1.5714x + 16.917	0.1177
3.	SPT N'_{70} Vs C_u by Triaxial UU (MH)	37	y = -0.5529x + 35.074	0.0102
4.	SPT N'_{70} Vs C_u by Triaxial UU (ML)	12	y = 0.0728x + 35.919	0.0003
5.	SPT N_{60} Vs C_u by Triaxial UU (CH)	46	y = 0.4729x + 27.934	0.0016
6.	SPT N_{60} Vs C_u by Triaxial UU (CL)	46	y = 5.6946x + 12.736	0.2154
7.	SPT N_{60} Vs C_u by Triaxial UU (MH)	37	y = 8.3942x + 6.9857	0.3155
8.	SPT N_{60} Vs C_u by Triaxial UU (ML)	12	y = 13.548x + 8.8855	0.4434
9.	SPT N_{field} Vs C_u by Triaxial UU (CH)	46	y = 0.2089x + 28.396	0.0012
10.	SPT N_{field} Vs C_u by Triaxial UU (CL)	46	y = 2.7859x + 13.844	0.1950
11.	SPT N_{field} Vs C_u by Triaxial UU (MH)	37	y = 4.323x + 9.4555	0.2366
12.	SPT N_{field} Vs C_u by Triaxial UU (ML)	12	y = 6.6791x + 13.005	0.3989

4.3. Analysis using Undrained Shear Strength by Field Vane Shear Test

4.3.1. Analysis on Fine Grained Soils, Complete Set.

In this step, Soil samples of which more than 50 % percent by weight passing the No 200 sieve (75μm) was analyzed without any divisions. In here, the undrained shear strength values of fine grained soils, determined with field vane shear test were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix IV, section 1.1, 1.2 and 1.3 respectively.

4.3.1.1 Results on Fine Grained Soils (Complete Set)

Table 4-19: Results on fine grained soils (Complete Set)

	Analysis	**No of Data sets**	**Correlation**	**R^2 Value**
1.	SPT N'_{70} Vs C_u by FVST (Complete Set)	76	Y = -0.0081x + 27.337	$6x10^{-6}$
2.	SPT N_{60} Vs C_u by FVST (Complete Set)	76	y = 1.1234x + 25.097	0.0083
3.	SPT N_{field} Vs C_u by FVST UU (Complete Set)	76	Y = 0.5826x + 25.02	0.0090

4.3.2 Analysis based on the variation of Liquid Limit.

The effects of the variation of liquid limit (LL) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to four sub categories based on their liquid lmits as LL<40%, 40%<LL<50%, 50%<LL<60% and LL>60% for this analysis.

Undrained shear strength values of fine grained soil samples, determined with undrained shear strength by field vane shear test were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix IV, section 2.1, 2.2 and 2.3 respectively.

Further to get an overall idea on the effects of the liquid limit on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective liquid limits, as shown in the Appendix IV section 2.4. The available data with SPT N_{field} value zero (0) were not considered in this analysis.

4.3.2.1 Results of analysis based on the variation of Liquid Limit

Table 4-20: Results of analysis based on the liquid limit variation

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Field Vane Shear (LL<40%)	7	Y = 1.3983x + 16.547	0.1791
2.	SPT N'_{70} Vs C_u by Field Vane Shear (40%<LL<50%)	24	Y = 1.8319x + 23.989	0.0452
3.	SPT N'_{70} Vs C_u by Field Vane Shear (50%<LL<60%)	18	Y = 0.6222x + 30.542	0.0052
4.	SPT N'_{70} Vs C_u by Field Vane Shear (LL>60%)	13	Y = -0.0509x + 30.53	0.0003
5.	SPT N_{60} Vs C_u by Field Vane Shear (LL<40%)	7	y = -0.5898x + 28.174	0.0158
6.	SPT N_{60} Vs C_u by Field Vane Shear (40%<LL<50%)	24	y = 1.3224x + 24.666	0.0182
7.	SPT N_{60} Vs C_u by Field Vane Shear (50%<LL<60%)	18	y = -1.5974x + 31.76	0.0122
8.	SPT N_{60} Vs C_u by Field Vane Shear (LL>60%)	13	y = 1.5794x + 24.405	0.0179
9.	SPT N_{field} Vs C_u by Field Vane Shear (LL<40%)	7	Y = 2.1581x + 14.818	0.2128
10.	SPT N_{field} Vs C_u by Field Vane Shear (40%<LL<50%)	24	Y = 7.1133x + 0.5159	0.4431
11.	SPT N_{field} Vs C_u by Field Vane Shear (50%<LL<60%)	18	Y = 1.8226x + 20.567	0.0481
12.	SPT N_{field} Vs C_u by Field Vane Shear (LL>60%)	13	Y = 1.7409x + 20.568	0.1172
13.	Cu / SPT N'_{70} factor Vs LL	56	$Y= 0.0096x^2 - 1.0518x + 32.191$	0.0937
14.	Cu / SPT N_{60} factor Vs LL	56	$y = 24.291 e^{-0.012x}$	0.0279
15.	Cu / SPT N_f factor Vs LL	56	$Y = 0.0081x^2 - 0.9644x + 35.369$	0.0401

4.3.3. Analysis based on the variation of Plastic Limit

The effects of the variation of plastic limit (PL) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to four sub categories based on their plastic limits as PL<20%, 20%<PL<30% and PL>30% for this analysis.

Undrained shear strength values of fine grained soil samples, determined with undrained shear strength by field vane shear test were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix IV, section 3.1, 3.2 and 3.3 respectively.

Further to get an overall idea on the effects of the plastic limit on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective Plastic Limits, as shown in the Appendix IV section 3.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.3.3.1 Results of analysis based on the variation of Plastic Limit

Table 4-21: Results of analysis based on the plastic limit variation

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Field Vane Shear (PL<20%)	11	y = -0.1977x + 25.997	0.0038
2.	SPT N'_{70} Vs C_u by Field Vane Shear (20%<PL<30%)	40	y = -0.2759x + 30.925	0.0064
3.	SPT N'_{70} Vs C_u by Field Vane Shear (PL>30%)	11	y = 0.7489x + 20.783	0.0533
4.	SPT N_{60} Vs C_u by Field Vane Shear (PL<20%)	11	y = 1.9896x + 21.528	0.0357
5.	SPT N_{60} Vs C_u by Field Vane Shear (20%<PL<30%)	40	y = 0.9336x + 27.007	0.0052
6.	SPT N_{60} Vs C_u by Field Vane Shear (PL>30%)	11	y = -1.6348x + 29.16	0.0374
7.	SPT N_{field} Vs C_u by Field Vane Shear (PL<20%)	11	y = 0.8192x + 22.144	0.0253
8.	SPT N_{field} Vs C_u by Field Vane Shear (20%<PL<30%)	40	y = 0.3799x + 27.379	0.0034
9.	SPT N_{field} Vs C_u by Field Vane Shear (PL>30%)	11	y = -0.6962x + 28.64	0.0265
10.	Cu / SPT N'_{70} factor Vs PL	57	y = -0.0115x + 5.1443	0.0003
11.	Cu / SPT N_{60} factor Vs PL	57	y = 0.1382x + 12.911	0.0047
12.	Cu / SPT N_f factor Vs PL	57	Y = $0.0082x^2$ - 0.3541x + 11.783	0.0066

4.3.4. Analysis based on the variation of Plasticity Index

The effects of the variation of plasticity index (PI) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to four sub categories based on their plasticity indexes as PI<20%, 20%<PI<30% and PI>30% for this analysis.

Undrained shear strength values of fine grained soil samples, determined with undrained shear strength by field vane shear test were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix IV, section 4.1, 4.2 and 4.3 respectively.

Further to get an overall idea on the effects of the plasticity index on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective plasticity index, as shown in the Appendix IV section 4.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.3.4.1 Results of analysis based on the variation of Plasticity Index

Table 4-22: Results of analysis based on the plasticity index variation.

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Field Vane Shear (PI<20%)	15	y = -0.2055x + 29.711	0.0034
2.	SPT N'_{70} Vs C_u by Field Vane Shear (20%<PI<30%)	32	y = -0.1795x + 29.477	0.003
3.	SPT N'_{70} Vs C_u by Field Vane Shear (PI>30%)	15	y = 0.2718x + 24.04	0.005
4.	SPT N_{60} Vs C_u by Field Vane Shear (PI<20%)	15	y = 0.2789x + 28.099	0.0005
5.	SPT N_{60} Vs C_u by Field Vane Shear (20%<PI<30%)	32	y = 0.527x + 27.057	0.0018
6.	SPT N_{60} Vs C_u by Field Vane Shear (PI>30%)	15	y = 2.3571x + 20.414	0.0388
7.	SPT N_{field} Vs C_u by Field Vane Shear (PI<20%)	15	y = 0.084x + 28.274	0.0002

8.	SPT N_{field} Vs C_u by Field Vane Shear (20%<PI<30%)	32	y = 0.2669x + 27.035	0.0019
9.	SPT N_{field} Vs C_u by Field Vane Shear (PI>30%)	15	y = 0.9145x + 21.769	0.0228
10.	Cu / SPT N'_{70} factor Vs PI	57	$y = 14.111 x^{-0.416}$	0.0169
11.	Cu / SPT N_{60} factor Vs PI	57	$y = 30.303 e^{-0.032x}$	0.0782
12.	Cu / SPT N_f factor Vs PI	57	$y = 14.803 e^{-0.031x}$	0.0718

4.3.5. Analysis based on the variation Fines Content.

The effects of the variation of fines content (FC) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to four sub categories based on their fines content as FC>90%, 90%<FC<80%, 80%<FC<70%, 70%<FC<60% and 60%<FC<50% for this analysis.

Undrained shear strength values of fine grained soil samples, determined with undrained shear strength by field vane shear test were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix IV, section 4.1, 4.2 and 4.3 respectively.

Further to get an overall idea on the effects of the fines content on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective fines content, as shown in the Appendix IV section 4.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.3.5.1 Results of analysis based on the variation of Fines Content

Table 4-23: Results of analysis based on the fines content variation.

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Field Vane Shear (FC>90%)	5	$y = 0.5096x + 34.45$	0.0325
2.	SPT N'_{70} Vs C_u by Field Vane Shear (80%<FC<90%)	14	$y = 0.4542x + 26.446$	0.0142
3.	SPT N'_{70} Vs C_u by Field Vane Shear (70%<FC<80%)	11	$y = -0.6253x + 27.181$	0.0364
4.	SPT N'_{70} Vs C_u by Field Vane Shear (60%<FC<70%)	21	$y = -0.04x + 29.018$	0.0002
5.	SPT N'_{70} Vs C_u by Field Vane Shear (50%<FC<60%)	24	$y = -0.1306x + 26.602$	0.0009
6.	SPT N_{60} Vs C_u by Field Vane Shear (FC>90%)	5	$y = 9.4674x + 21.604$	0.4300
7.	SPT N_{60} Vs C_u by Field Vane Shear (80%<FC<90%)	14	$y = -0.3757x + 30.582$	0.0003
8.	SPT N_{60} Vs C_u by Field Vane Shear (70%<FC<80%)	11	$y = 0.6259x + 20.481$	0.0063
9.	SPT N_{60} Vs C_u by Field Vane Shear (60%<FC<70%)	21	$y = 2.3293x + 24.635$	0.0534
10.	SPT N_{60} Vs C_u by Field Vane Shear (50%<FC<60%)	24	$y = -0.0438x + 25.786$	10^{-5}
11.	SPT N_{field} Vs C_u by Field Vane Shear (FC>90%)	5	$y = 4.3465x + 23.691$	0.3318
12.	SPT N_{field} Vs C_u by Field Vane Shear (80%<FC<90%)	14	$y = 0.2115x + 28.894$	0.0004
13.	SPT N_{field} Vs C_u by Field Vane Shear (70%<FC<80%)	11	$y = 0.3098x + 20.481$	0.0063
14.	SPT N_{field} Vs C_u by Field Vane Shear (60%<FC<70%)	21	$y = 1.0163x + 25.19$	0.0413
15.	SPT N_{field} Vs C_u by Field Vane Shear (50%<FC<60%)	24	$y = -0.0077x + 25.729$	10^{-6}
16.	Cu /SPT N'_{70} factor Vs FC	70	$y = 0.0028x^2 - 0.3913x + 18.151$	0.0116
17.	Cu /SPT N_{60} factor Vs FC	70	$y = 0.0028x^2 - 0.4369x + 32.694$	0.0039
18.	Cu /SPT N_f factor Vs FC	70	$y = 0.0022x^2 - 0.3382x + 20.564$	0.0057

4.3.6. Analysis based on the variation Clay Content.

The effects of the variation of clay content (CC) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to four sub categories based on their clay content as 50%<CC<70%, 40%<CC<50%, 30%<CC<40%, 20%<CC<30% and CC<20% for this analysis.

Undrained shear strength values of fine grained soil samples, determined with undrained shear strength by field vane shear test were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix IV, section 4.1, 4.2 and 4.3 respectively.

Further to get an overall idea on the effects of the clay content on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective clay content, as shown in the Appendix IV section 4.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.3.6.1 Results of analysis based on the variation of Clay Content

Table 4-24: Results of analysis based on the clay content variation.

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Field Vane Shear (40%<CC<60%)	8	y = 7.2655x + 2.0439	0.3202
2.	SPT N'_{70} Vs C_u by Field Vane Shear (30%<CC<40%)	15	y = -0.3829x + 24.017	0.0503
3.	SPT N'_{70} Vs C_u by Field Vane Shear (20%<CC<30%)	65	y = 0.1362x + 27.61	0.0019
4.	SPT N'_{70} Vs C_u by Field Vane Shear (CC<20%)	17	y = 0.9437x + 19.646	0.0473
5.	SPT N_{60} Vs C_u by Field Vane Shear (40%<CC<60%)	8	y = 28.68x - 13.88	0.6058
6.	SPT N_{60} Vs C_u by Field Vane Shear (30%<CC<40%)	15	y = 0.2954x + 20.236	0.0019

7.	SPT N_{60} Vs C_u by Field Vane Shear (20%<CC<30%)	65	y = 1.614x + 25.426	0.0186
8.	SPT N_{60} Vs C_u by Field Vane Shear (CC<20%)	17	y = 0.6907x + 25.184	0.0049
9.	SPT N_{field} Vs C_u by Field Vane Shear (40%<CC<60%)	8	y = 14.875x - 13.888	0.575
10.	SPT N_{field} Vs C_u by Field Vane Shear (30%<CC<40%)	15	y = 0.034x + 20.779	10^{-4}
11.	SPT N_{field} Vs C_u by Field Vane Shear (20%<CC<30%)	65	y = 0.7391x + 25.71	0.0157
12.	SPT N_{field} Vs C_u by Field Vane Shear (CC<20%)	17	y = 0.4895x + 24.684	0.009
13.	Cu /SPT N'_{70} factor Vs CC	70	$y = 0.0026x^2 - 0.074x + 4.6597$	0.0585
14.	Cu /SPT N_{60} factor Vs CC	70	y = -0.0791x + 18.272	0.0069
15.	Cu /SPT N_f factor Vs CC	70	$y = 0.0057x^2 - 0.3486x + 12.697$	0.0299

4.3.7. Analysis based on the variation Sampling Depth.

The effects of the variation of sampling depth (SD) on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to four sub categories based on their sampling depth as 0.3m, 1.3m, 2.3m, 3.3m, 4.3, 5.3 to 6.3m, 7.3 to 13.3m. for this analysis.

Undrained shear strength values of fine grained soil samples, determined with undrained shear strength by field vane shear test were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix IV, section 4.1, 4.2 and 4.3 respectively.

Further to get an overall idea on the effects of the Sampling depth on the undrained shear strength / SPT N ratio factor, the calculated factors for SPT N'_{70}, SPT N_{60} and SPT N_{field}, were plotted against the respective sampling depth, as shown in the

Appendix IV section 4.4. The available data with SPT N_{field} value zero (0) were not considered in this Analysis.

4.3.7.1 Results of analysis based on the variation of Sampling Depth

Table 4-25: Results of analysis based on the sampling depth variation.

	Analysis	**No of Data sets**	**Correlation**	**R^2 Value**
1.	SPT N'_{70} Vs C_u by Field Vane Shear (0.3m)	22	y = 0.299x + 23.212	0.0136
2.	SPT N'_{70} Vs C_u by Field Vane Shear (1.3m)	41	y = 0.1894x + 24.902	0.0021
3.	SPT N'_{70} Vs C_u by Field Vane Shear (2.3m)	14	y = 1.597x + 26.53	0.0564
4.	SPT N_{60} Vs C_u by Field Vane Shear (0.3m)	22	y = 1.7073x + 23.185	0.0196
5.	SPT N_{60} Vs C_u by Field Vane Shear (1.3m)	41	y = 2.0469x + 21.586	0.0329
6.	SPT N_{60} Vs C_u by Field Vane Shear (2.3m)	14	y = 1.0236x + 30.604	0.0063
7.	SPT N_{field} Vs C_u by Field Vane Shear (0.3m)	22	y = 0.8451x + 23.185	0.0196
8.	SPT N_{field} Vs C_u by Field Vane Shear (1.3m)	41	y = 1.0132x + 21.586	0.0329
9.	SPT N_{field} Vs C_u by Field Vane Shear (2.3m)	14	y = 0.5742x + 30.604	0.0063
10.	Cu /SPT N'_{70} factor Vs SD	72	$y = 1.4071x^2 - 1.0959x + 3.4888$	0.2113
11.	Cu /SPT N_{60} factor Vs SD	72	$y = 5.2994x^2 - 14.211x + 22.945$	0.0676
12.	Cu /SPT N_f factor Vs SD	72	$y = 3.2269x^2 - 8.0005x + 11.593$	0.0845

4.3.8. Analysis based on the Unified Soil Classification System (USCS)

The effects of the variation of Soil Type on the relationship between SPT N'_{70}, SPT N_{60} and SPT N_{field} and undrained shear strength by field vane shear test is studied in this section. Unified soil classification system (USCS) is used for the classification of available fine grained soil samples and categorized in to four divisions as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) and low plastic silt (ML) for this analysis.

Undrained shear strength values of undisturbed fine grained soil samples, determined with field vane shear test were plotted against the SPT N'_{70}, SPT N_{60} and SPT N_{field} values, observed from the respective soil stratums at the field, after correction and they are shown in the Appendix VI, section 8.1, 8.2 and 8.3 respectively, with aforesaid categories, categorized based on USCS.

4.3.8.1 Results of analysis based on the Unified Soil Classification System (USCS)

Table 4-26: Results of analysis based on the USCS.

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'_{70} Vs C_u by Field Vane Shear (CH)	24	y = 0.2667x + 27.923	0.0044
2.	SPT N'_{70} Vs C_u by Field Vane Shear (CL)	25	y = 1.5714x + 16.917	0.1177
3.	SPT N'_{70} Vs C_u by Field Vane Shear (MH)	9	y = -0.5529x + 35.074	0.0102
4.	SPT N'_{70} Vs C_u by Field Vane Shear (ML)	4	y = 0.0728x + 35.919	0.0003
5.	SPT N_{60} Vs C_u by Field Vane Shear (CH)	24	y = 0.2802x + 24.673	0.0006
6.	SPT N_{60} Vs C_u by Field Vane Shear (CL)	25	y = 1.8274x + 22.892	0.0207
7.	SPT N_{60} Vs C_u by Field Vane Shear (MH)	9	y = 1.0268x + 33.585	0.0025
8.	SPT N_{60} Vs C_u by Field Vane Shear (ML)	4	y = 1.1907x + 32.883	0.0364
9.	SPT N_{field} Vs C_u by Field Vane Shear (CH)	24	y = 4.0627x + 13.832	0.2193
10.	SPT N_{field} Vs C_u by Field Vane Shear (CL)	25	y = 2.7859x + 13.844	0.195
11.	SPT N_{field} Vs C_u by Field Vane Shear (MH)	9	y = -1.7427x + 18.311	0.2076
12.	SPT N_{field} Vs C_u by Field Vane Shear (ML)	4	y = -0.1364x + 24.5	0.0022

4.4 Analysis Using Reliable Data

It was unable to establish a firm correlation between SPT N (field, N_{60} & N'_{70}) and undrained shear strength, with all the detailed analysis performed under both of above sections 4.2 and 4.3, for the results of unconsolidated undrained (UU) triaxial test and field vane shear test. Highly heterogeneous samples, disturbed samples, inaccurate testing and reporting could be the main reasons for above.

A methodology of identifying the outliers or fault data contains in the available data set was required to extend the analysis in to the next level to avoid the aforesaid errors. Then it was decided to sort the available data, based on the reliability of them. Since all the tests results and data were extracted from the available geotechnical reports of major Sri Lankan projects, it was unable to omit any error data based on the testing or sampling records. Hence the *"Deviation Factor"* was introduce for the analysis, (Equation 25) in order to select the most accurate set of data. In here, the data sets of samples that have the test results of undrained shear strength determined by both unconsolidated undrained triaxial tests and field vane shear test were used for this analysis. The *Deviation factor* of each considered samples were calculated by taking the percentage of the difference between C_u from UU triaxial and C_u from FVST results (value only) to the average of the C_u from UU triaxial and C_u from FVST values, please refer Appendix V. In here, data sets with *lower "Deviation Factor"* consists with samples having closer C_u values from UU triaxial and FVST results which are *assumed to be accurate in this study*.

$$Deviation\ Factor = \left[\frac{\| C_u\ (UU\ Triaxial) - C_u\ (FVST) \|}{Avg\ [C_u (UU\ Triaxial) \& C_u\ (FVST)]}\right] x100 \quad \textit{(Equation 25)}$$

The average values of undrained shear strength values taken of both UU Triaxial Test and field vane shear test were plotted against both SPT N'_{70} SPT N_{60} and SPT N_{field} values under below five categories as percentage of deviation less than 10% (Figure 6), less than 25% (Figure 7) and less than 35% (Figure 8) defined according to their deviation factors.

4.4.1 SPT N’70, SPT N60 & SPT Nfield Vs Undrained Shear Strength (Average)

4.4.1.1 Percentage of deviation less than 10% for SPT N’70.

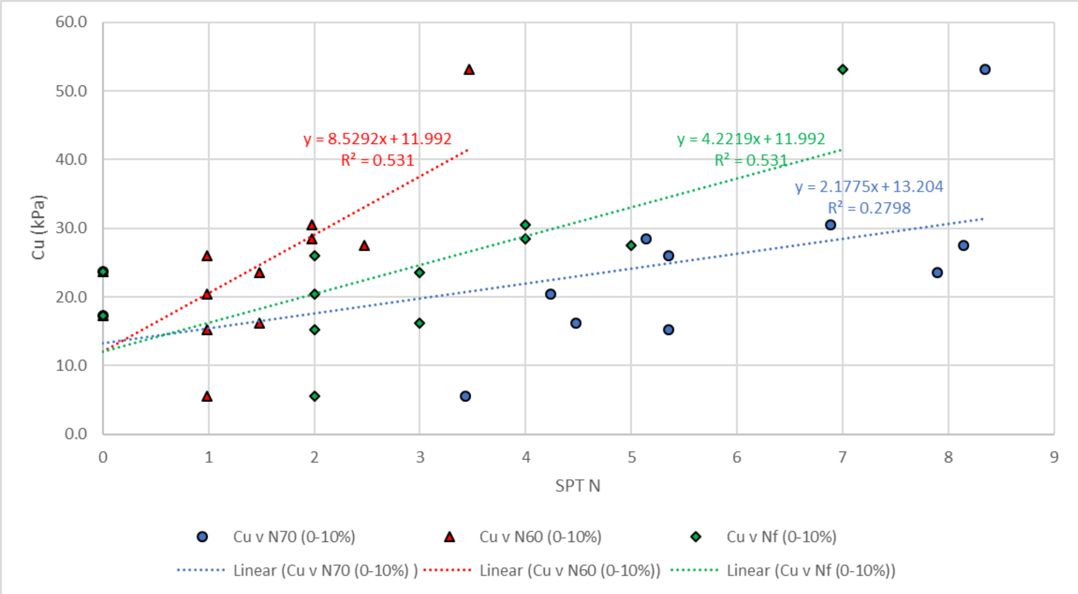

Figure 4-1 : SPT N’$_{70}$, SPT N$_{60}$ & SPT N$_{\text{field}}$ Vs undrained shear strength (Average) with percentage of deviation factor 10%

4.4.1.2 Percentage of deviation less than 25%.

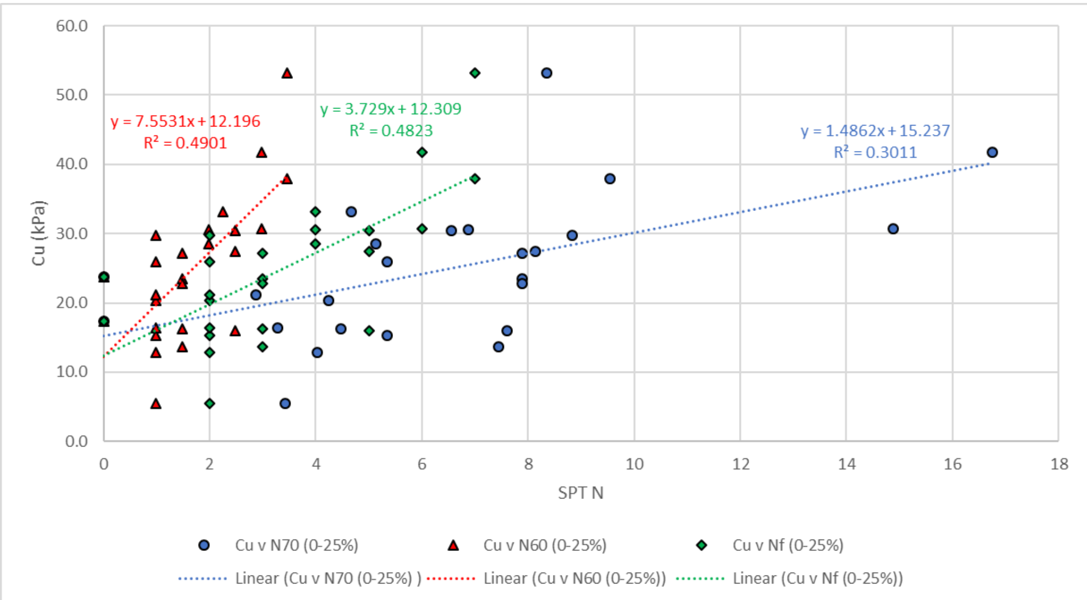

Figure 4-2 : SPT N’$_{70}$, SPT N$_{60}$ & SPT N$_{\text{field}}$ Vs undrained shear strength (Average) with percentage of deviation factor 25%

4.4.1.3 Percentage of deviation less than 35%.

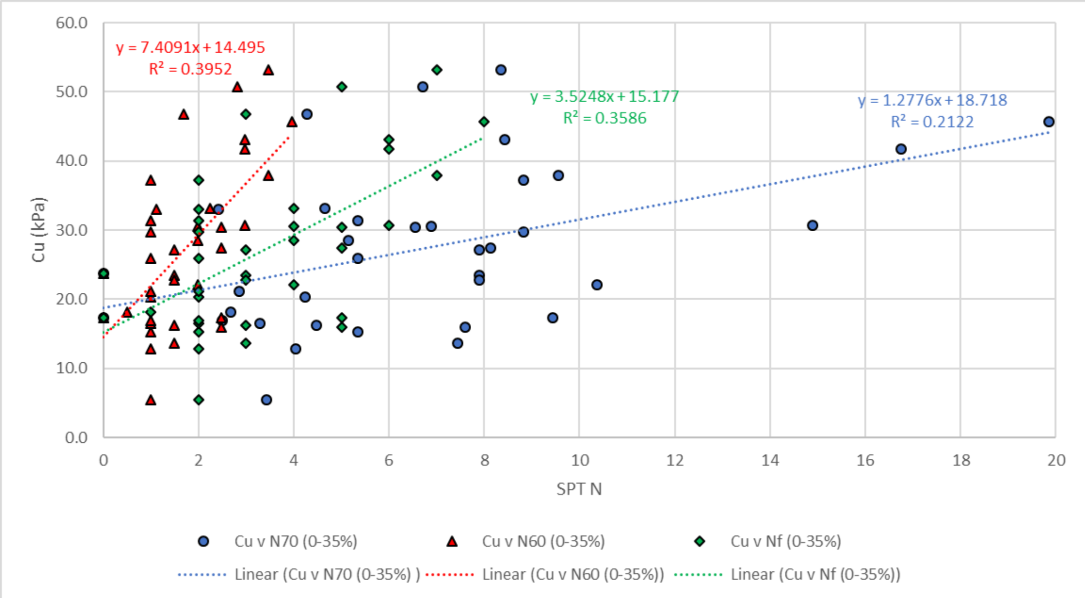

Figure 4-3 : SPT N'$_{70}$, SPT N$_{60}$ & SPT N$_{field}$ Vs undrained shear strength (Average) with percentage of deviation factor 35%

4.4.2 Results of analysis based on the "Reliable Data"

Table 4-27: Results of analysis based on the "*Reliable Data*".

	Analysis	No of Data sets	Correlation	R^2 Value
1.	SPT N'$_{70}$ Vs C_u (percentage of deviation less than 10%)	12	y = 2.1775x + 13.204	0.2798
2.	SPT N'$_{70}$ Vs Cu (percentage of deviation less than 25%)	25	y = 1.4862x + 15.237	0.3011
3.	SPT N'$_{70}$ Vs Cu (percentage of deviation less than 35%)	36	y = 1.2776x + 18.718	0.2122
4.	SPT N$_{60}$ Vs C_u (percentage of deviation less than 10%)	12	y = 8.5292x + 11.992	0.5310
5.	SPT N$_{60}$ Vs Cu (percentage of deviation less than 25%)	25	y = 7.5531x + 12.196	0.4901
6.	SPT N$_{60}$ Vs Cu (percentage of deviation less than 35%)	36	y = 7.4091x + 14.495	0.3952
7.	SPT N$_f$ Vs C_u (percentage of deviation less than 10%)	12	y = 4.2219x + 11.992	0.531
8.	SPT N$_f$ Vs Cu (percentage of deviation less than 25%)	25	y = 3.729x + 12.309	0.4823
9.	SPT N$_f$ Vs Cu (percentage of deviation less than 35%)	36	y = 3.5248x + 15.177	0.3586

4.4.3 Establishing a correlation

It was evident that there is a pattern observed in the plot of SPT N_{60} and SPT N_f against the average C_u value obtained from UU Triaxial and FVST, for the deviation factor below 10% with R^2 of 0.531. Analysis on the data set with the deviation factor below 25% showed 0.4901 of R^2 value for SPT N_{60} and 0.4823 of R^2 value for SPT N_f.

Considering the R^2 and the better representative of energy application of SPT test SPT N_{60} was selected as the best option of representing the correlation and the correlation was established based on SPT N_{60}. Further, the facts that only 12 available data sets for 10% deviation factor, which is quite low and the R^2 of 0.4901 attain from the 25% deviation analysis, the establishment of correlation was done for 25% deviation factor, as shown in *Figure 9*.

Hence $\mathbf{C_u = 7.55\ N_{60} + 12.2}$ was taken as correlation between SPT N_{60} and undrained shear strength.

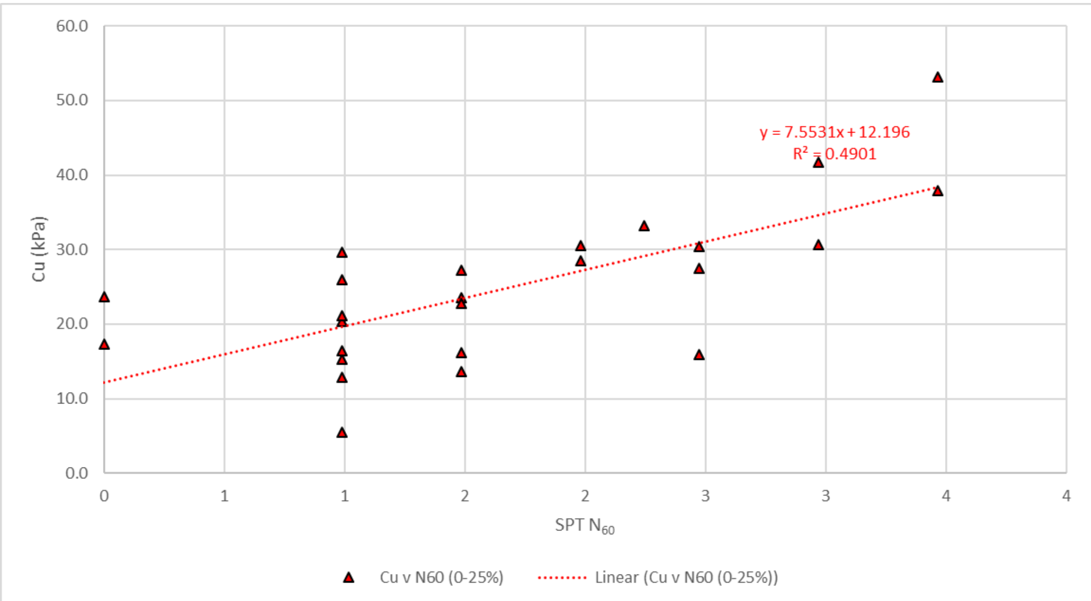

Figure 4-4: SPT N_{60} undrained shear strength (Average) with percentage of deviation factor 25%

4.4.3.1 Further Analysis

Considering the fact that having a relatively low R^2, value of 0.4901, it was decided to propose a range rather than a fix valued equation, which is more appropriate and an envelope was defined with an upper and lower boundary as follows.

Upper Boundary : $C_u = 7.55\ N_{60} + 24.4$

Lower Boundary : $C_u = 7.55\ N_{60}$, as shown in Figure 10.

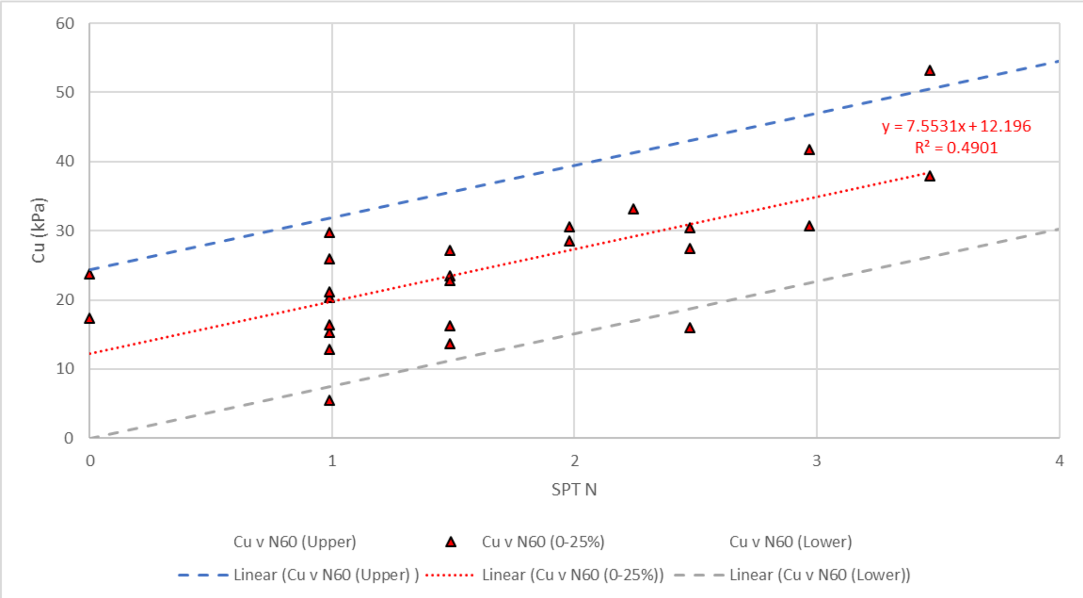

Figure 4-5: SPT N_{60} V undrained shear strength (Average) with percentage of deviation factor 25% with upper and lower boundary

88 % of the considered data sets (of 25) fell in to the aforementioned envelop and 8% (2) over estimated and 4% (1) under estimated by it. Also it was observed that 96% (of 25) of the data set analyzed are silt material (on grain size) and only one data set is clay material. Also all these concerned data from shallow depths varying only from 0 to 2.5m depths.

The proposed envelop was applied to the available complete silt size material set with undrained shear strength determined by UU triaxial Test) of 119 data set and the applicability was analyzed. It was revealed that 77 (65%) of the data set were within the proposed envelop or underestimated and 42 (35%) were overestimated as shown in *Figure 4-6* which is an acceptable grouping.

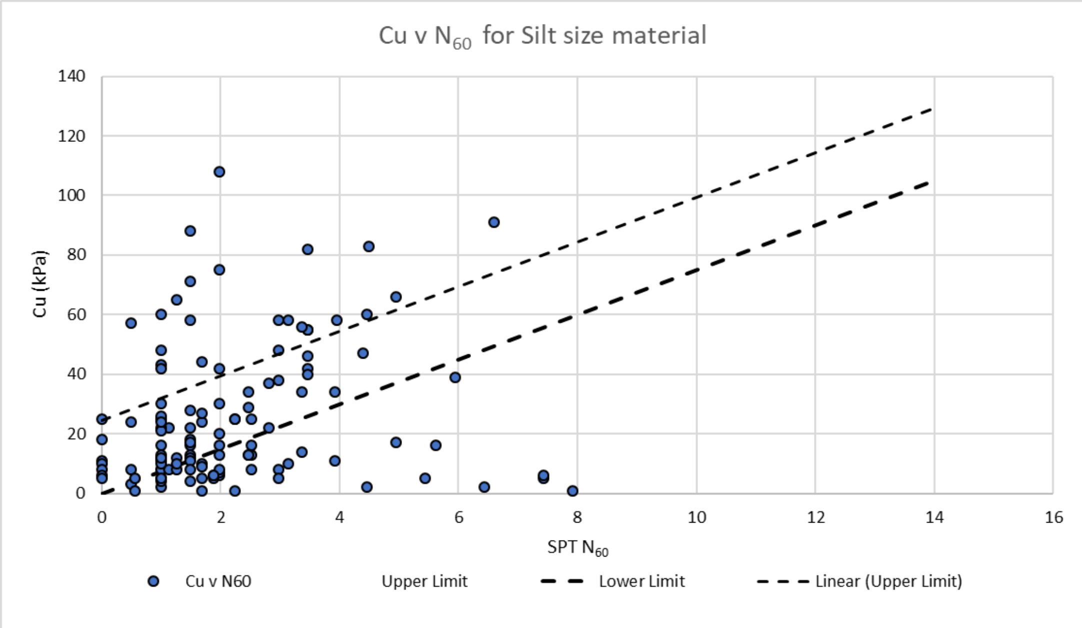

Figure 4-6: SPT N_{60} V undrained shear strength (UU triaxial) for silt material by grain size.

5. DISCUSSION

5.1 Evaluation of available correlations.

As the first step of the research, the available correlations between undrained shear strength and SPT N values were analyzed in section 4.1, under three subcategories formed based on the SPT values considered, as SPT N'_{70}, SPT N_{60} & SPT N_{field}.

a) SPT N'_{70} V undrained shear strength
   i. Relationship proposed by Joseph E. Bowles
b) SPT N_{60} V undrained shear strength
   a. Relationship proposed by Strouds, (1974)
   b. Relationship proposed by Hara A et al., (1974)
   c. Relationship proposed by Sivikaya & Togrol, (2007)
   d. Relationship proposed by Décourt, (1990)
   e. Relationship proposed by Terzaghi & Peck, (1967)
c) SPT N_{field} V undrained shear strength
   a. Relationship proposed by Terzaghi & Peck, (1967)
   b. Relationship proposed by Sowers, (1979)
   c. Relationship proposed by Sivikaya & Togrol, (2007)
   d. Relationship proposed by Décourt, (1990)

Undrained shear strength values predicted from the aforementioned correlations were analyzed with the available results of undrained shear strength values, obtained from both unconsolidated undrained triaxial tests and field vane shear test separately. Applicability of them on Sri Lankan conditions were analyzed and it was revealed that the available data set does not satisfy any of the available correlations studied under the literature review of this thesis. The closest agreement of predicted results with the UU triaxial test results exhibited by the correlation proposed by Strouds, (1974) for C_U = 6-7 N_{60} (for PI<20), with a R_2 of 0.3701.

Possible reasons for the aforementioned deviations are listed below and discussed.

1. Changes in geological formation, material types and compositions.

All the available correlations considered here were studied and published for soils from foreign geological conditions and formations which are quite different from the Sri Lankan conditions, since more than 95% of the samples / data used for the study are from alluvial origin and this differences in the geological formation could be a reason for the deviation of the calculated results from the available correlations from the actual results.

2. Inaccuracy of the available data.

Errors occurred at the time of in-situ tests (SPT & FVST), during undisturbed sampling, at the time of laboratory testing (UU triaxial tests), at reporting the results could have caused the deviation of the calculated results from the available correlations from the actual results.

3. Problems associated with the correlations.

All the considered, available correlations between SPT N value and undrained shear strength do not give an undrained shear strength value for the soils with zero SPT N values. But when we consider the actual data it is evident that the soils with SPT N zero have undrained shear strength values. For the considered data set the undrained shear strength values of samples corresponding to SPT N zero, varies from 5kPa to 25kPa.

This also induce deviations of actual test results from the results attain from the available correlations.

5.2 Analysis of available data to develop a new correlation

Since it was unable to validate an existing correlation to estimate the undrained shear strength from SPT results for fine grained soils with available local set, (Refer Appendix I) the focus of the analysis was set to develop a new correlation between the SPT results and undrained shear strength as the second stage.

In the studies of the back ground in the literature review, it was revealed that the index properties, grain sizes, sampling depth (for SPT), soil classification are the main influencing factors for the relationship between SPT N value and the undrained shear strength of fine grained soils.

Hence a detailed analysis was conducted on the available local data set, with categorizing liquid limit, plastic limit, plasticity index, clay content, fines content, sampling depth and soil texture as influencing factors for the correlation between SPT N value (SPT N_f, SPT N_{60} and SPT N'_{70}) and undrained shear strength of local fine grained soils.

Further, the both available undrained shear strength values taken from UU triaxial tests and field vane shear test were studied separately and R squared (R^2) was used for the statistical measures and find the line of best fit from the considered regression model.

As described in the analysis sections 4.2 and 4.3 all of the analytical approaches used failed to provide inconclusive evidences to establish a correlation between SPT N values and undrained shear strength. The possible reasons for this are listed below and discussed.

1. Composition of the soil (properties and grain size based)

When the available correlations are considered, most of the correlations had been established for a single material type and composition, for examples St. Paulo clay, Oxford clay, London clay, Kimeridge clay, Chicargo, Turkish soils and etc. Hence the complete data set consists with results of tests conducted on soils with mostly similar properties.

Whereas, the composition of soils of the considered in this study, are highly heterogeneous in nature. Most of the samples contain considerable, different amounts of sand and silt contents. Hence, it is difficult to pin point a conclusion in the form of an equation rather than recommending a range of applicability.

2. Inaccuracy of the available data.

The test results used in this research had been conducted for construction purposes and not for research purposes. Hence the performance of the testing could not have been perfect and necessarily according to the prescribed standards. Thus, errors occurred at the time of in-situ tests (SPT & FVST), at the time of undisturbed sampling, at the time of laboratory testing (UU Triaxial Tests), at reporting the results could have caused the deviation of the calculated results in the analysis.

5.3 Analysis on the reliable data set.

To minimize the effects of aforesaid errors occurred during both laboratory and in-situ testing, it was decided to identify the most reliable data (refer Appendix V) from the available data set. The reliability of the data was measured in terms of a newly introduces factor called "*deviation factor"* (Equation 25) which was calculated by dividing the difference between C_u from UU triaxial and C_u from FVST results (value only), by the average of C_u from UU triaxial and C_u from FVST results (section 4.4.), It's Lower the deviation factor, higher the reliability of the game.

The analysis of reliable data considering deviation factor provided the correlation

$$C_u = 7.5\, N_{60} + 12.2$$

The above correlation provides an undrained shear strength value of 12kPa for the SPT zero valued soil conditions which actually simulates the actual test results obtained from both UU triaxial tests and FVST.

Further developed an envelope with boundaries as,

Upper Boundary : $C_u = 7.55\, N_{60} + 24.4$

Lower Boundary : $C_u = 7.55\, N_{60}$

which enhance the efficiency of the proposed correlation, since it presents the opportunity for the users to go on the conservative side as well as towards the upper boundary, based on the requirement. Further it should be noted that this correlation was defined only for the silt soils (by grain size).

The possible reasons for deviations observed with applying all the available of silt material in section 4.4.3.1. are listed below.

1. This correlation was only defined for the samples attained from depths 0 to 2.5m.

The available FVST data were only within the range 0m to 2.5m depth, hence the reliable data used to establish the correlation only within the range of 0m to 2.5m depths. This might cause some deviation of the actual test results from the correlation developed results, due to inaccurate correction factor for depth in SPT N_{60} correction.

2. Variations of the material composition.

Composition of the available silt soils (by grain size) varies in a large rage, from 84% to 27% of silt content by weight. Which could be affected the variation of results, since the data set considered for establishing the correlation (with deviation factor 25%) contains 92% of samples with silt contains only varies from 30% to 60%.

3. Inaccuracy of the available data.

As explained above, the test results used for this research had been conducted for the construction purposes and not for the research purposes. Hence the performance of the testing could not have been perfect and errors occurred at the time of in-situ tests (SPT), at the time of undisturbed sampling, at the time of laboratory testing (UU triaxial tests), at reporting the results could have caused the deviation of the calculated results from the new correlations from the actual results.

6. RECOMMENDATIONS

This study was carried out to establish a correlation between standard penetration tests results and undrained shear strength of fine grained soils in Sri Lankan geological conditions. Based on the available data set, mainly from the alluvial formation of the Western and North Central part of the country, none of the available correlations for the fine grained soils could be validated with a certain confidence level.

Then, the analysis was focused on to develop a new correlation by considering the variations of soil USCS classification, liquid limit, plastic limit, plastic index, fines content, clay content and sampling depth. However, these efforts were ended up not yielding a satisfactory correlation with a certain confidence level between the standard penetration tests results and undrained shear strength. Analysis were further carried out on set of reliable test data after the removal of outliers on a defined coefficient called "*deviation factor*" and a correlation was proposed between standard penetration tests results and undrained shear strength based on that.

The proposed correlation and the envelop were established based on the tests results conducted mostly on silt soils at shallow depths, 0 to 2.5m depths for Sri Lankan geological conditions and with a low R^2 value on the regression analysis. Hence it is recommended to extend this analysis for different types of soils considering below mentioned points.

$C_u = 7.55\ N_{60} + 12.2$

Upper Boundary : $C_u = 7.55\ N_{60} + 24.4$

Lower Boundary : $C_u = 7.55\ N_{60}$

The validity of the of above needs to be analyzed for deeper depths and clayey soils with accurate data sets. Special attention must be paid for the correctly performed SPT tests, undisturbed sampling, laboratory tests including UU triaxial tests and etc.

Further, application of multiple regression by altering the available soil properties could produce better and accurate correlations and also study must be extended to cover all the soil formations encountered in Sri Lanka, especially for soils with residual formation which is the predominant type of formation in Sri Lanka.

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Appendix I : Complete Data Set

Table I-1: Complete data set

Borehole No	Water Table at (m)	Layer Depth (m)	Description	USCS	Sample Depth (m)	Particle Size Distribution					Atterberg Limits			Specific Gravity	NMC (%)	Unconsolidated Undrained TT			Vane Shear Test			SPT Correction			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	LL (%)	PL (%)	PI (%)			No of Samples	C_u (kPa)	Φ_u	Depth (m)	Peak S/S (kN/m^2)	Residual S/S (kN/m^2)	Depth	SPT N_f	SPT N'_{70}	SPT N_{60}
BH 8500 L	0.50	0.0-1.4	clayey SILT with traces of sand	M H	0.0	0	7	83	10	93	60	41	19	2.46	70.6	3	11	0.5				0.3	0	0	0
BH 8500 L	0.50	0.0-1.4	clayey SILT with traces of sand	M H	0.0	0	7	83	10	93	60	41	19	2.46	70.6	3	10	1.33	1.00	28.0	12.5	1.3	0	0	0
BH 6247 N-C	0.50	0.0-1.0	sandy SILT with traces of clay	C L	0.0	0	47	47	6	53	34	19	15	2.62	38.4	2	8	1				0.3	1	3	0
BH 6354 N-C	0.60	0.8-1.8	sandy SILT with traces of clay & organic matter	M L	1.0	0	19	73	8	81	NP	NP	NP	2.47	87.8	1	5	0				1.3	2	3	1
BH 6354 N-C	0.60	0.8-1.8	sandy SILT with traces of clay & organic matter	M L	1.0	0	19	73	8	81	NP	NP	NP	2.47	87.8	2	2	0				1.3	2	3	1
BH 6440 N-C	0.20	0.8-2.8	sandy SILT with clay	C L	1.0	0	43	33	24	57	39	17	22	2.61	34.5	2	3	1				1.3	1	2	0
BH 6440 N-C	0.20	0.8-2.8	sandy SILT with clay	C L	1.0	0	43	33	24	57	39	17	22	2.61	34.5	1	5	0				2.3	1	1	1
BH 6440 N-C	0.20	0.8-2.8	sandy SILT with clay	C L	2.0	0	42	32	26	58	40	18	22	2.61	32.3	1	1	0				2.3	1	1	1
BH 6440 N-C	0.20	2.8-4.0	sandy SILT with clay	C L	3.0	0	42	33	25	58	41	17	24	2.60	34.2	2	1	0				3.3	3	4	2
BH 22843 N-C	1.30	2.0-3.0	clayey SILT with sand	M H	2.0	0	27	43	30	73	58	35	23	2.74	39.5	2	34	0				2.3	7	7	4
BH 22843 N-C	1.30	3.0-4.0	sandy SILT with clay	C L	3.0	0	46	32	22	54	36	17	19	2.70	26.2	2	14	2				3.3	6	6	3
BH 23034 N-R	0.90	0.0-1.0	clayey SILT with some sand	M L	0.0	0	13	69	18	87	NP	NP	NP	2.51	47.0	1	43	0				0.3	2	5	1
BH 23074 N-L	0.20	0.0-0.8	clayey SILT with traces of sand	M L	0.0	0	6	74	20	94	NP	NP	NP	2.55	50.9	2	48	0	0.50	35.4	23.3	0.3	6	17	3
BH 23074 N-R	1.50	0.8-1.9	clayey SILT with sand	M L	1.0	0	28	43	29	72	NP	NP	NP	2.59	22.2	2	42	0				1.3	7	8	3
BH 23074 N-R	1.50	0.8-1.9	clayey SILT with sand	M L	1.0	0	28	43	29	72	NP	NP	NP	2.59	22.2	1	55	0	1.40	51.3	28.0	1.3	7	8	3
BH 23636 N-L	0.30	0.0-0.8	clayey SILT with sand	C H	0.0	0	16	56	28	84	54	28	26	2.54	35.5	1	58	0	0.70	33.5	23.6	0.3	8	20	4
BH 23636 N-R	0.30	0.0-0.8	clayey SILT with sand	M H	0.0	0	20	60	20	80	59	31	28	2.51	42.6	2	12	4	0.50	50.6	26.8	0.3	3	8	1
BH 23656 N-R	0.80	0.0-0.8	sandy SILT with traces of clay & organic debris	M L	0.0	2	27	63	8	71	NP	NP	NP	2.46	38.0	1	7	0				0.3	4	10	2
BH 23797 N-L	0.90	0.6-1.6	sandy SILT with clay	C L	1.0	0	44	34	22	56	43	20	23	2.59	37.4	1	34	0	1.10	26.8	17.1	1.3	5	7	2
BH 23797 N-L	0.90	1.6-2.5	sandy SILT with clay	M H	2.0	0	47	27	26	53	56	32	24	2.62	61.6	2	9	1				2.3	3	3	2
BH 23797 N-L	0.90	1.6-2.5	sandy SILT with clay	M H	2.0	0	47	27	26	53	56	32	24	2.62	61.6	2	5	1				2.3	3	4	2
BH 23797 N-R	0.40	0.6-1.7	sandy SILT with clay	C H	1.0	0	35	38	27	65	56	19	37	2.64	38.1	2	5	1				1.3	15	22	7
BH 23797 N-R	0.40	0.6-1.7	sandy SILT with clay	C H	1.0	0	35	38	27	65	56	19	37	2.64	38.1	2	6	1				1.3	15	22	7
BH 23817 N-R	0.40	0.7-1.5	sandy SILT with clay	C L	1.0	0	46	31	23	54	46	19	27	2.64	32.0	1	5	0	1.00	28.9	13.2	1.3	6	9	3
BH 24117 N-C	0.40	0.0-1.0	sandy SILT with traces of clay & organic debris	M L	0.0	2	31	59	8	67	NP	NP	NP	2.48	48.6	2	5	0				0.3	11	27	5
BH 24214 N-L	0.20	0.0-1.0	sandy SILT with clay	M L	0.0	0	37	56	7	63	48	30	18	2.51	53.9	2	18	0	0.50	44.4	19.7	0.3	3	9	1
BH 24214 N-R	0.50	1.0-1.6	sandy SILT with clay	C L	1.0	0	41	36	23	59	42	21	21	2.59	42.8	1	13	0	1.00	19.9	9.7	1.3	2	3	1
BH 24838 N-L	0.80	0.0-1.0	sandy SILT with clay	M L	0.0	1	41	38	20	58	45	27	18	2.56	41.2	1	38	0	0.50	23.3	9.2	0.3	6	15	3
BH 24838 N-R	0.50	0.0-0.7	sandy SILT with some clay	M L	0.0	0	47	39	14	53	47	28	19	2.56	33.1	1	22	0	0.50	32.4	12.7	0.3	3	8	1
BH 24945 N-C	0.00	0.0-0.8	sandy SILT with traces of clay	M H	0.0	0	26	65	9	74	61	37	24	2.48	81.7	1	25	0	0.50	34.4	19.4	0.3	2	9	1
BH 24945 N-C	0.00	1.8-3.5	sandy SILT with clay	M H	2.0	0	21	62	17	79	58	33	25	2.56	67.9	2	1	0				2.3	4	6	2
BH 13360 N-C	1.30	2.8-3.8	SILT with clay	C L	3.0	2	25	56	17	73	43	21	22	2.64	37.6	1	25	0				3.3	4	4	2
BH 13360 N-C	1.30	3.8-5.0	clayey SILT with some sand	C H	4.0	0	10	60	30	90	56	29	27	2.59	57.0	1	58	0				4.3	5	4	3
BH 26268-N-L	0.45	0.8-1.6	sandy SILT with clay	C H	1.0	1	45	32	22	54	51	28	23	2.64	29.4	2	13	0	1.00	61.0	32.8	1.3	5	8	2

Borehole No	Water Table at (m)	Layer Depth (m)	Description	USCS	Sample Depth (m)	Particle Size Distribution					Atterberg Limits			Specific Gravity	NMC (%)	Unconsolidated Undrained TT			Vane Shear Test			SPT Correction			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	LL (%)	PL (%)	PI (%)			No of Samples	C_u (kPa)	Φ_u	Depth (m)	Peak S/S (kN/m^2)	Residual S/S (kN/m^2)	Depth	SPT N_f	SPT N'_{70}	SPT N_{60}
BH 26268-N-L	0.45	1.6-2.6	clayey SILT with sand	C H	2.0	1	15	54	30	84	60	28	32	2.62	42.4	1	11	0				2.3	7	8	4
BH 26426 N-C	1.50	0.6-2.6	sandy SILT with clay	M L	1.0	3	30	50	14	64	49	28	21	2.64	34.4	1	66	0				1.3	10	12	5
BH 26426 N-C	1.50	0.6-2.6	sandy SILT with clay	M L	1.0	3	30	50	14	64	49	28	21	2.64	34.4	1	17	0	1.10	44.4	27.7	1.3	10	12	5
BH 26426 N-C	1.50	0.6-2.6	sandy SILT with clay	C L	2.0	2	41	40	17	57	41	22	19	2.66	32.3	1	83	0	2.20	17.6	6.9	2.3	8	8	4
BH 26868-N-C	0.50	0.8-1.7	sandy SILT with clay	C H	1.0	1	29	43	27	70	55	28	27	2.63	48.4	1	2	0	1.00	16.0	7.9	1.3	9	13	4
BH 26868-N-C	0.50	1.7-2.9	sandy SILT with clay	C H	2.0	1	30	39	30	69	51	24	27	2.62	57.4	1	8	0	1.50	24.5	24.5	2.3	0	0	0
BH 26968-N-C	0.00	0.0-1.0	sandy SILT with some clay	M H	0.0	0	25	62	13	75	61	32	29	2.59	26.2	1	42	0				0.3	4	16	2
BH 27068-N-C	0.49	1.8-2.8	sandy SILT with clay	C L	2.0	2	45	30	23	53	36	17	19	2.67	32.5	1	6	0	1.50	21.0	15.5	2.3	0	0	0
BH 27068-N-C	0.49	1.8-2.8	sandy SILT with clay	C L	2.0	2	45	30	23	53	36	17	19	2.67	32.5	3	5	0				2.3	0	0	0
BH 27100-N-L	0.80	0.6-1.7	sandy SILT with clay	C L	1.0	0	33	44	23	67	41	25	16	2.67	32.8	2	11	0	1.25	25.0	20.3	1.3	3	4	1
BH 27100-N-R	0.80	0.0-1.2	sandy SILT with some clay	M H	0.0	0	14	75	11	86	73	37	36	2.58	29.1	2	6	0	0.75	18.0	13.6	0.3	4	10	2
BH 27100-N-R	0.80	1.2-1.8	clayey SILT with some sand	M H	1.0	1	14	48	37	85	64	33	31	2.60	39.8	2	8	1	1.25	16.9	6.9	1.3	6	9	3
BH 27310-N-R	0.59	0.0-0.7	sandy SILT with traces of clay	M H	0.0	0	17	67	16	83	57	32	25	2.59	36.1	1	13	0	0.50	34.7	19.7	0.3	3	8	1
BH 14664-N-L	1.20	5.8-7.0	sandy SILT with clay	C L	6.0	2	26	47	25	72	48	19	29	2.65	28.8	3	5	2				6.3	3	2	2
BH 14664-N-L	1.20	5.8-7.0	sandy SILT with clay	C L	6.0	2	26	47	25	72	48	19	29	2.65	28.8	1	6	0				6.3	3	2	2
BH 14827-N-L	1.40	0.8-1.8	sandy SILT with clay	C L	1.0	2	34	42	22	64	46	23	23	2.63	46.9	1	30	0	1.40	27.0	13.4	1.3	4	5	2
BH 14867-N-L	1.00	0.5-1.8	sandy SILT with clay with traces of gravel	C L	1.0	4	35	41	20	61	45	23	22	2.66	47.2	2	46	5	1.50	29.8	0.7	1.3	7	10	3
BH 14867-N-L	1.00	1.8-3.9	sandy SILT with clay	C L	3.0	1	38	38	23	61	36	16	20	2.65	38.6	1	22	0	2.00	43.9	29.8	2.3	2	2	1
BH 14867-N-L	1.00	4.6-5.9	sandy SILT with clay	C L	5.0	0	40	40	20	60	35	17	18	2.70	36.8	2	8	0				5.3	4	4	3
BH 14867-N-L	1.00	4.6-5.9	sandy SILT with clay	C L	5.0	0	40	40	20	60	35	17	18	2.70	36.8	1	25	0				5.3	4	4	3
BH14867-N-R	1.20	0.7-1.6	sandy SILT with clay	C L	1.0	4	43	33	20	53	40	22	18	2.69	33.3	2	13	5	1.50	43.9	11.3	1.3	4	5	2
BH 20865 N-L	1.00	0.8-2.0	sandy SILT with clay	C H	1.0	0	44	32	24	56	59	30	29	2.75	34.0	1	82	0	1.30	9.0	5.1	1.3	7	9	3
BH 20865 N-R	1.60	0.0-0.8	sandy SILT with clay	C H	0.0	0	35	35	30	65	50	23	27	2.68	29.1	1	60	0	0.50	21.7	9.0	0.3	9	22	4
BH 21135 N-L	0.70	0.7-1.8	sandy SILT with some clay	M L	1.0	0	12	78	10	88	NP	NP	NP	2.58	39.3	1	71	0	0.60	20.3	10.0	1.3	3	4	1
BH 21135 N-L	0.70	0.7-1.8	sandy SILT with some clay	M L	1.0	0	12	78	10	88	NP	NP	NP	2.58	39.3	2	16	3	1.20	16.4	9.2	1.3	3	4	1
BH 21295 N-C	1.30	0.6-2.8	clayey SILT with sand	C H	2.0	0	14	48	38	86	59	26	33	2.64	31.6	2	37	3	2.00	17.6	6.7	2.3	5	5	3
BH 21295 N-C	1.30	0.6-2.8	clayey SILT with sand	C H	2.0	0	14	48	38	86	59	26	33	2.64	31.6	3	22	1				2.3	5	5	3
BH 21396.5 N-C	1.20	0.0-0.8	sandy SILT with some clay	M H	0.0	0	24	63	13	76	56	34	22	2.62	34.4	2	20	5				0.3	4	10	2
BH 21495 N-C	1.70	0.6-1.7	sandy SILT with some clay	C L	1.0	0	45	41	14	55	45	20	25	2.68	24.9	2	4	0				1.3	3	4	1
BH 21534 N-R	1.10	1.8-3.0	clayey SILT with sand	C H	2.0	0	23	50	27	77	70	29	41	2.61	43.3	1	25	0	2.00	22.4	8.0	2.3	0	0	0
BH 21684 N-R	0.60	0.0-0.8	clayey SILT with traces of sand & some organic materials	M H	0.0	0	7	80	13	93	71	37	34	2.53	67.6	3	2	1				0.3	13	31	6
BH 21684 N-R	0.60	0.8-1.6	clayey SILT with traces of organic materials	M L	1.0	0	4	84	12	96	NP	NP	NP	2.50	84.9	2	1	1				1.3	16	21	8
BH 29110-N-C	0.08	0.6-1.6	sandy SILT with clay	C H	1.0	4	44	30	22	52	51	21	30	2.60	29.5	2	10	0	1.50	15.7	14.6	1.3	2	4	1
BH 17835 N-C	1.30	0.0-0.9	sandy SILT with clay	C L	0.0	1	38	46	15	61	48	23	25	2.58	25.9	1	8	0	0.50	51.6	19.3	0.3	2	5	1
BH 17887 N-C	1.00	0.0-1.2	sandy SILT with some clay	C L	0.0	1	28	56	15	71	48	25	23	2.62	32.7	1	12	0				0.3	2	5	1
BH 17887 N-C	1.00	1.2-1.8	sandy SILT with clay	C H	1.0	1	31	43	25	68	57	29	28	2.61	37.7	1	11	0	1.00	46.5	17.3	1.3	2	3	1

Borehole No	Water Table at (m)	Layer Depth (m)	Description	USCS	Sample Depth (m)	Particle Size Distribution					Atterberg Limits			Specific Gravity	NMC (%)	Unconsolidated Undrained TT			Vane Shear Test			SPT Correction			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	LL (%)	PL (%)	PI (%)			No of Samples	C_u (kPa)	Φ_u	Depth (m)	Peak S/S (kN/m^2)	Residual S/S (kN/m^2)	Depth	SPT N_f	SPT N'_{70}	SPT N_{60}
BH 17887 N-C	1.00	1.2-1.8	sandy SILT with clay	C H	1.0	1	31	43	25	68	57	29	28	2.61	37.7	1	8	0				1.3	2	3	1
BH 17957 N-C	0.70	1.6-2.5	sandy SILT wit clay & traces of gravel	M H	2.0	7	35	37	21	58	56	34	22	2.71	49.2	2	8	0				2.3	2	3	1
BH 17986 N-R	0.90	0.6-2.5	sandy SILT with clay	C H	1.0	0	33	36	31	67	54	22	32	2.64	37.0	1	21	0				1.3	2	3	1
BH 17986 N-R	0.90	0.6-2.5	sandy SILT with clay	C H	1.0	0	33	36	31	67	54	22	32	2.64	37.0	1	24	0	1.00	18.3	11.1	1.3	2	3	1
BH 5319 N-R	0.45	0.0-0.9	sandy SILT with traces of clay	M L	0.0	2	42	49	7	56	NP	NP	NP	2.51	45.5	1	28	0	0.50	17.6	13.4	0.3	3	8	1
BH 5339 N-L	0.65	0.0-0.9	sandy SILT with traces of clay	M L	0.0	2	29	60	9	69	NP	NP	NP	2.47	49.1	1	16	0	0.50	14.6	7.4	0.3	2	5	1
BH 5339 N-L	0.65	0.9-1.8	sandy SILT with traces of clay	M L	1.0	0	37	54	9	63	NP	NP	NP	2.58	23.4	1	13	0	1.00	18.9	13.6	1.3	5	8	2
BH 27310 N-L	1.50	0.7-1.5	sandy elastic SILT	M H	1.0	5	25	36	34	70	68	39	29	2.64	42.9	1	39	0				1.3	12	14	6
BH 31881 N-L	0.35	0.0-0.9	sandy SILT with clay	M L	0.0	0	43	32	25	57	NP	NP	NP	2.62	32.1	1	26	0	0.50	25.9	13.9	0.3	2	5	1
BH 31881 N-R	1.36	2.5-3.5	clayey SILT	M L	3.0					0	NP	NP	NP	2.67	39.4	1	24	0				3.3	1	1	1
BH 13554 N-R	1.50	3.6-6.3	elastic SILT with sand	M H	4.0	3	19	44	34	78	68	34	34	2.64	70.1	1	8	0				4.3	2	2	1
BH 13554 N-R	1.50	3.6-6.3	elastic SILT with sand	M H	5.0	1	14	46	39	85	68	34	34	2.67	65.8	2	10	2				4.3	2	2	1
BH 13554 N-R	1.50	3.6-6.3	elastic SILT with sand	M H	5.0	1	14	46	39	85	68	34	34	2.67	65.8	2	6	1				5.3	3	2	2
BH 16320 N-C	1.50	0.8-1.6	clayey SILT with sand and traces of clay	M L	1.0	5	21	42	32	74	NP	NP	NP	2.60	41.9	1	55	0	1.00	21.7	15.9	1.3	7	8	3
BH 16398 N-C	0.00	0.7-2.9	elastic SILT	M H	1.0	0	7	50	43	93	69	36	33	2.73	57.8	2	22	5	1.00	18.7	11.5	1.3	2	4	1
BH 16398 N-C	0.00	0.7-2.9	elastic SILT	M H	2.0	0	12	52	36	88	64	32	32	2.73	40.7	2	24	0				2.3	3	5	2
BH 19264 N-R	0.00	0.0-1.7	sandy SILT with clay	M L	0.0	1	41	38	20	58	NP	NP	NP	2.59	40.8	1	48	0	0.50	26.6	12.7	0.3	2	9	1
BH 19264 N-R	0.00	0.0-1.7	sandy SILT with clay	M L	1.0	0	47	29	24	53	NP	NP	NP	2.60	31.5	1	88	0	1.20	22.2	14.3	1.3	3	6	1
BH 6796 N-R	0.40	0.6-1.6	sandy CLAY	C L	1.0	-	-	-	-	-	49	21	28	-	83.3	2	5	0	1.25	6.0	4.2	1.3	2	3	1
BH 6247 N-C	0.50	1.0-1.8	sandy CLAY with silt	C H	1.0	0	37	29	34	63	60	26	34	2.66	32.6	2	6	1				1.3	9	13	4
BH 23034 N-R	0.90	1.0-1.8	silty CLAY with sand	M H	1.0	0	18	36	46	82	57	30	27	2.55	42.2	1	12	0	1.00	49.5	22.2	1.3	4	6	2
BH 23034 N-R	0.90	1.0-1.8	silty CLAY with sand	M H	1.0	0	18	36	46	82	57	30	27	2.55	42.2	1	8	0	1.75	65.7	28.4	1.3	4	6	2
BH 23034 N-R	0.90	1.8-2.6	silty CLAY with sand	C H	2.0	2	27	32	39	71	55	27	28	2.58	10.4	1	24	0				2.3	9	11	5
BH 23074 N-L	0.20	1.8-3.0	silty CLAY with some sand	C H	2.0	0	10	38	52	90	63	30	33	2.62	48.6	1	35	0	2.00	66.6	32.4	2.3	5	7	3
BH 23074 N-R	1.50	1.9-2.8	silty CLAY	M L	2.0	0	4	43	53	96	NP	NP	NP	2.54	45.8	2	10	5	1.90	39.3	31.9	2.3	3	3	2
BH 23074 N-R	1.50	2.8-3.6	silty CLAY with some sand	C H	3.0	0	13	40	47	87	57	28	29	2.56	37.5	2	42	0				3.3	12	11	7
BH 23656 N-L	0.20	0.8-2.5	silty CLAY with sand	C L	1.0	0	26	35	39	74	32	18	17	2.60	30.2	1	60	0				1.3	26	37	13
BH 23656 N-L	0.20	0.8-2.5	silty CLAY with sand	M L	2.0	0	56	17	27	44	NP	NP	NP	2.62	32.2	1	60	0				1.3	26	37	13
BH 23656 N-L	0.20	0.8-2.5	silty CLAY with sand	M L	2.0	0	56	17	27	44	NP	NP	NP	2.62	32.2	2	3	4				2.3	16	18	9
BH 23656 N-R	0.80	0.8-1.6	silty CLAY with sand	M L	1.0	0	23	36	41	77	NP	NP	NP	2.62	31.7	2	4	0				1.3	5	7	2
BH 23656 N-R	0.80	1.6-3.0	sandy CLAY with silt	C H	2.0	0	34	30	36	66	50	20	30	2.63	29.2	2	21	3				2.3	7	8	4
BH 23817 N-R	0.40	1.5-2.9	sandy CLAY with silt	C H	2.0	0	45	24	31	55	56	21	35	2.64	31.3	2	11	0				2.3	7	8	4
BH 23817 N-R	0.40	1.5-2.9	sandy CLAY with silt	C H	2.0	0	45	24	31	55	56	21	35	2.64	31.3	2	11	0				2.3	7	8	4
BH 24838 N-R	0.50	0.7-2.0	silty CLAY with sand	C H	1.0	1	28	31	40	71	59	27	32	2.58	30.3	1	36	0				1.3	7	11	3
BH 24945 N-C	0.00	0.8-1.8	sandy CLAY with silt	C H	1.0	1	33	29	37	66	50	16	34	2.57	36.3	1	12	0	1.00	22.7	14.3	1.3	5	9	2
BH 26968-N-C	0.00	1.0-1.8	sandy CLAY with silt	C H	1.0	1	46	25	28	53	62	29	33	2.64	26.1	2	9	3	1.10	24.7	12.7	1.3	7	13	3

Borehole No	Water Table at (m)	Layer Depth (m)	Description	USCS	Sample Depth (m)	Particle Size Distribution					Atterberg Limits			Specific Gravity	NMC (%)	Unconsolidated Undrained TT			Vane Shear Test			SPT Correction			
						Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	LL (%)	PL (%)	PI (%)			No of Samples	C_u (kPa)	Φ_u	Depth (m)	Peak S/S (kN/m^2)	Residual S/S (kN/m^2)	Depth	SPT N_f	SPT N'_{70}	SPT N_{60}
BH 26968-N-C	0.00	1.8-2.8	sandy CLAY with silt	C L	2.0	1	47	25	27	52	47	27	20	2.66	30.2	2	34	1	1.60	59.6	39.8	2.3	3	4	2
BH 29694 N-R	0.50	0.8-1.7	CLAY with sand & traces of gravel	C H	1.0	7	24	30	39	69	67	30	37	2.61	32.9	2	60	1				1.3	8	12	4
BH 3624 N-R	1.20	0.7-1.5	fat CLAY with sand	C H	1.0	2	26	34	38	72	73	31	42	2.54	32.4	1	67	0	1.50	25.6	25.6	1.3	9	11	4
BH 4935 N-R	0.30	0.0-1.0	sandy lean CLAY	C L	0.0	1	48	43	8	51	41	23	18	2.54	41.4	2	4	0	0.50	17.3	9.2	0.3	2	5	1
BH 5110 N-C	0.20	1.0-1.6	sandy CLAY with silt	M L	1.0	4	40	28	28	56	NP	NP	NP	2.60	30.7	2	2	0	1.50	6.2	0.0	1.3	3	5	1
BH 5200 N-C	0.15	0.7-2.8	sandy lean CLAY	C L	1.0	1	48	29	22	51	41	16	25	2.62	21.3	3	8	0	1.50	36.1	22.4	1.3	3	6	1
BH 5200 N-C	0.15	0.7-2.8	sandy lean CLAY	C L	2.0	2	46	28	24	52	45	18	27	2.59	22.3	1	27	0				2.3	3	4	2
BH 5319 N-L	0.70	0.0-0.8	sandy lean CLAY	C L	0.0	2	41	44	13	57	41	22	19	2.52	35.9	2	16	2	0.50	28.2	19.4	0.3	4	10	2
BH 5319 N-R	0.45	0.9-1.6	sandy lean CLAY	C L	1.0	2	38	36	24	60	40	13	27	2.60	29.3	1	29	0	1.00	25.9	21.2	1.3	5	8	2
BH 5339 N-R	0.40	0.0-0.8	sandy lean CLAY	C L	0.0	0	45	39	16	55	35	19	16	2.55	27.4	1	17	0	0.50	10.2	9.5	0.3	3	7	1
BH 26740 N-R	0.96	1.5-2.7	sandy fat CLAY	C H	2.0	4	35	29	32	61	63	28	35	2.62	49.1	2	8	0	2.00	46.0	16.4	2.3	4	5	2
BH 27310 N-L	1.50	1.5-2.8	sandy fat CLAY	C H	2.0	0	28	30	42	72	69	30	39	2.58	33.9	1	44	0				2.3	11	11	6
BH 31881 N-L	0.35	0.9-1.7	fat CLAY	C H	1.0	0	13	39	48	87	61	28	35	2.57	42.8	1	29	0	1.00	32.1	9.5	1.3	4	7	2
BH 31881 N-L	0.35	1.7-3.0	fat CLAY	C H	2.0	0	14	41	45	86	61	27	34	2.61	39.7	1	33	0				2.3	3	4	2
BH 32187 N-L	0.00	0.0-0.9	sandy lean CLAY	C L	0.0	0	30	39	31	70	49	24	25	2.67	35.9	1	60	0	0.50	12.0	5.5	0.3	2	9	1
BH 32187 N-L	0.00	0.9-1.8	fat CLAY with sand	C H	1.0	0	23	45	32	77	55	25	30	2.73	33.1	1	75	0	1.00	9.2	1.6	1.3	4	8	2
BH 32187 N-R	0.00	0.0-0.8	sandy fat CLAY	C H	0.0	0	31	40	29	69	52	23	29	2.67	34.7	1	30	0	0.50	7.2	1.8	0.3	2	9	1
BH 32187 N-R	0.00	0.8-1.5	fat CLAY with sand	C H	1.0	0	25	38	37	75	55	25	30	2.67	35.0	1	40	0	1.00	7.9	3.5	1.3	7	14	3
BH 13554 N-L	1.40	4.5-5.9	fat CLAY	C H	5.0	0	9	50	41	91	52	26	26	2.63	42.3	2	10	0				5.3	5	4	3
BH 17743 N-L	0.70	0.7-1.4	fat CLAY with sand	C H	1.0	4	14	43	39	82	63	31	32	2.62	44.3	1	58	0	1.50	28.2	12.7	1.3	6	8	3
BH 14800 N-L	1.20	0.6-1.5	sandy fat CLAY	C H	1.0	1	38	42	19	61	55	26	29	2.59	41.5	1	57	0				1.3	1	1	0
BH 14800 N-R	3.50	0.8-3.5	sandy fat CLAY	C H	2.0	1	37	57	5	62	52	24	28	2.61	28.5	2	16	5				2.3	10	9	6
BH 16220 N-C	1.20	1.0-1.6	sandy fat CLAY	C H	1.0	1	35	33	31	64	56	26	30	2.67	51.1	1	12	0	1.00	21.7	15.2	1.3	2	3	1
BH 16220 N-C	1.20	1.6-2.8	fat CLAY with sand	C H	2.0	1	17	38	44	82	76	35	41	2.70	63.5	1	26	0	1.50	11.8	6.0	2.3	2	2	1
BH 16320 N-C	1.50	1.6-2.8	sandy fat CLAY with gravel	C H	2.0	21	21	32	26	58	69	33	36	2.65	21.9	1	56	0	1.50	18.2	9.5	2.3	6	6	3
BH 16320 N-C	1.50	1.6-2.8	sandy fat CLAY with gravel	C H	2.0	21	21	32	26	58	69	33	36	2.65	21.9	2	34	2				2.3	6	6	3
BH 16398 N-C	0.00	2.9-3.8	fat CLAY	C H	3.0	0	7	46	47	93	69	31	38	2.79	54.2	1	39	0				3.3	2	3	1
BH 16398 N-C	0.00	3.8-4.5	lean CLAY with sand	C L	4.0	0	29	37	34	71	47	19	28	2.64	26.2	1	47	0				4.3	7	8	4
BH 32375 N-L	0.00	1.0-2.0	lean CLAY with sand	C L	1.0	0	28	41	31	72	47	23	24	2.59	39.0	1	58	0	1.00	20.1	9.7	1.3	3	6	1
BH 32375 N-R	1.00	0.0-0.7	soft lean CLAY with sand	C L	0.0	0	28	50	22	72	45	26	19	2.56	44.2	2	42	3	0.50	20.8	12.9	0.3	2	5	1
BH 32375 N-R	1.00	0.7-2.5	lean CLAY with sand	C L	1.0	0	16	43	41	84	40	17	23	2.60	52.0	1	108	0	1.00	21.7	10.6	1.3	4	5	2
BH 32375 N-R	1.00	0.7-2.5	lean CLAY with sand	M L	2.0	0	39	32	29	61	NP	NP	NP	2.64	35.3	1	25	0	2.00	41.3	20.1	2.3	4	5	2
BH 32425 N-L	0.30	0.7-1.8	sandy lean CLAY	C L	1.0	3	30	39	28	67	49	24	25	2.62	43.6	2	18	0	1.00	16.6	8.3	1.3	0	0	0
BH 32425 N-L	0.30	0.7-1.8	sandy lean CLAY	C L	2.0	5	40	32	23	55	41	19	22	2.68	38.8	2	10	2	2.00	24.5	15.9	2.3	3	4	2
BH 32425 N-R	0.30	0.0-0.9	sandy lean CLAY	C L	0.0	0	38	38	24	62	35	18	17	2.62	31.1	1	24	0	0.50	12.2	6.9	0.3	1	3	0
BH01	3.13		Sandy silty CLAY	M H	6.0-6.5	0	11	31	58	89	59	34	25	2.63	64.0	1	57	0				6.3	5	4	3

Borehole No	Water Table at (m)	Layer Depth (m)	Description	USCS		Sample Depth (m)	Particle Size Distribution					Atterberg Limits			Specific Gravity	NMC (%)	Unconsolidated Undrained TT			Vane Shear Test			SPT Correction			
							Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	LL (%)	PL (%)	PI (%)			No of Samples	C_u (kPa)	Φ_u	Depth (m)	Peak S/S (kN/m^2)	Residual S/S (kN/m^2)	Depth	SPT N_f	SPT N'_{70}	SPT N_{60}
BH02	4.50		Organic silty CLAY	M	H	9.0-9.5	1	27	48	24	72	50	32	18		59.0	1	12	0				7.3	2	1	1
BH03	5.33		Sandy silty CLAY	M	L	2.0-2.5	0	61	17	22	39	NP	NP	NP		20.0	1	6	0				1.5	2	2	1
BH03	5.33		Slightly sandy organic silty CLAY	M	L	5.5-6.0	1	34	40	25	65	NP	NP	NP		32.0	1	65	0				5.3	2	1	1
BH04	6.00		Sandy clayey SILT	M	L	4.0-4.45	0	55	23	22	45	32	27	5	2.47	30.0	1	44	0				3.3	3	2	2
BH05	4.45		Sandy silty CLAY	M	H	3.0-3.45	0	51	21	28	49	54	31	23		30.0	1	97	0				2.3	9	8	5
BH07	5.70		Slightly sandy silty CLAY	M	H	5.0-5.5	0	5	30	65	95	66	36	30	2.62	57.0	1	40	0				4.3	5	3	3
BH07	5.70		Slightly sandy organic silty CLAY	M	L	8.0-8.5	0	56	18	26	44	49	29	20	2.63	45.0	1	21	0				9.3	4	2	3
BH08	6.90		Sandy silty CLAY	C	L	5.0-5.5	0	56	18	26	44	38	23	15	2.44	35.0	1	53	0				6.3	7	4	4
BH13	6.45		Slightly silty gravelly CLAY	M	H	9.45-9.85					0	57	33	24		31.0	1	106	0				9.3	8	4	5
BH15	4.88		Slightly gravelly slightly sandy silty CLAY	M	L	3.45-4.0	1	34	22	43	65	47	28	19		39.0	1	55	0				4.3	6	4	4
BH15	4.88		Sandy Silty CLAY	M	H	5.45-6.0					0	60	33	27	2.63	46.0	1	50	0				5.3	7	4	4
BH15	4.88		Slightly gravelly slightly sandy organic silty CLAY	C	L	9.0-9.45	1	11	52	36	88	40	25	15			1	8	0				10.3	3	2	2
BH19	5.00		Slightly sandy silty CLAY	M	L	2.0-2.6	0	51	19	30	49	46	32	14	2.51	31.0	1	75	0				1.5	3	4	1
BH19	5.00		Slightly sandy silty CLAY	M	H	4.0-4.6	0	51	19	30	49	54	35	19		40.0	1	102	0				3.3	4	3	2
BH19	5.00		Sandy silty CLAY	M	L	8.0-8.5	0	7	33	60	93	49	34	15	2.54	47.0	1	54	0				7.3	4	2	3
BH19	5.00		Slightly sandy silty CLAY	M	H	10.0-10.5	0	7	33	60	93	56	41	15		46.0	1	26	0				9.3	3	2	2
BH21	7.68		Slightly Sandy gravelly CLAY	M	H	7.5-8.0					0	63	44	19	2.63	23.0	1	51	0				7.3	13	6	8
BH21	7.68		Slightly gravelly slightly sandy silty CLAY	M	H	11.0-11.45	4	4	32	60	92	76	42	34		58.0	1	38	0				10.3	10	4	7
BH21	7.68		Slightly gravelly slightly sandy silty CLAY	M	H	12.5-13.0	0	5	56	39	95	57	41	16			1	91	0				13.3	10	4	7
BH22	4.80		Slightly sandy clayey SILT	M	H	3.0-3.5	0	5	56	39	95	57	41	16		50.0	1	13	0				4.3	4	3	3
BH23	5.40		Slightly sandy silty CLAY	M	H	9.0-9.45	0	15	42	43	85	52	29	23	2.55	46.0	1	24	0				7.8	2	1	1
BH25	6.50		Sandy silty CLAY	M	L	2.0-2.45	0	47	23	30	53	46	28	18		40.0	1	136	0				1.5	13	14	6
BH25	6.50		Sandy silty CLAY	M	H	3.0-3.25					0	52	36	16	2.63	32.0	1	86	0				4.3	8	5	5
BH25	6.50		slightly gravelly slightly sandy silty CLAY	M	L	13.0-13.50	15	20	19	46	65				2.50	33.0	1	79	0				12.3	6	3	4
BH27	4.80		Silty organic CLAY	C	L	6.5-7.0	20	39	41	32	73	37	19	18		22.0	1	16	0				6.3	4	2	3
BH29	3.27		Slightly gravelly sandy CLAY	M	L	7.5-8.0					0	44	29	15		32.0	1	111	0				7.3	10	6	6

NP – Non plastic

ML – Low plastic silt

MH – High plastic silt

CL – Low plastic clay

CH – High plastic clay

Appendix II : Graphs of Analyses on Existing Correlations

1. Relationship proposed by Joseph E. Bowles

1.1 Analysis between C_u (Triaxial) and C_u (Energy) by Bowles

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.1.1 by using the SPT N'_{70} values obtained from the respective soil stratums at the field is shown in the *Figure II-1*.

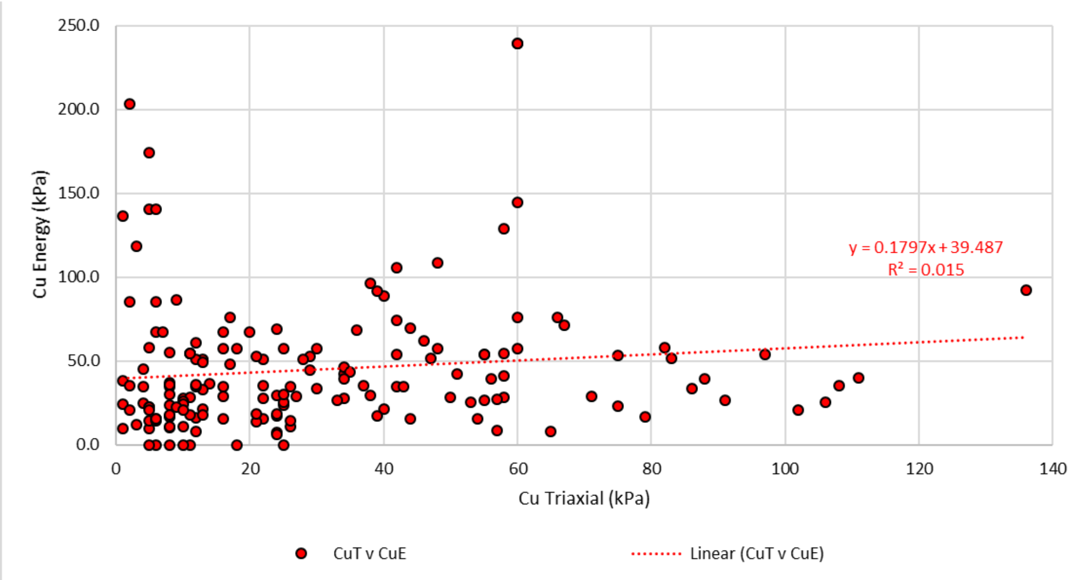

Figure II-1: C_u (Triaxial) Vs C_u (Energy) by Bowles

1.2 Analysis between C_u (FVST) and C_u (Energy) by Bowles

Undrained shear strength values of fine grained soil samples, determined with in-situ field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.1.1 by using the SPT N'_{70} values obtained from the respective soil stratums at the field, is shown in the *Figure II-2*.

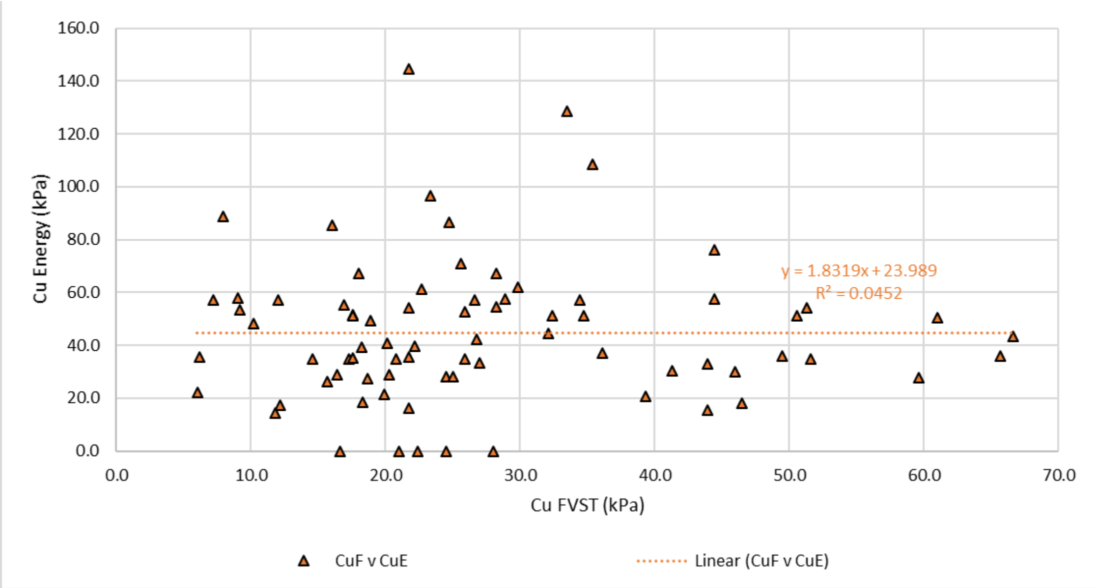

Figure II-2: C_u (FVST) Vs C_u (Energy) by Bowles

2. Relationship proposed by Strouds, 1974

2.1 Analysis between C_u (Triaxial) and C_u (Energy) by Strouds

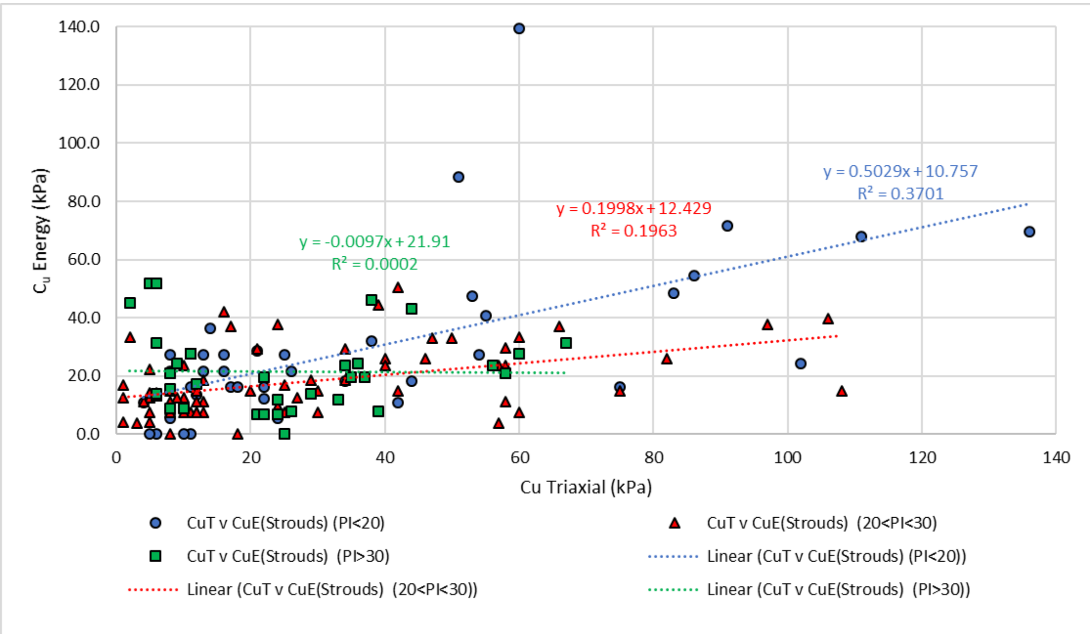

Figure II-3: C_u (Triaxial) Vs C_u (Energy) by Strouds

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.1 by using the SPT N_{60}

values obtained from the respective soil stratums at the field (with the subdivided Plasticity Index groups) is shown in the *Figure II-3*.

2.2 Analysis between C_u (FVST) and C_u (Energy) by Strouds (1984)

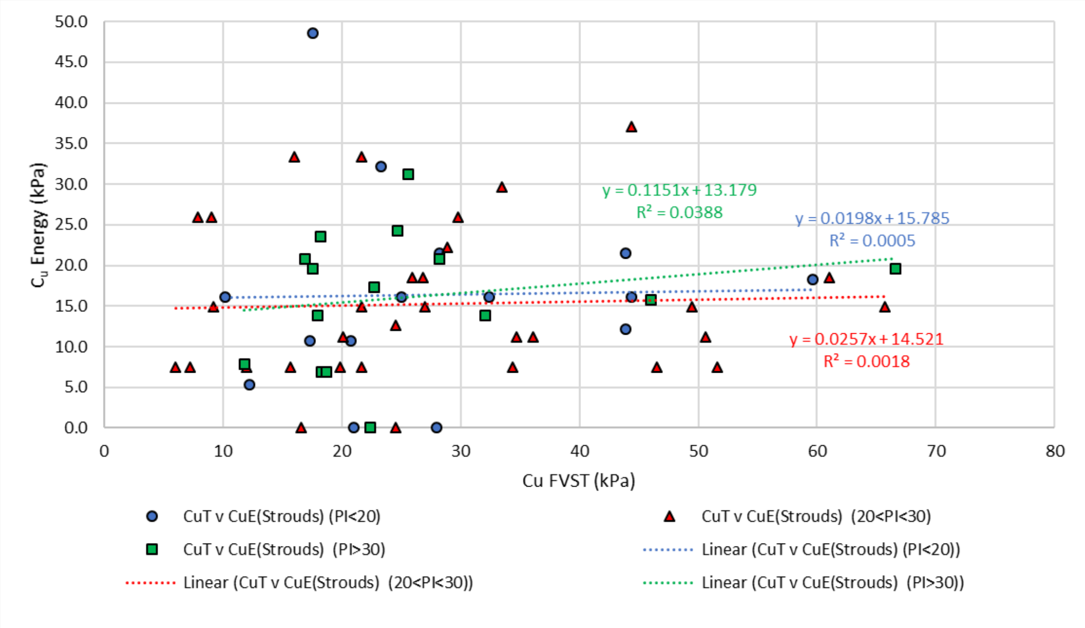

Figure II-4: C_u (FVST) Vs C_u (Energy) by Strouds

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.1 by using the SPT N_{60} values obtained from the respective soil stratums at the field (with the subdivided plasticity index groups) is shown in the *Figure II-4*.

3. Relationship proposed by Hara A et al., (1974)

3.1 Analysis between C_u (Triaxial) and C_u (Energy) by Hara A et al.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.2 by using the SPT N_{60} values obtained from the respective soil stratums at the field is shown in the *Figure II-5*.

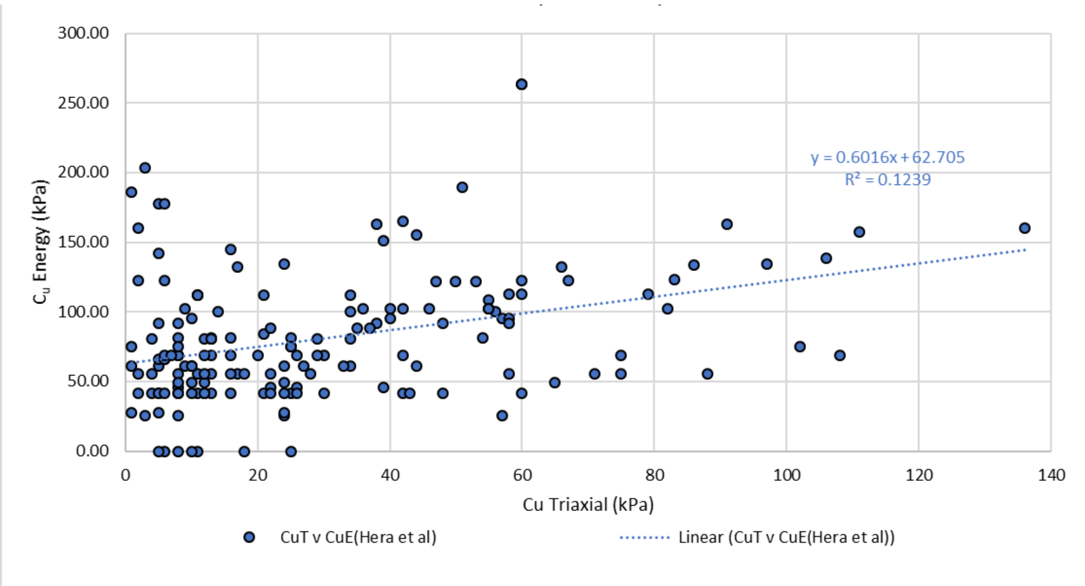

Figure II-5: C_u (Triaxial) Vs C_u (Energy) by Hera A, et al. (1974)

3.2 Analysis between C_u (FVST) and C_u (Energy) by Hera A, et al. (1974)

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.2 by using the SPT N_{60} values obtained from the respective soil stratums at the field is shown in the *Figure II-6.*

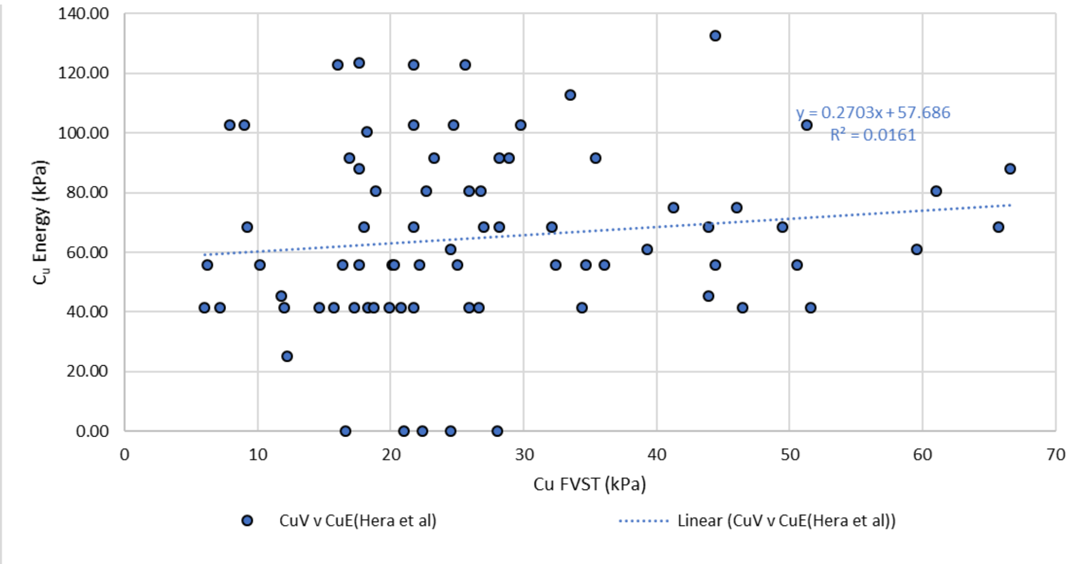

Figure II-6: Cu (FVST) Vs Cu (Energy) by Hera A, et al.(1974)

4. Relationship proposed by Sivikaya & Togrol, (2007)

4.1 Analysis between C_u (Triaxial) and C_u (Energy / N_{60}) by Sivikaya & Togrol, (2007)

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.3 by using the SPT N_{60} values obtained from the respective soil stratums at the field, categorized in four divisions as high plastic clays (CH), low plastic clays (CL), clays and fine grained soils is shown in the *Figure II-7*.

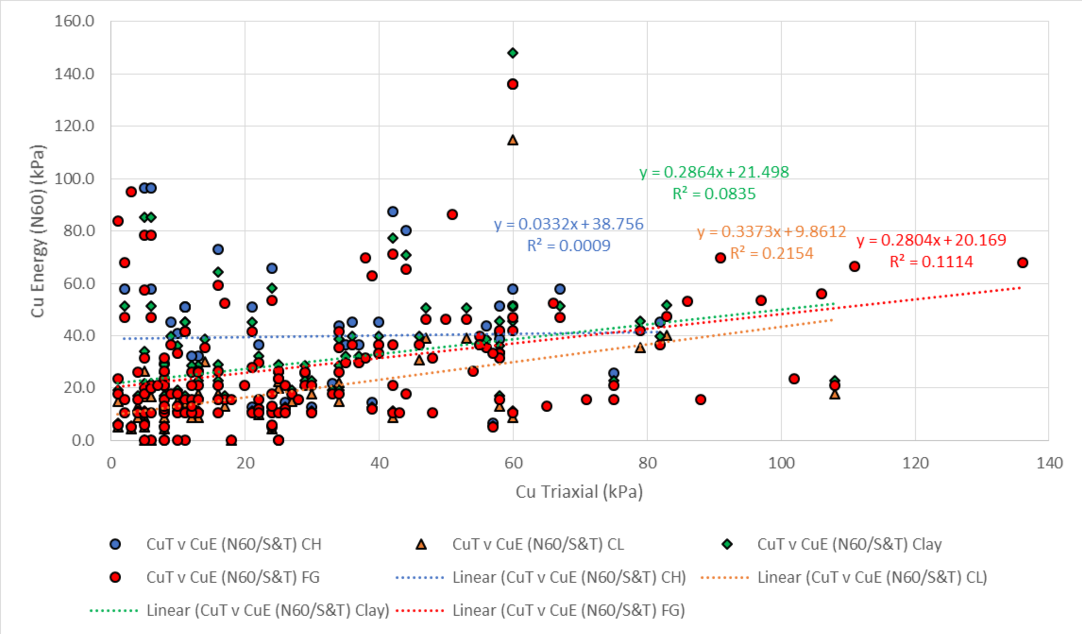

Figure II-7: C_u (Triaxial) Vs C_u (Energy / N_{60}) by Sivikaya & Togrol, (2007)

4.2 Analysis between C_u (FVST) and C_u (Energy / N_{60}) by Sivikaya & Togrol, (2007)

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.3 by using the SPT N_{60} values obtained from the respective soil stratums at the field, categorized in four divisions as high plastic clays (CH), low plastic clays (CL), clays and fine grained soils is shown in the *Figure II-8*.

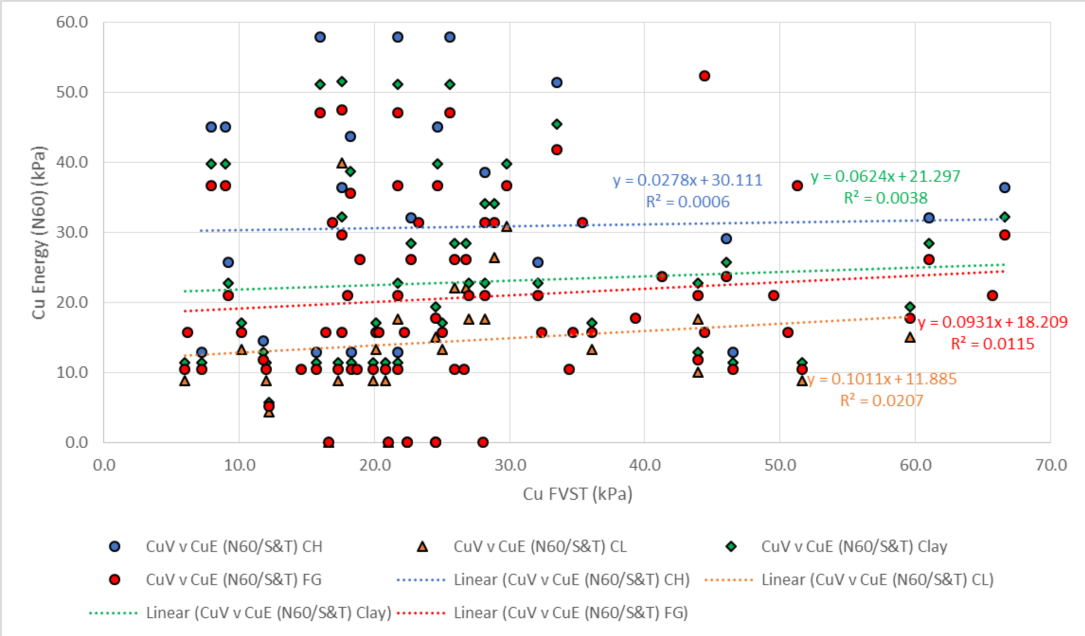

Figure II-8: C_u (FVST) Vs C_u (Energy / N_{60}) by Sivikaya & Togrol, (2007)

5. Relationship proposed by Décourt, (1990)

5.1 Analysis between C_u (Triaxial) and C_u (Energy / N_{60}) by Décourt, (1990)

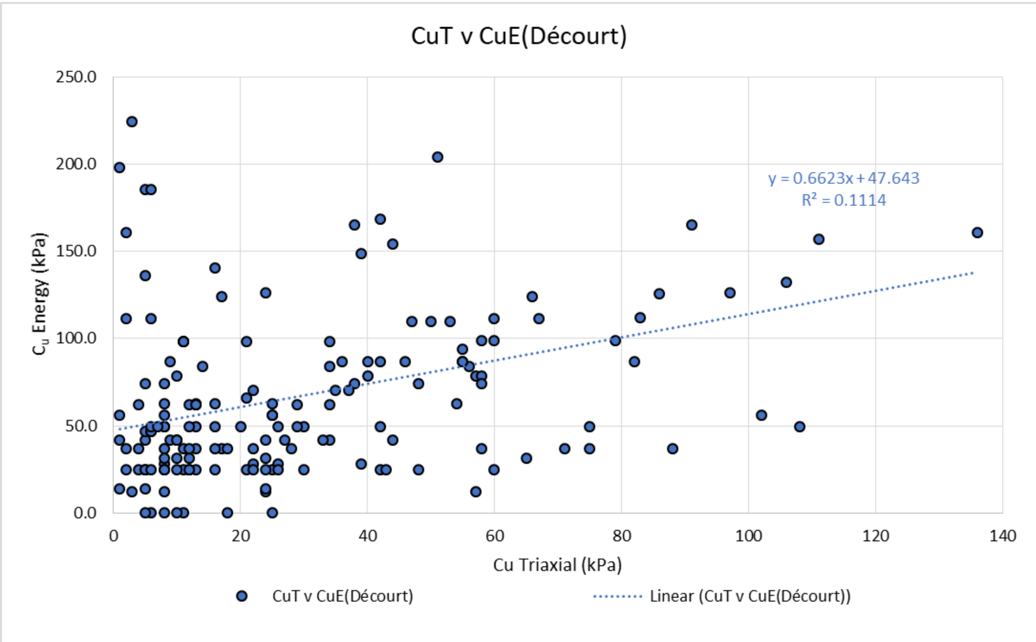

Figure II-9: C_u (Triaxial) Vs C_u (Energy / N_{60}) by Décourt, (1990)

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.4 by using the SPT N_{60}

values obtained from the respective soil stratums at the field is shown in the *Figure II-9.*

5.2 Analysis between C_u (FVST) and C_u (Energy / N_{60}) by Décourt, (1990)

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.4 by using the SPT N_{60} values obtained from the respective soil stratums at the field is shown in the *Figure II-10.*

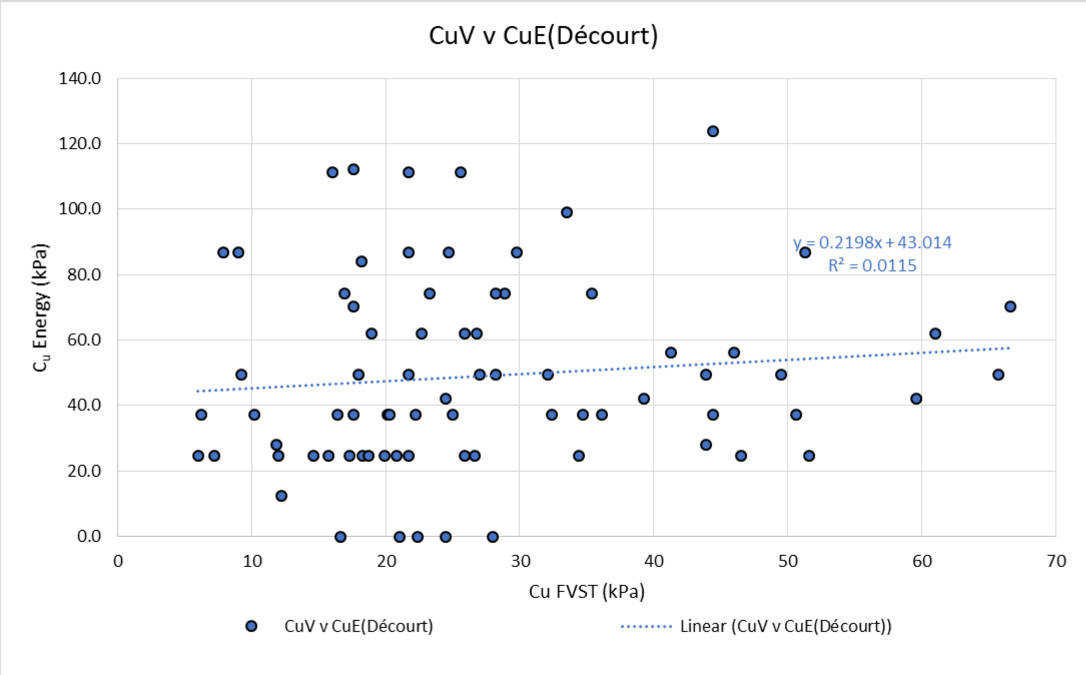

Figure II-10: C_u (FVST) Vs C_u (Energy / N_{60}) by Décourt, 1990

6. Relationship proposed by Terzaghi & Peck, (1967)

6.1 Analysis between C_u (Triaxial) and C_u (Energy / N_{60}) by Terzaghi & Peck, (1967)

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.5 by using the SPT N_{60} values obtained from the respective soil stratums at the field is shown in the Figure II-11.

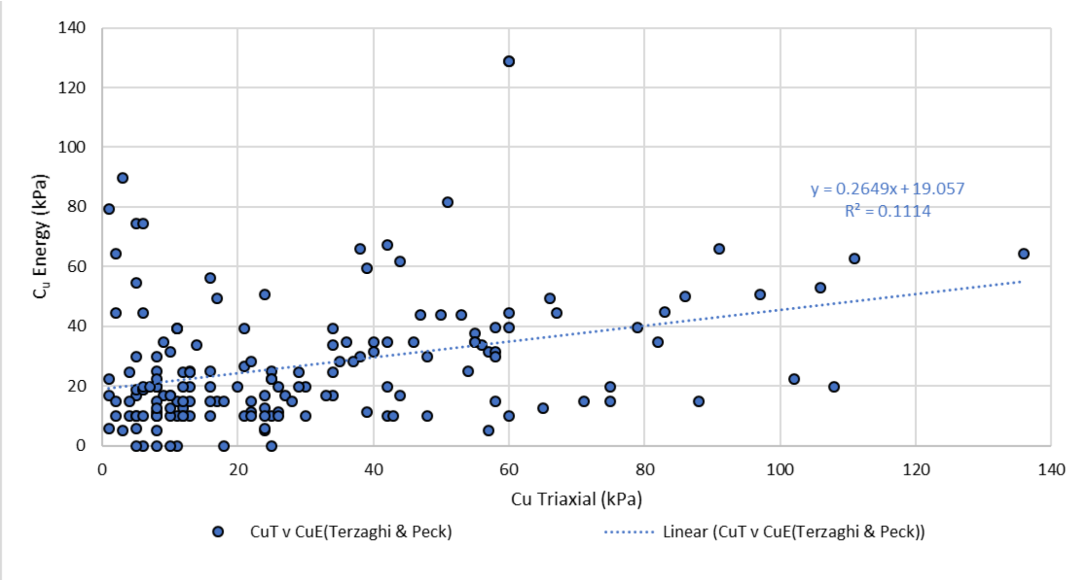

Figure II-11: C_u (Triaxial) Vs C_u (Energy / N_{60}) by Terzaghi & Peck, (1967)

6.2 Analysis between C_u (FVST) and C_u (Energy / N_{60}) by Terzaghi & Peck, 1967

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.2.5 by using the SPT N_{60} values obtained from the respective soil stratums at the field is shown in the *Figure II-12*.

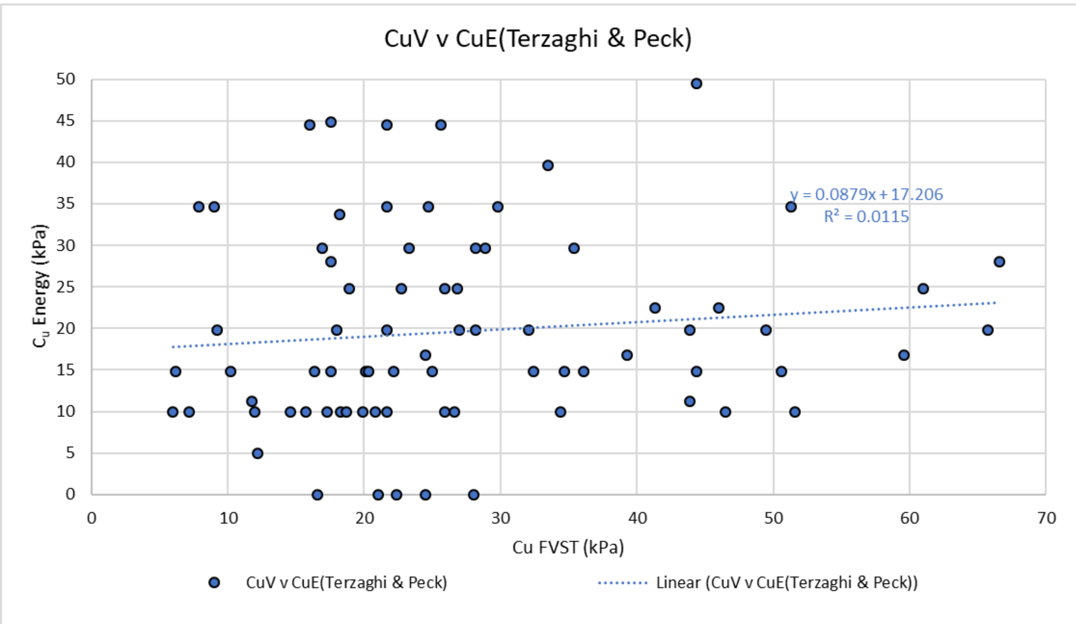

Figure II-12: C_u (FVST) Vs C_u (Energy / N_{60}) by Terzaghi & Peck, (1967)

7. Relationship proposed by Terzaghi & Peck, (1967)

7.1 Analysis between C_u (Triaxial) and C_u (Energy / N_f) by Terzaghi & Peck, (1967)

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.3.1 by using the SPT N_f values obtained from the respective soil stratums at the field is shown in the *Figure II-13.*

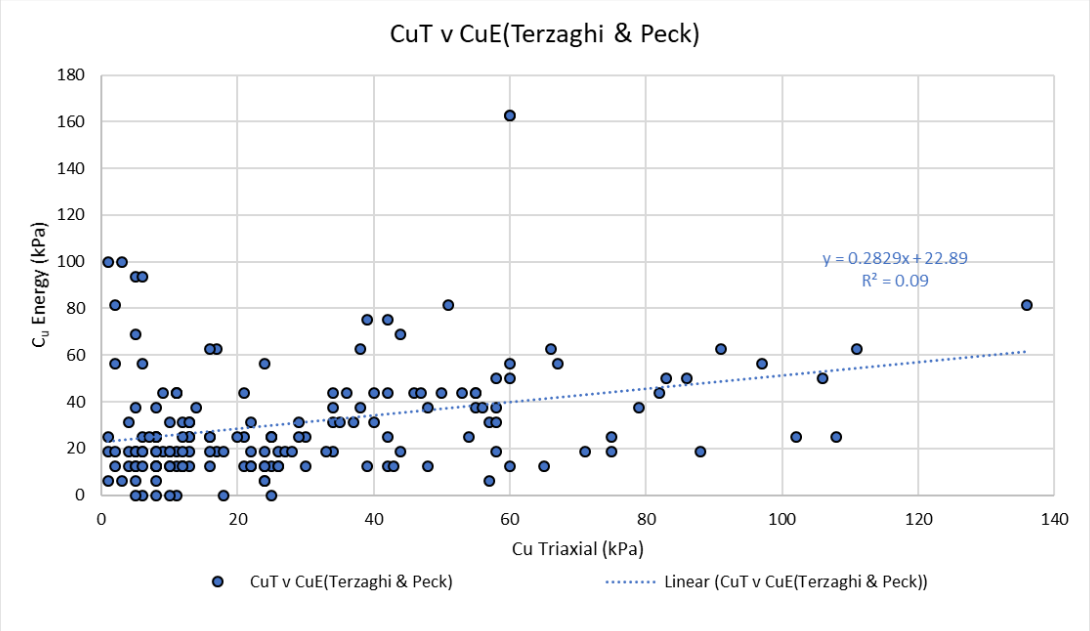

Figure 2-13: C_u (Triaxial) Vs C_u (Energy / N_f) by Terzaghi & Peck, (1967)

7.2 Analysis between C_u (FVST) and C_u (Energy / N_f) by Terzaghi & Peck, (1967)

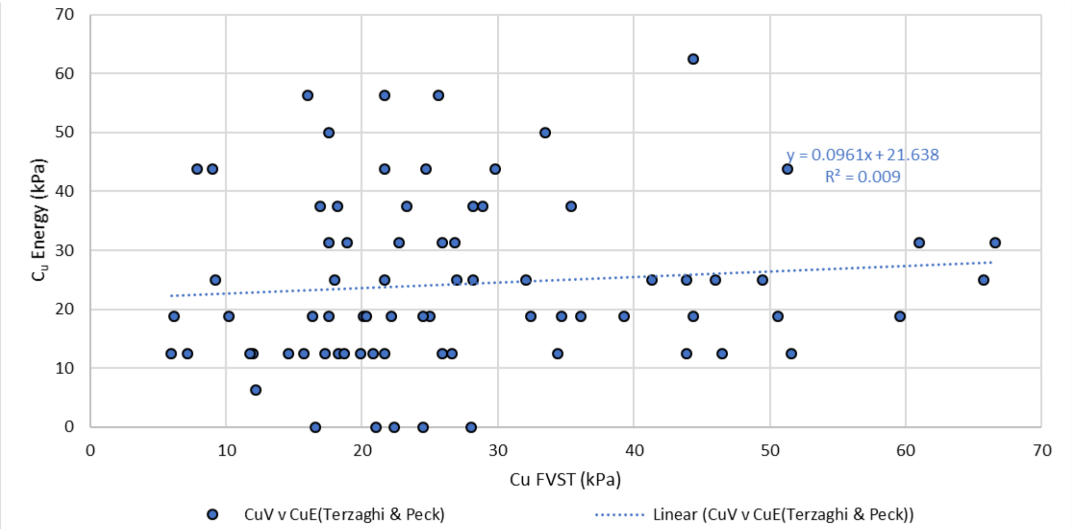

Figure II-14: C_u (FVST) Vs C_u (Energy / N_f) by Terzaghi & Peck, (1967) Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.31 by using the SPT N_f values obtained from the respective soil stratums at the field is shown in the *Figure II-14*.

8. Relationship proposed by Sowers, (1979)

8.1 Analysis between C_u (Triaxial) and C_u (Energy / N_{field}) by Sowers, (1979)

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.3.2 by using the SPT N_{field} values obtained from the respective soil stratums at the field. categorized in three divisions as low plasticity clay (SC-ML), Only the analysis of categories medium plasticity clay (CL) and high plasticity clay (CH) soils is shown in the *Figure II-15* since unavailability of data on low plasticity clay (SC-ML) soils.

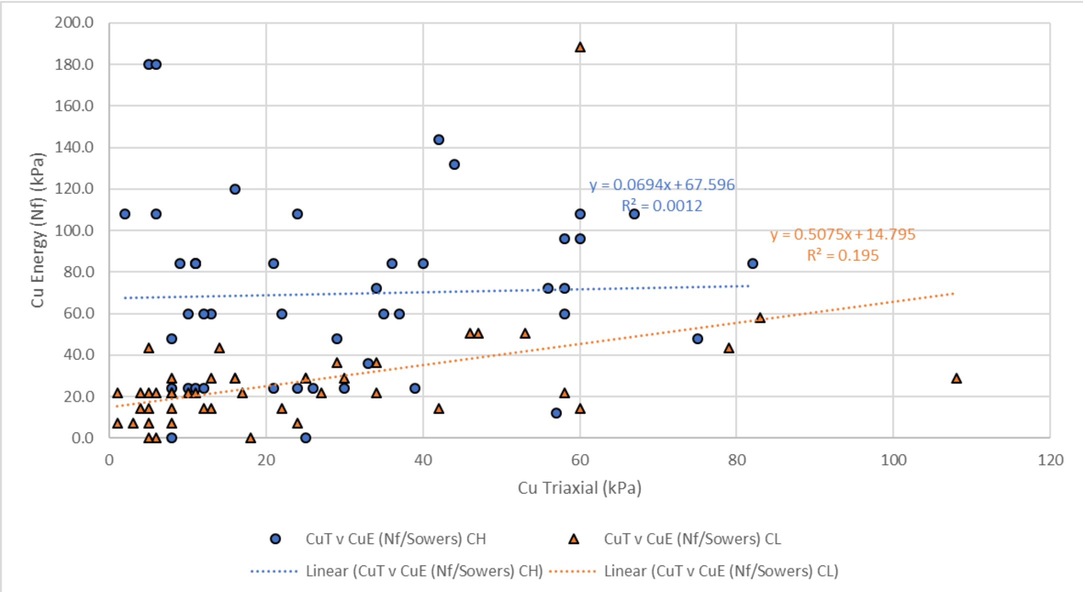

Figure II-153: C_u (Triaxial) Vs C_u (Energy / N_f) by Sowers, (1979)

8.2 Analysis between C_u (FVST) and C_u (Energy / N_{field}) by Sowers, (1979)

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.3.2 by using the SPT N_{field} values obtained from the respective soil stratums at the field. Only the analysis of categories medium plasticity clay (CL) and high plasticity clay (CH) soils is shown in the *Figure II-16*, since unavailability of data on low plasticity clay (SC-ML) soils.

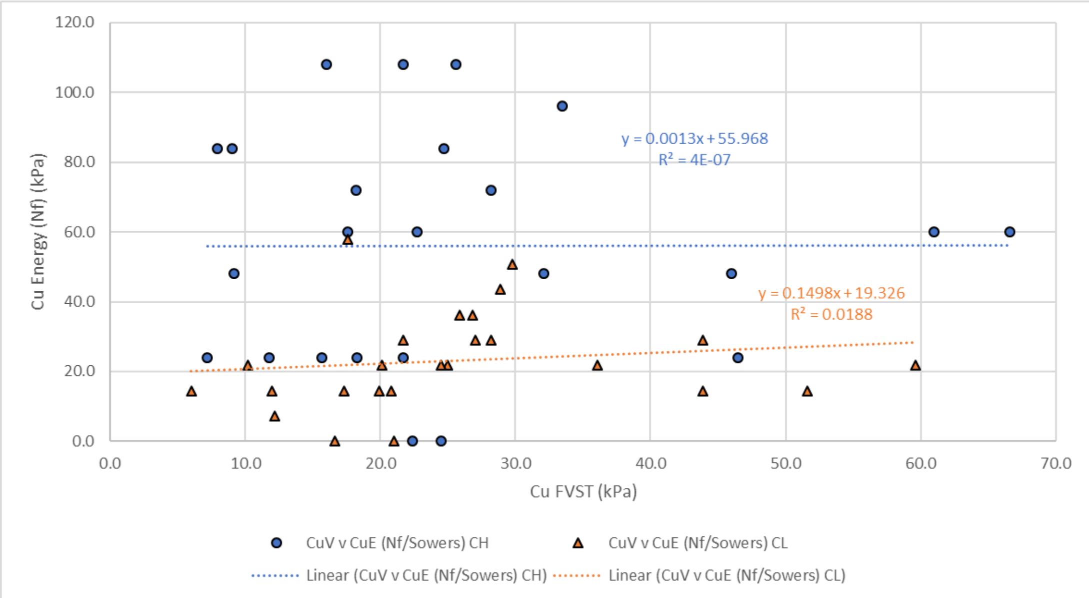

Figure II-16: Cu (FVST) Vs Cu (Energy / N_f) by Sowers, (1979)

9. Relationship proposed by Sivikaya & Togrol, (2007)

9.1 Analysis between C_u (Triaxial) and C_u (Energy / N_{field}) by Sivikaya & Togrol, (2007)

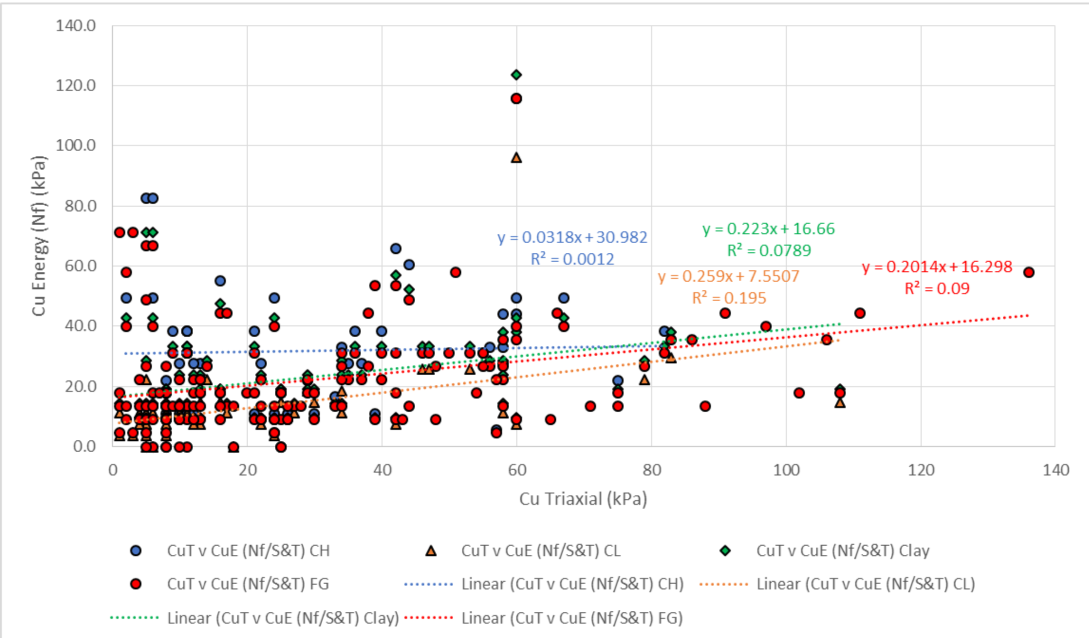

Figure II-17: C_u (Triaxial) Vs C_u (Energy / N_{field}) by Sivikaya & Togrol, (2007) Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.3.3 by using the SPT N_{field} values obtained from the respective soil stratums at the field, categorized in four divisions as High Plastic Clays (CH), Low Plastic Clays (CL), Clays and Fine grained soils is shown in the *Figure II-17*.

9.2 Analysis between C_u (FVST) and C_u (Energy / N_{field}) by Sivikaya & Togrol, (2007)

Undrained shear strength values of undisturbed fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.13.3 by using the SPT N_{field} values obtained from the respective soil stratums at the field, categorized in four divisions as high plastic clays (CH), low plastic clays (CL), clays and fine grained soils is shown in the *Figure II-18*.

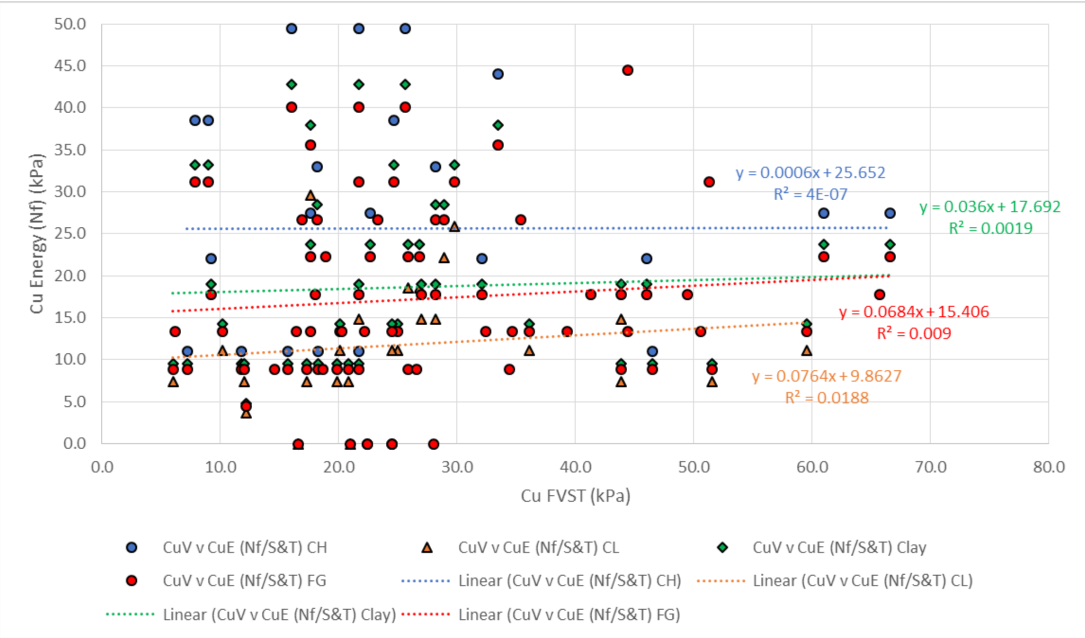

Figure II-18: C_u (FVST) Vs C_u (Energy / N_{field}) by Sivikaya & Togrol, (2007)

10. Relationship proposed by Décourt, (1990)

10.1 Analysis between C_u (Triaxial) and C_u (Energy / N_{field}) by Décourt, (1990)

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the undrained shear strength values determined with the correlation described in section 4.1.3.4 by using the SPT N_{field} values obtained from the respective soil stratums at the field, is shown in the *Figure II-19*.

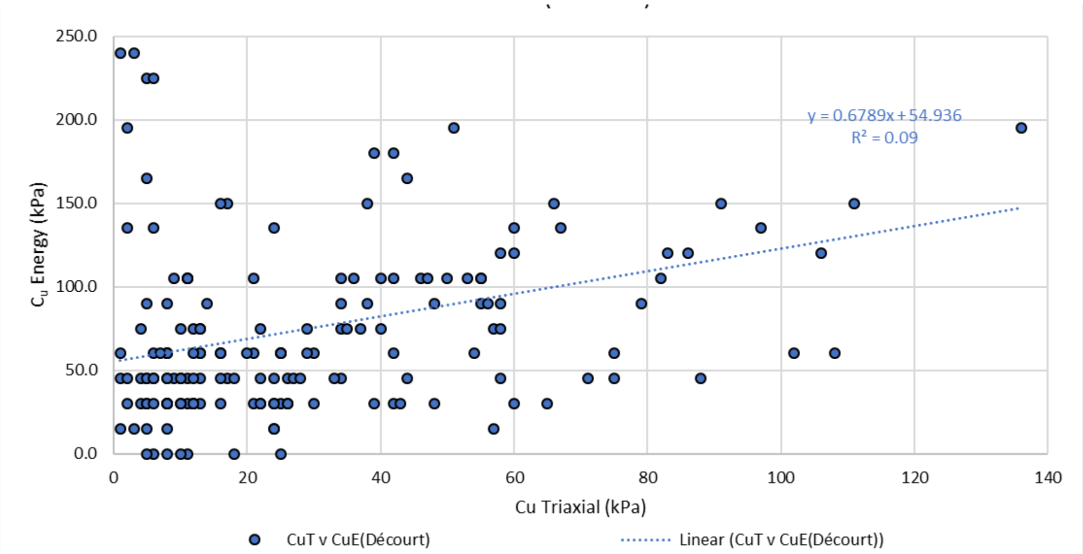

Figure II-19: C_u (Triaxial) Vs C_u (Energy / N_{field}) by Décourt, (1990)

10.2 Analysis between C_u (FVST) and C_u (Energy / N_{field}) by Décourt, (1990)

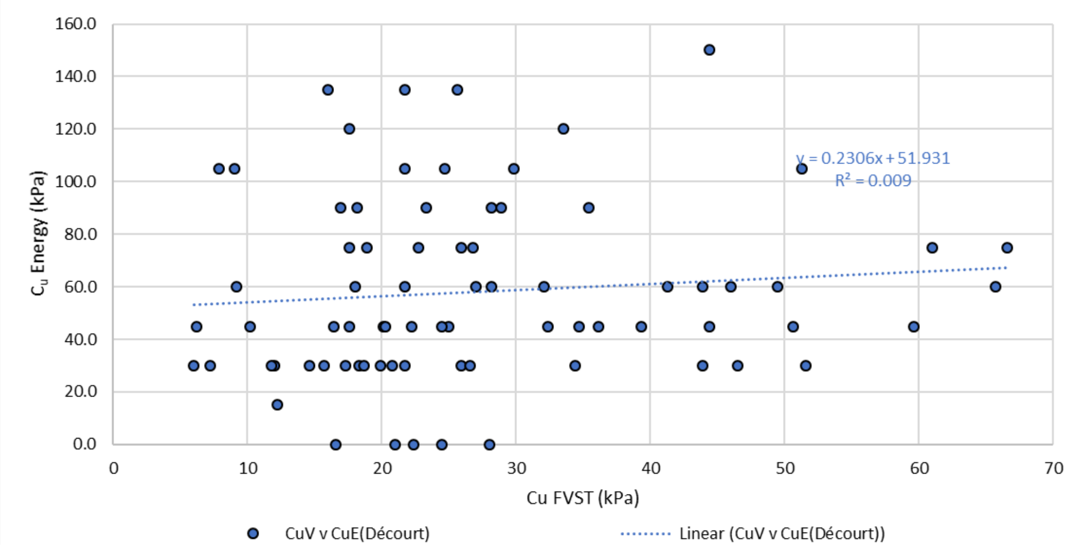

Figure II-20: C_u (FVST) Vs C_u (Energy / N_{field}) by Décourt, (1990) Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the undrained shear strength values determined with the correlation described in section 4.1.3.4 by using the SPT N_{field} values obtained from the respective soil stratums at the field, is shown in the *Figure II-20.*

Appendix III : Graphs of Analysis using Undrained Shear Strength by Triaxial UU Tests.

1. Analysis on Fine Grained Soils, Complete Set.

1.1 SPT N’$_{70}$ Vs Undrained Shear Strength by Triaxial UU Tests. (Complete Set)

Soil samples of which more than 50 % percent by weight passing the No 200 sieve (75µm) were considered for the analysis without any divisions.

First the undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N’$_{70}$ values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-1*.

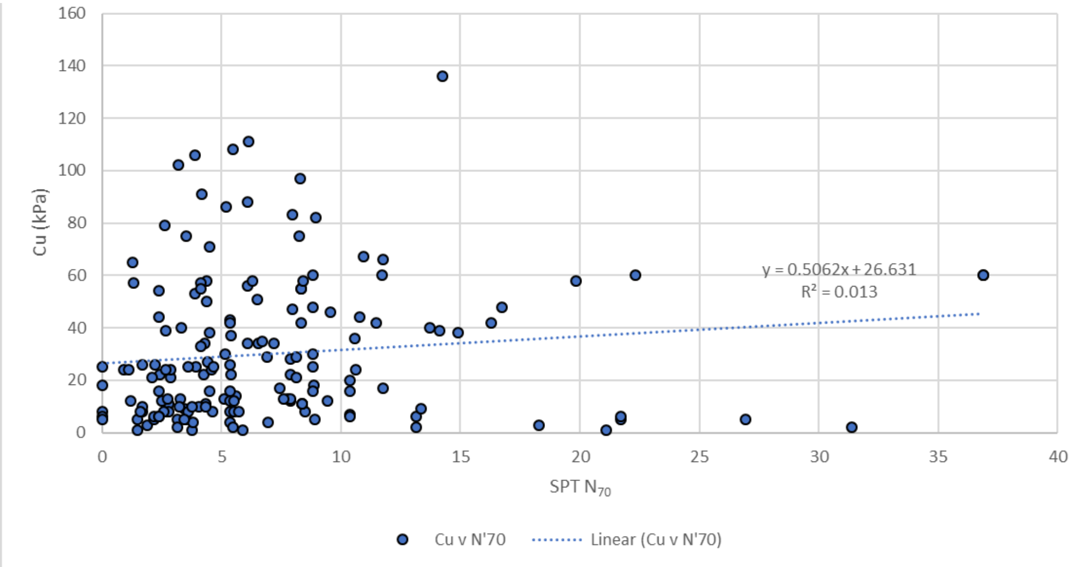

Figure III-1: SPT N’$_{70}$ Vs undrained shear strength by triaxial UU tests (Complete Set)

Since the spread of the plotted data of SPT N’$_{70}$ Vs undrained shear strength for complete data set doesn’t indicate any pattern, there are insufficient facts to get to a conclusion on a correlation between SPT N’$_{70}$ against the undrained shear strength of fine grained soils.

1.2 SPT N_{60} Vs Undrained Shear Strength by triaxial UU tests (Complete Set)

It was decided to plot the undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests against the SPT N_{60} values, as in *Figure III-2* to observe the spread before applying the correction factors on SPT $N_{60.}$ Main purpose of this step is to negate the effects of the "Adjustment for effective overburden pressure P'$_o$" $C_{N,}$ which makes a considerable impact of the SPT N'_{70} values, especially at shallow and very deep levels.

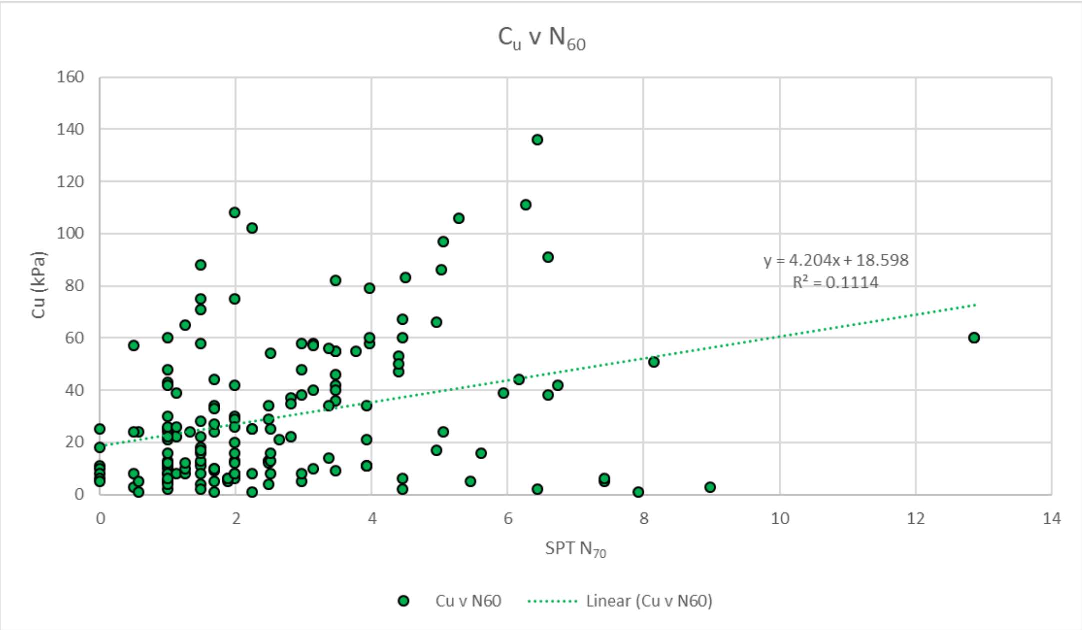

Figure III-2: SPT N_{60} Vs undrained shear strength by triaxial UU tests (Complete Set)

1.3 SPT N_{field} Vs Undrained Shear Strength by Triaxial UU Tests (Complete Set)

It was decided to plot the undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests against the SPT N_{field} values asshown in *Figure III-3* to observe the spread before applying the correction factors on SPT $N_{field..}$ Main purpose of this step is to negate the effects of the "Adjustment for effective overburden pressure P'$_o$" $C_{N,}$ as well as the effects of correction factors which make a considerable impact of the SPT N'_{70} and SPT N_{60} values, especially at shallow and very deep levels.

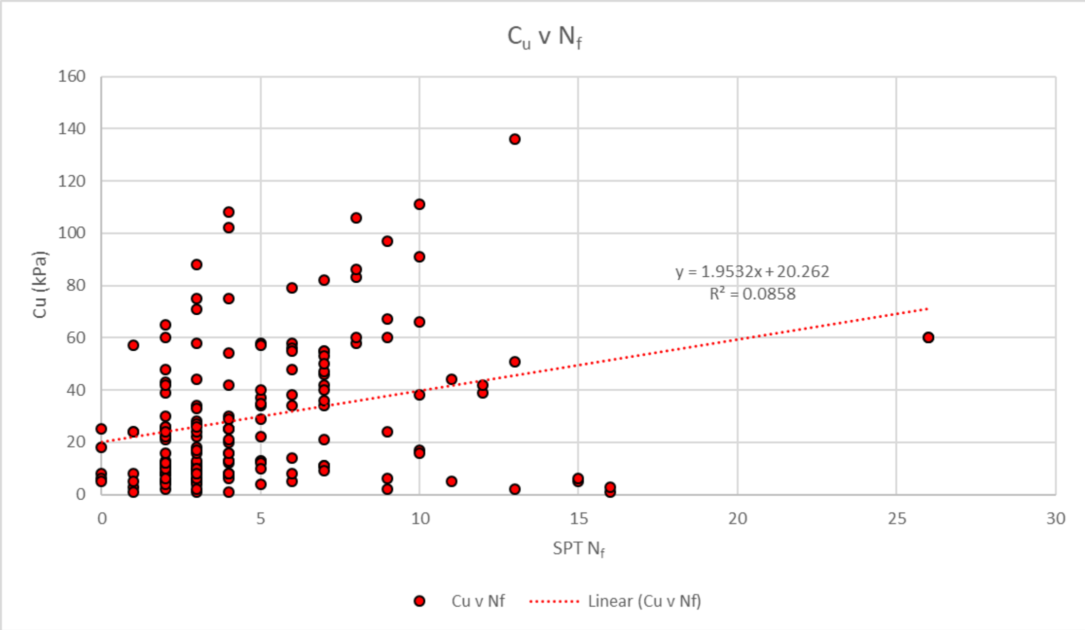

Figure III-3: SPT N_{field} Vs undrained shear strength by triaxial UU tests (Complete Set)

2. Analysis based on the variation of Liquid Limit.

2.1 SPT N'$_{70}$ Vs Undrained Shear Strength by Triaxial UU Tests.

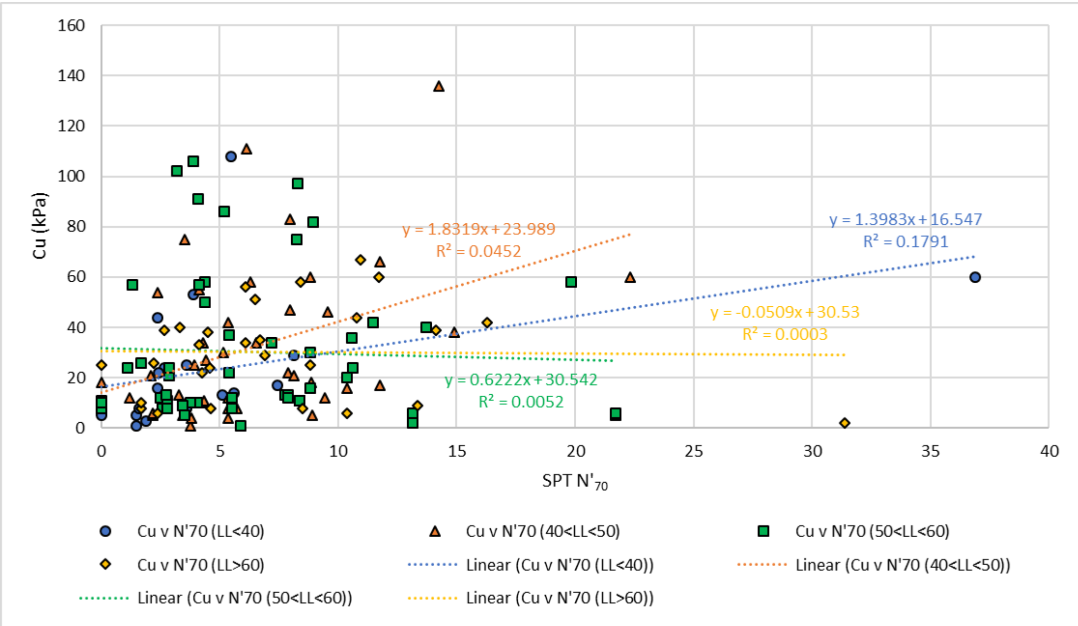

Figure III-4: SPT N'$_{70}$ Vs undrained shear strength by triaxial UU tests (based on LL)

The effects of the variation of liquid limit (LL) on the relationship between SPT N'$_{70}$ and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to four sub categories based on their liquid limits as LL<40%, 40%<LL<50%, 50%<LL<60% and LL>60%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-4* with aforesaid categories, categorized based on liquid limits

2.2 SPT N_{60} Vs Undrained Shear Strength by Triaxial UU Tests.

The effects of the variation of liquid limit (LL) on the relationship between SPT N_{60} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to four sub categories based on their liquid limits as LL<40%, 40%<LL<50%, 50%<LL<60% and LL>60%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-5* with aforesaid categories, categorized based on liquid limits

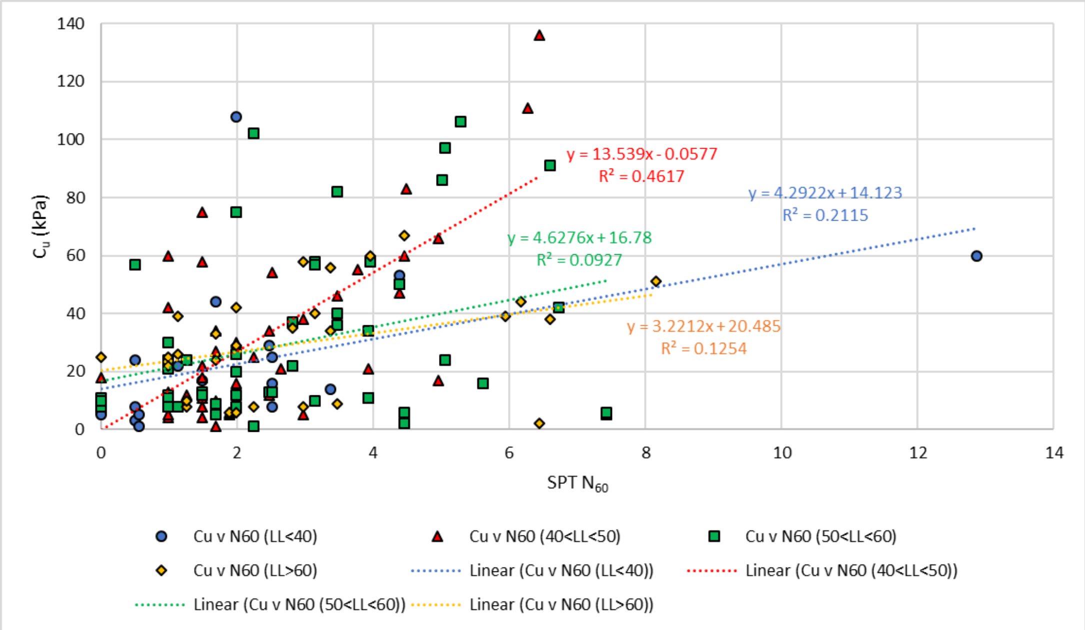

Figure III-5: SPT N_{60} Vs undrained shear strength by triaxial UU tests (based on LL)

2.3. SPT N_f Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of liquid limit (LL) on the relationship between SPT N_f and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to four sub categories based on their Liquid Limits as LL<40%, 40%<LL<50%, 50%<LL<60% and LL>60%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure III-6* with aforesaid categories, categorized based on liquid limits

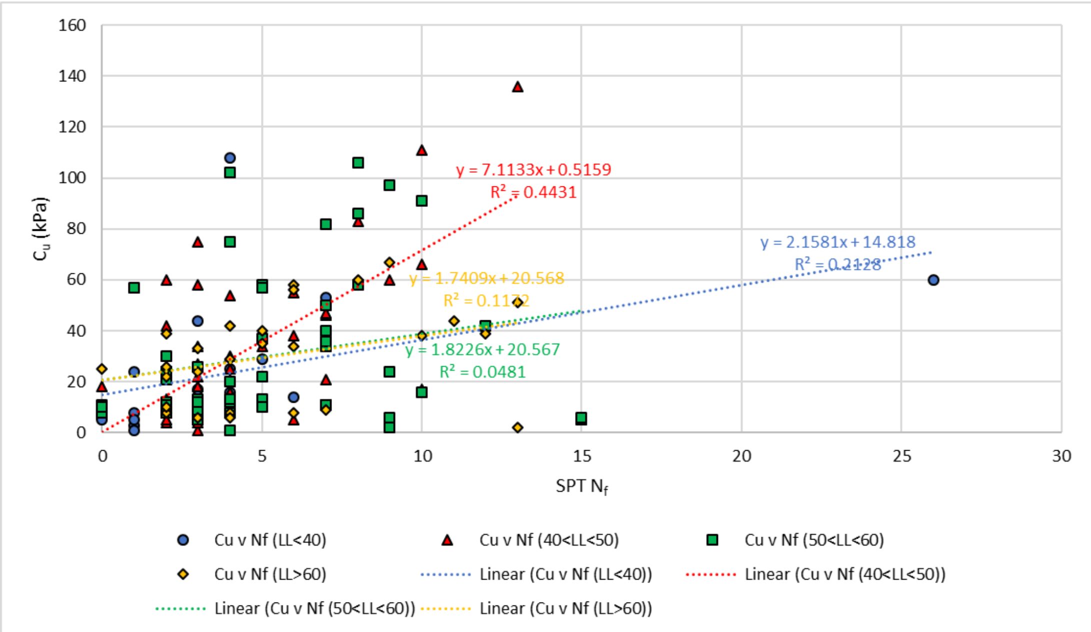

Figure III-6: SPT N_f Vs undrained shear strength by triaxial UU tests (based on LL)

2.4. C_u/SPT N Ratio against Liquid Limit.

To get an overall idea on the effects of the liquid limit on the undrained shear strength / SPT N'_{70} factor, undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by triaxial UU tests / SPT N'_{70}, undrained shear strength by triaxial UU tests / SPT N_{60} and undrained shear strength by triaxial UU tests / SPT N_f calculated factors were plotted against the respective liquid limits, given in the *Figure III-7*. The available data with SPT N_{field} value zero (0) were not considered in this analysis.

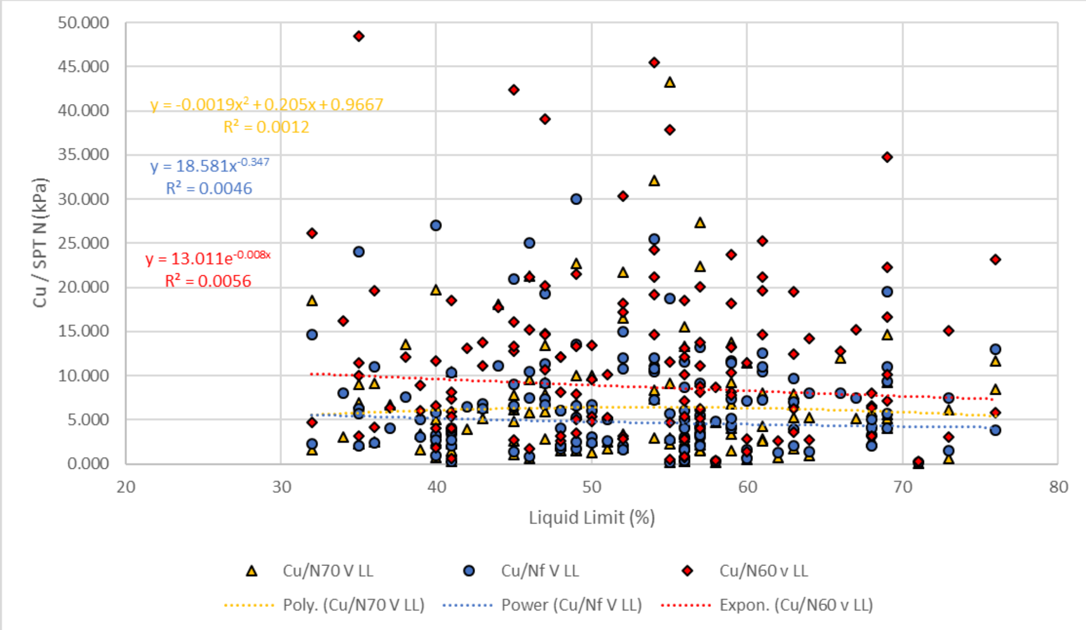

Figure III-7: C_u/SPT N Ratio against liquid limit.

3. Analysis based on the variation of Plastic Limit

3.1. SPT N'$_{70}$ Vs Undrained Shear Strength by Triaxial UU Tests

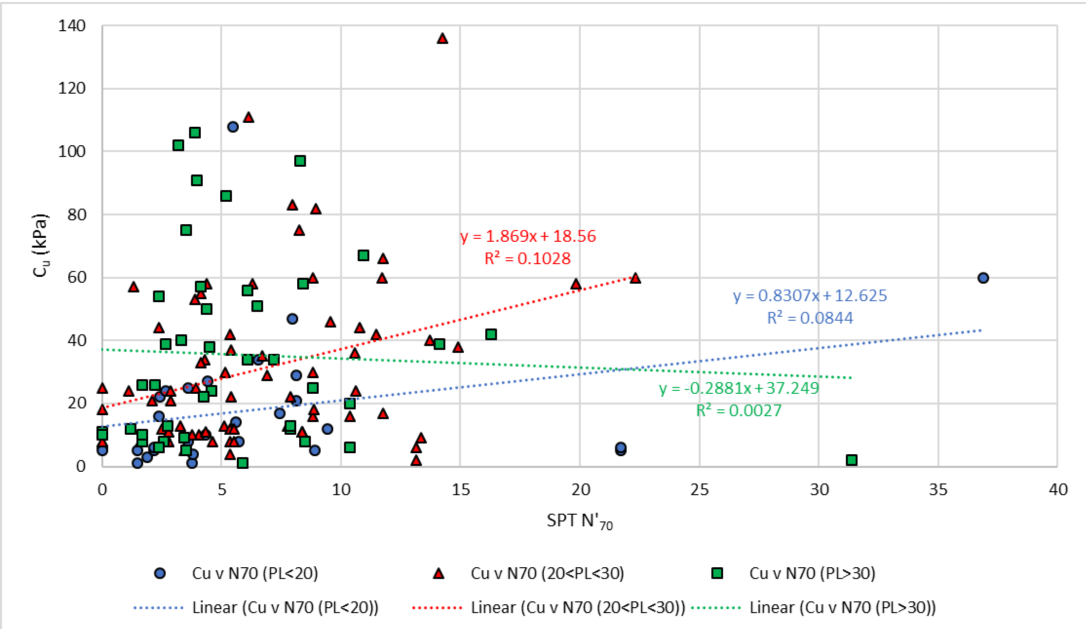

Figure III-8: SPT N'$_{70}$ Vs undrained shear strength by triaxial UU tests (based on PL)

The effects of the variation of plastic limit (PL) on the relationship between SPT N'$_{70}$ and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to three sub categories based on their plastic limits as PL<20%, 20%<PL<30% and PL>30%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-8* with aforesaid categories, categorized based on plastic limits.

3.2 SPT N_{60} Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of plastic limit (PL) on the relationship between SPT N_{60} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to three sub categories based on their plastic limits as PL<20%, 20%<PL<30% and PL>30%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-9* with aforesaid categories, categorized based on plastic limits.

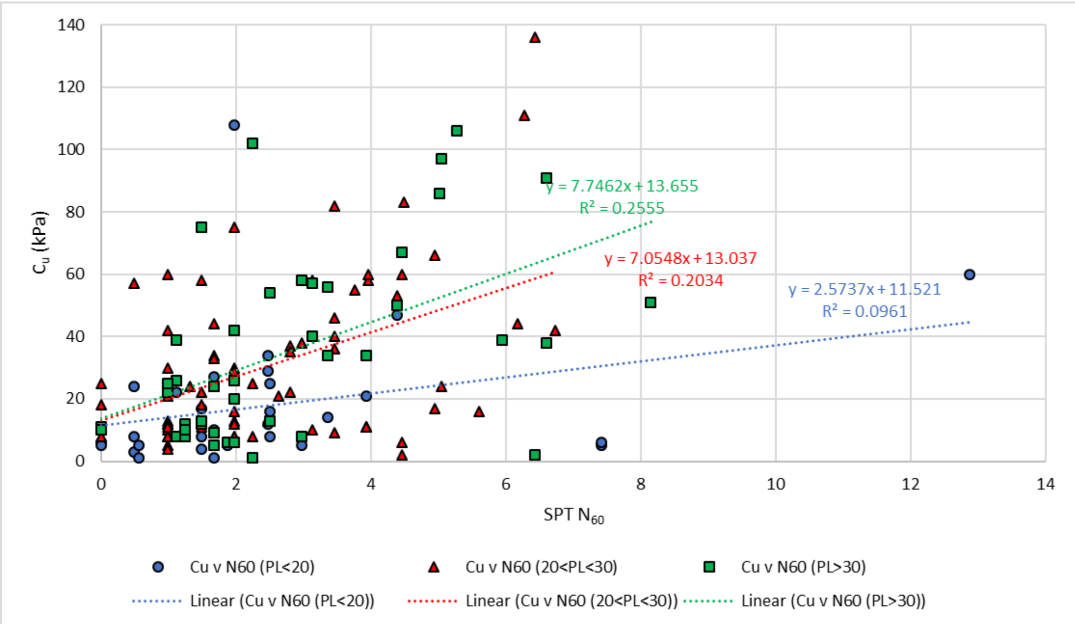

Figure III-9: SPT N_{60} Vs undrained shear strength by triaxial UU tests (based on PL)

3.3 SPT N_f Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of plastic limit (PL) on the relationship between SPT N_f and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to three sub categories based on their plastic limits as PL<20%, 20%<PL<30% and PL>30%.

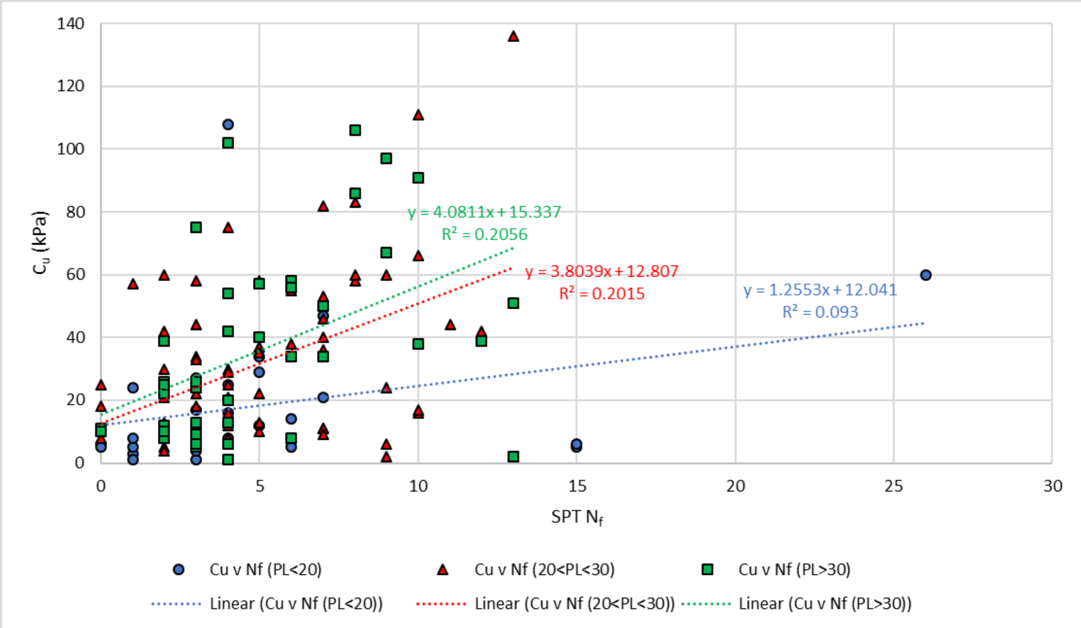

Figure III-10: SPT N_{field} Vs undrained shear strength by triaxial UU tests (based on PL)

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure III-10* with aforesaid categories, categorized based on plastic limits.

3.4 C_u/SPT N Ratio against Plastic Limit.

To get an overall idea on the effects of the plastic limit on the undrained shear strength / SPT N'$_{70}$, undrained shear strength / SPT N'$_{60}$ factor and undrained shear strength / SPT N_f factor, the undrained shear strength by triaxial UU tests / SPT N'$_{70,}$ undrained shear strength by triaxial UU tests / SPT N_{60} and undrained shear strength by triaxial UU tests / SPT N_f calculated factors were plotted against the respective plastic limits, given in the *Figure III-11*. The available data with SPT N_{field} value zero (0) were not considered for this analysis.

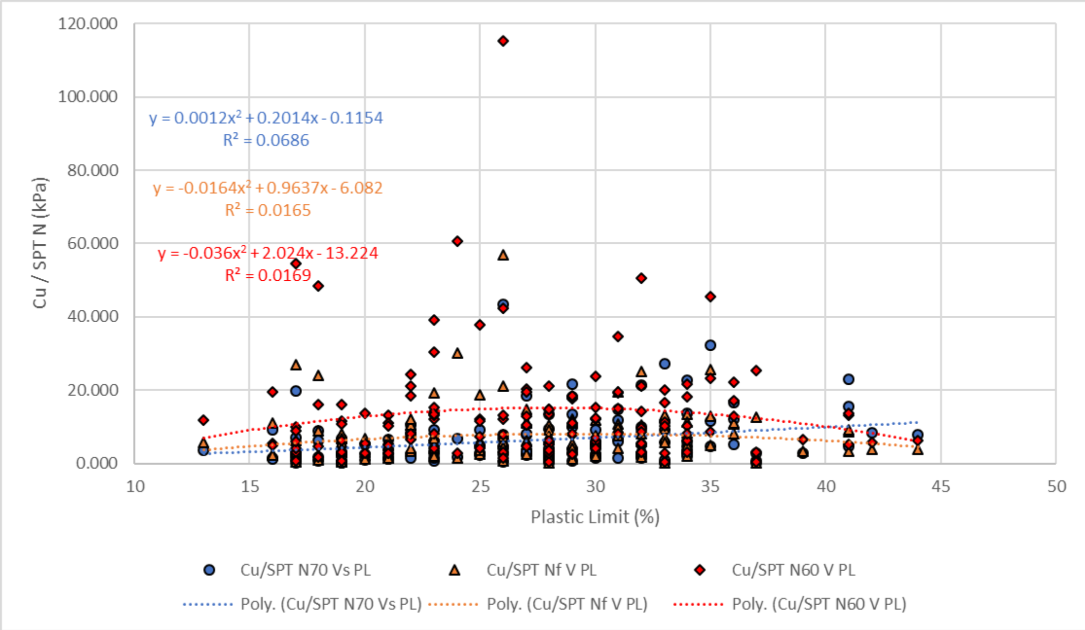

Figure III-11: C_u/SPT N Ratio against plastic limit.

4. Analysis based on the variation of Plasticity Index

4.1. SPT N'$_{70}$ Vs Undrained Shear Strength by Triaxial UU Tests

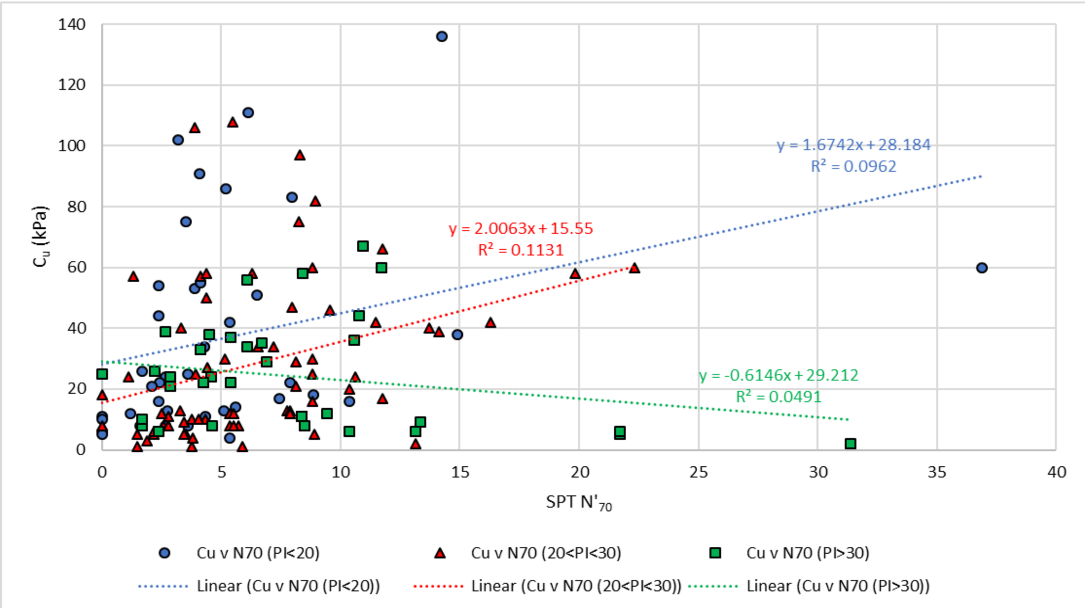

Figure III-12: SPT N'$_{70}$ Vs undrained shear strength by triaxial UU tests (based on PI)

The effects of the variation of plasticity index (PI) on the relationship between SPT N'$_{70}$ and undrained shear strength by triaxial UU tests is studied in this section.

Available data set was categorized in to three sub categories based on their plasticity lndexes as PI<20%, 20%<PI<30% and PI>30%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-12* with aforesaid categories, categorized based on plasticity indexes.

4.2 SPT N_{60} Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of plasticity index (PI) on the relationship between SPT N_{60} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to three sub categories based on their plasticity lndexes as PI<20%, 20%<PI<30% and PI>30%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-13* with aforesaid categories, categorized based on plasticity indexes.

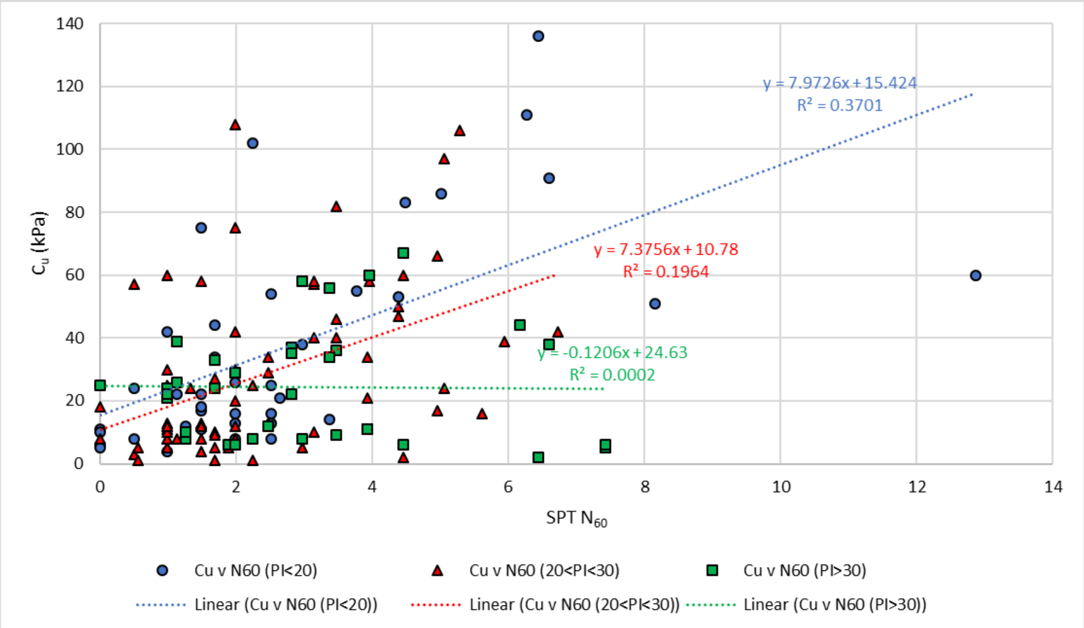

Figure III-13: SPT N_{60} Vs undrained shear strength by triaxial UU tests (based on PI)

4.3 SPT N_f Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of plasticity index (PI) on the relationship between SPT N_f and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to three sub categories based on their plasticity index as PI<20%, 20%<PI<30% and PI>30%.

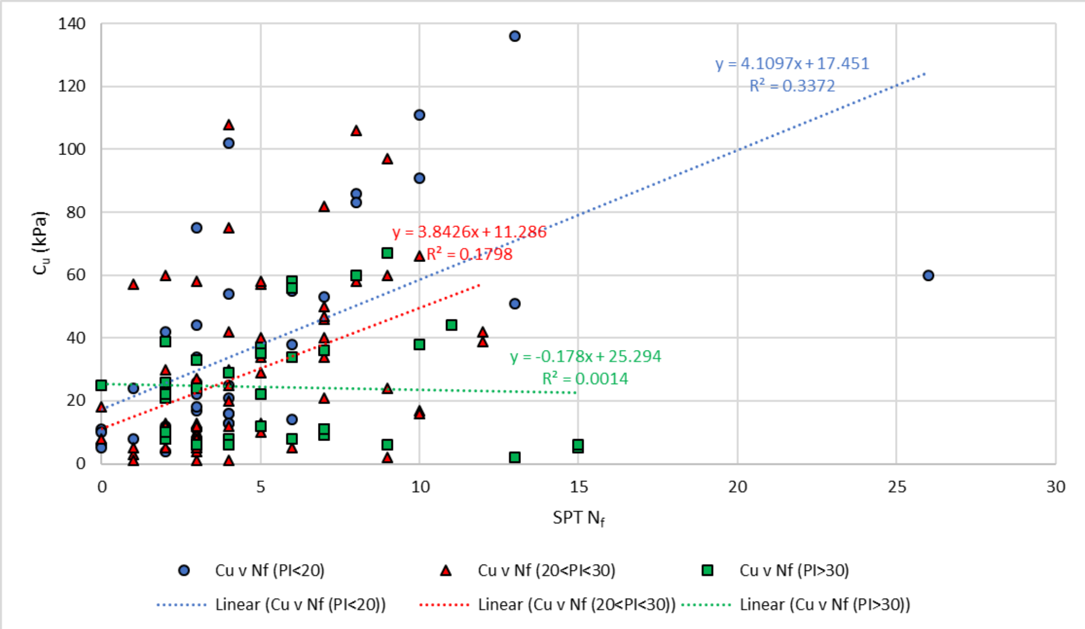

Figure III-14: SPT N_{field} Vs undrained shear strength by triaxial UU tests (based on PI)

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure III-14* with aforesaid categories, categorized based on plasticity indexes.

4.4. C_u/SPT N Ratio against Plasticity Index.

To get an overall idea on the effects of the plasticity index on the undrained shear strength / SPT N'_{70} factor, undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by triaxial UU tests / SPT $N'_{70,}$ the undrained shear strength by triaxial UU tests / SPT N_{60} and undrained shear strength by triaxial UU tests / SPT N_f calculated factors were plotted against the respective Plasticity Index, given in the *Figure III-15*. The available data with SPT N_{field} value zero (0) were not considered for this analysis.

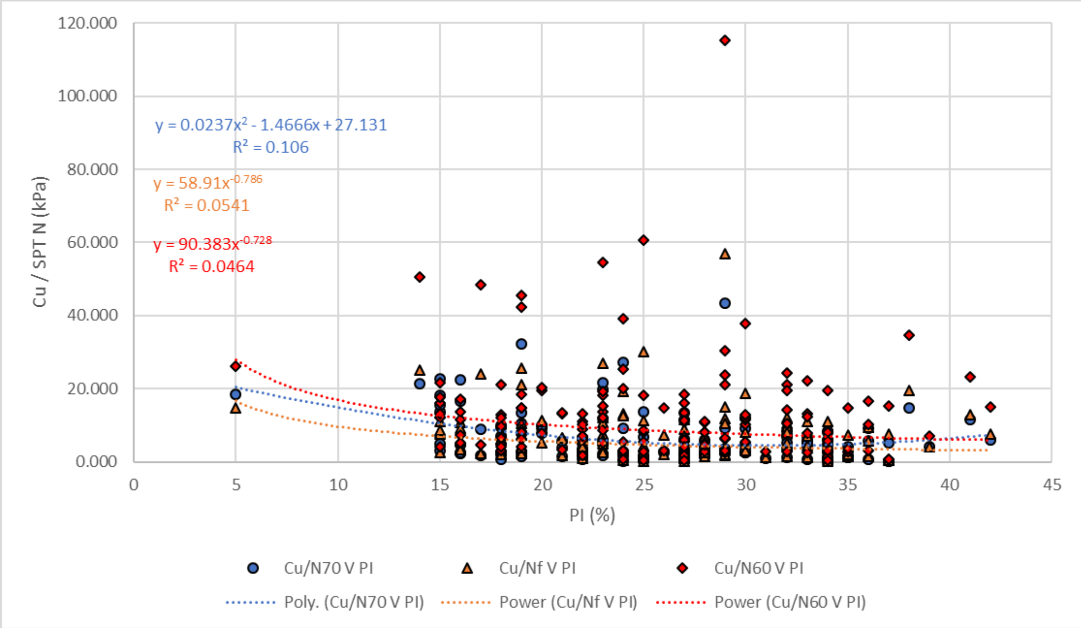

Figure III-15: C_u/SPT N Ratio against plasticity index.

5. Analysis based on the variation Fines Content.

5.1. SPT N'$_{70}$ Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of fines content (FC) on the relationship between SPT N'$_{70}$ and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to five sub categories based on their fines content as FC>90%, 90%<FC<80%, 80%<FC<70%, 70%<FC<60% and 60%<FC<50%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'$_{70}$ values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-16* with aforesaid categories, categorized based on fines content.

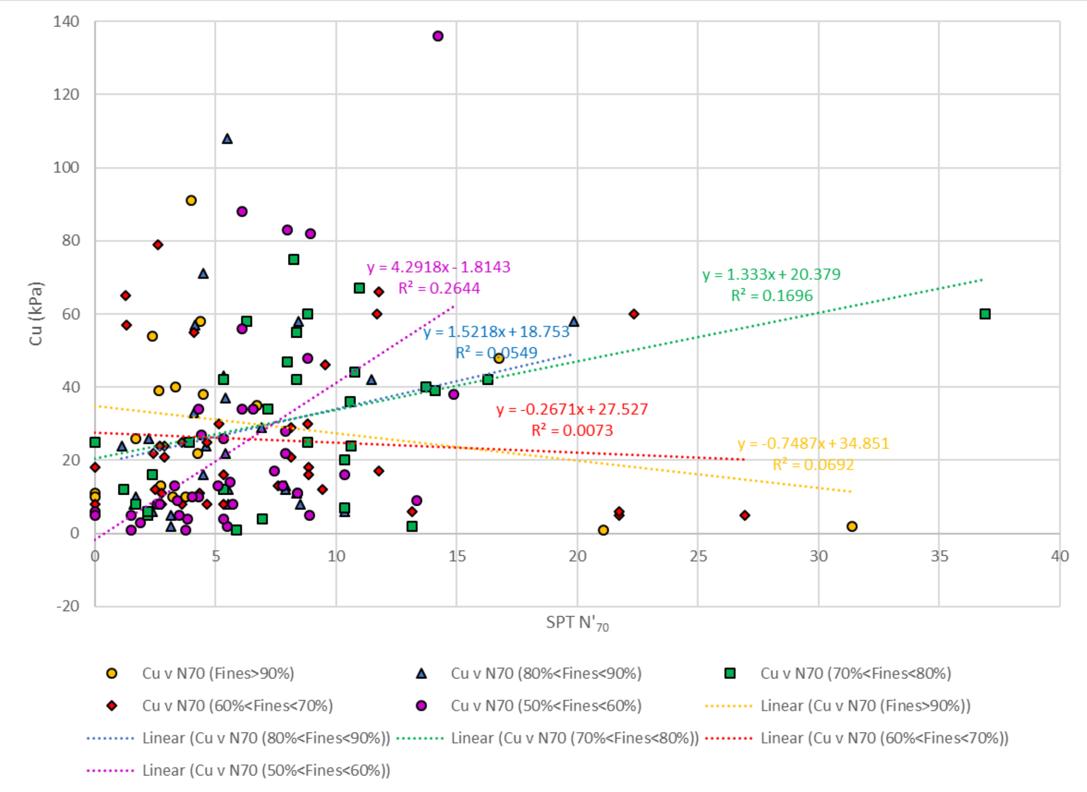

Figure III-16: SPT N’$_{70}$ Vs undrained shear strength by triaxial UU tests (based on FC)

5.2 SPT N_{60} Vs Undrained Shear Strength by Triaxial UU Tests

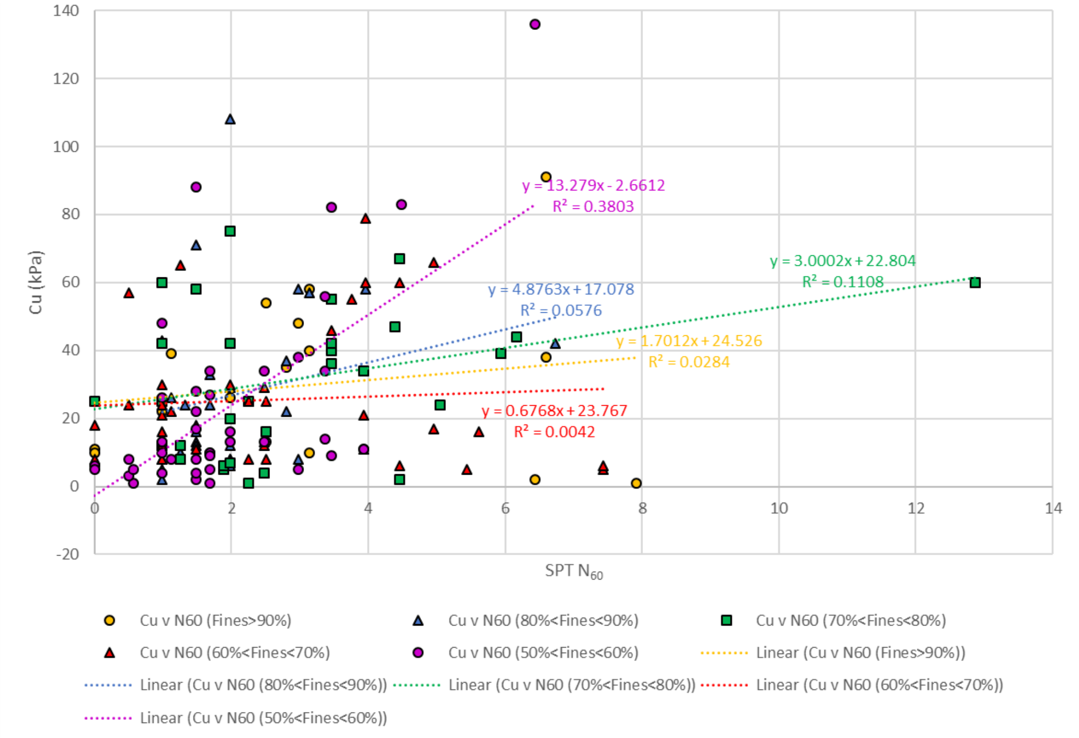

Figure III-17: SPT N_{60} Vs undrained shear strength by triaxial UU tests (based on FC)

The effects of the variation of fines content (FC) on the relationship between SPT N_{60} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to five sub categories based on their fines content as FC>90%, 90%<FC<80%, 80%<FC<70%, 70%<FC<60% and 60%<FC<50%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-17* with aforesaid categories, categorized based on fines content.

5.3 SPT N_f Vs Undrained Shear Strength by Triaxial UU Tests

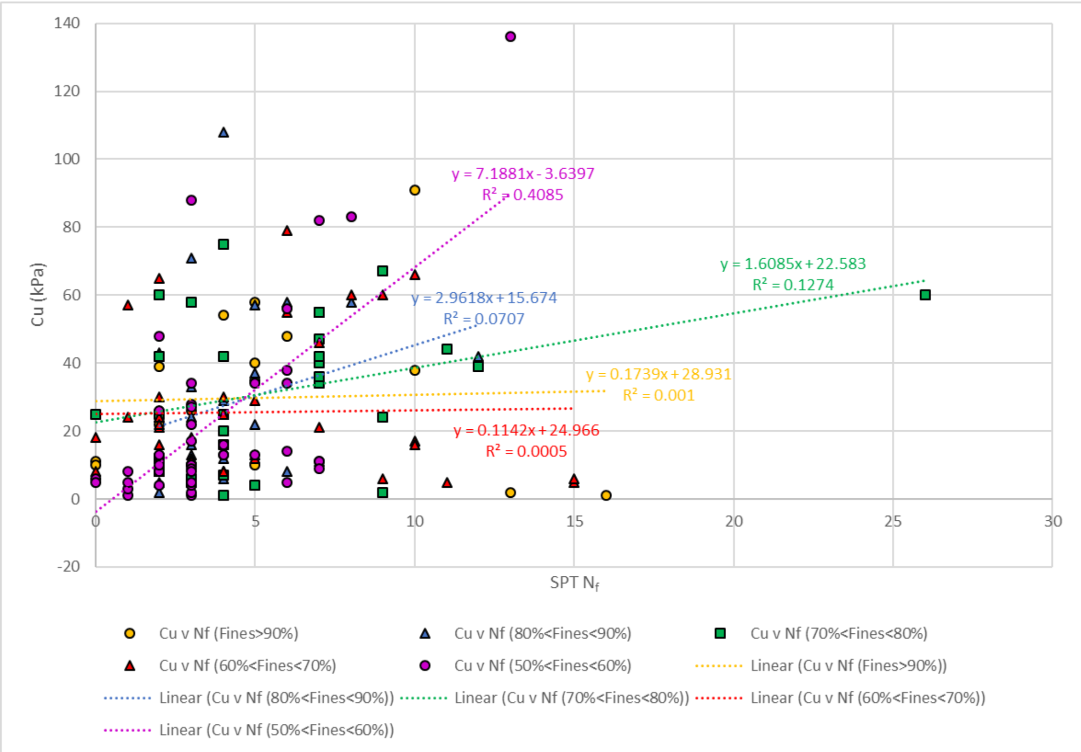

Figure III-18: SPT N_{field} Vs undrained shear strength by triaxial UU tests (based on FC)

The effects of the variation of fines content (FC) on the relationship between SPT N_f and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to five sub categories based on their fines content as FC>90%, 90%<FC<80%, 80%<FC<70%, 70%<FC<60% and 60%<FC<50%.

Undrained Shear Strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_f values, observed from the respective soil stratums at the field, respective soil stratums at the field, is shown in the *Figure III-18* with aforesaid categories, categorized based on fines content.

5.4 C_u/SPT N Ratio against Fines Content.

To get an overall idea on the effects of the fines content on the undrained shear strength / SPT N'_{70} factor, undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by triaxial UU tests / SPT N'_{70}, undrained shear strength by triaxial UU tests / SPT N_{60} and undrained shear strength by triaxial UU tests / SPT N_f calculated factors were plotted against the respective fines content, given in the *Figure III-19*. The available data with SPT N_{field} value zero (0) were not considered for this analysis

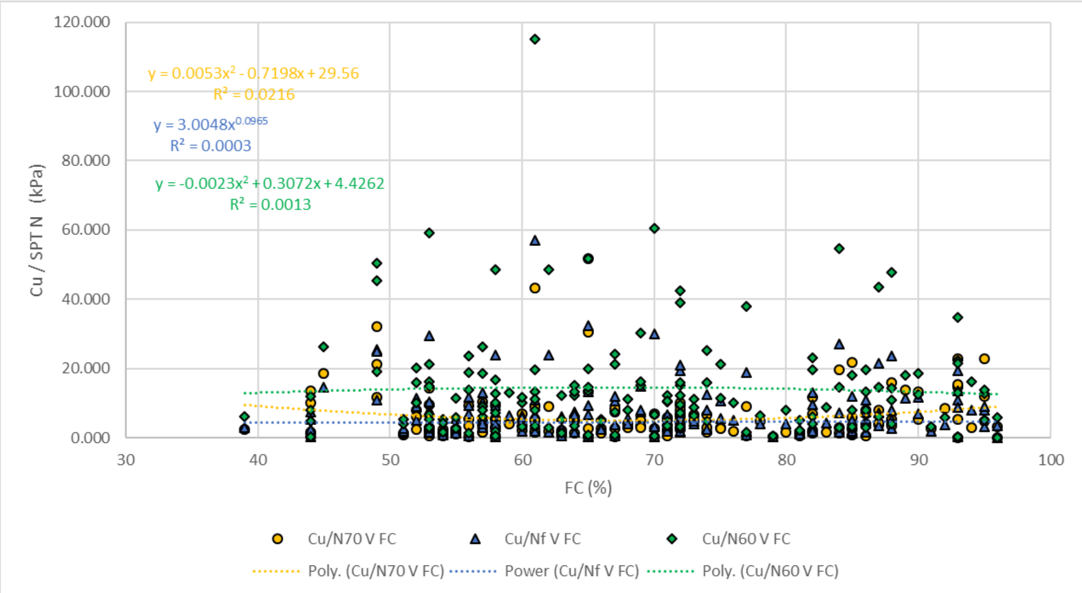

Figure III-19 C_u/SPT N Ratio against fines content.

6. Analysis based on the variation Clay Content.

6.1. SPT N'_{70} Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of clay content (CC) on the relationship between SPT N'_{70} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to five sub categories based on their clay content as 50%<CC<70%, 40%<CC<50%, 30%<CC<40%, 20%<CC<30% and CC<20%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-20* with aforesaid categories, categorized based on clay content.

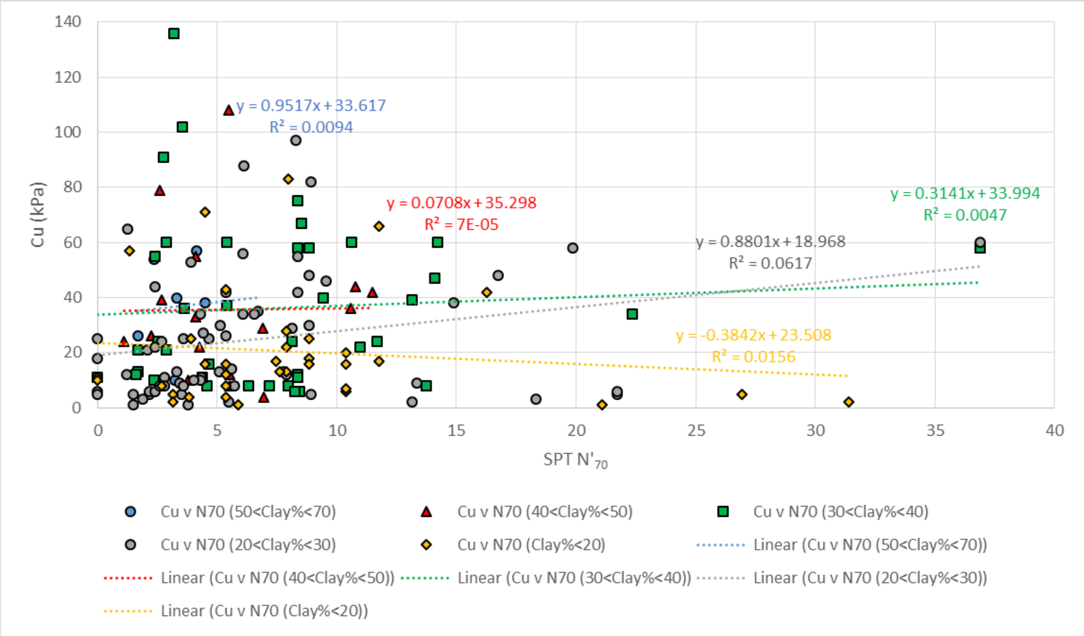

Figure III-20: SPT N'$_{70}$ Vs undrained shear strength by triaxial UU tests (based on CC)

6.2 SPT N_{60} Vs Undrained Shear Strength by Triaxial UU Tests

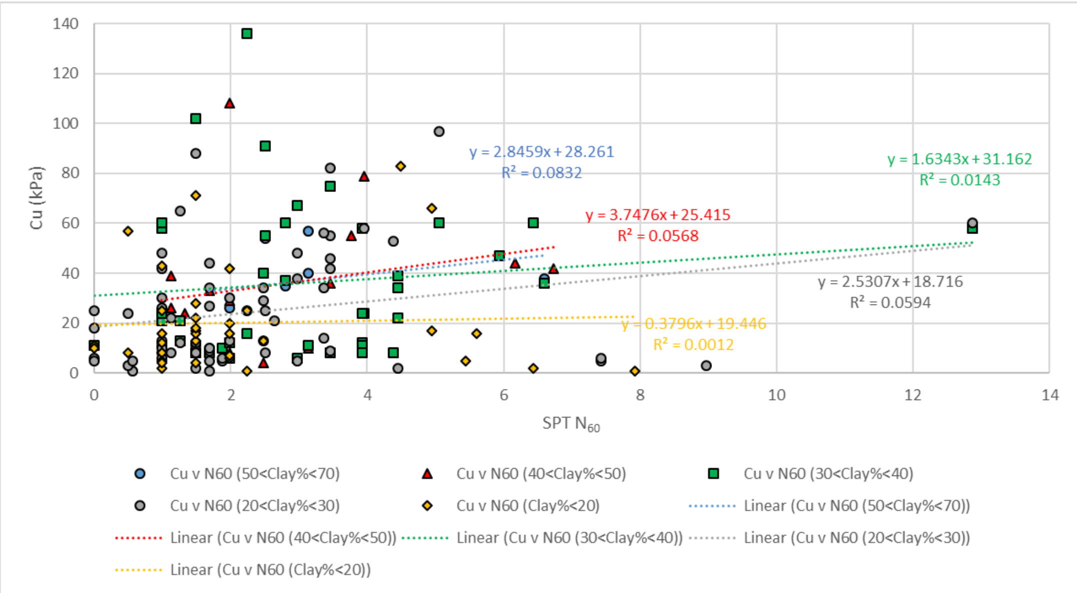

Figure III-21: SPT N_{60} Vs Undrained Shear Strength by triaxial UU tests (based on CC)

The effects of the variation of clay content (CC) on the relationship between SPT N_{60} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to five sub categories based on their clay content as 50%<CC<70%, 40%<CC<50%, 30%<CC<40%, 20%<CC<30% and CC<20%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-21* with aforesaid categories, categorized based on clay content.

6.3 SPT N_f Vs Undrained Shear Strength by Triaxial UU Tests

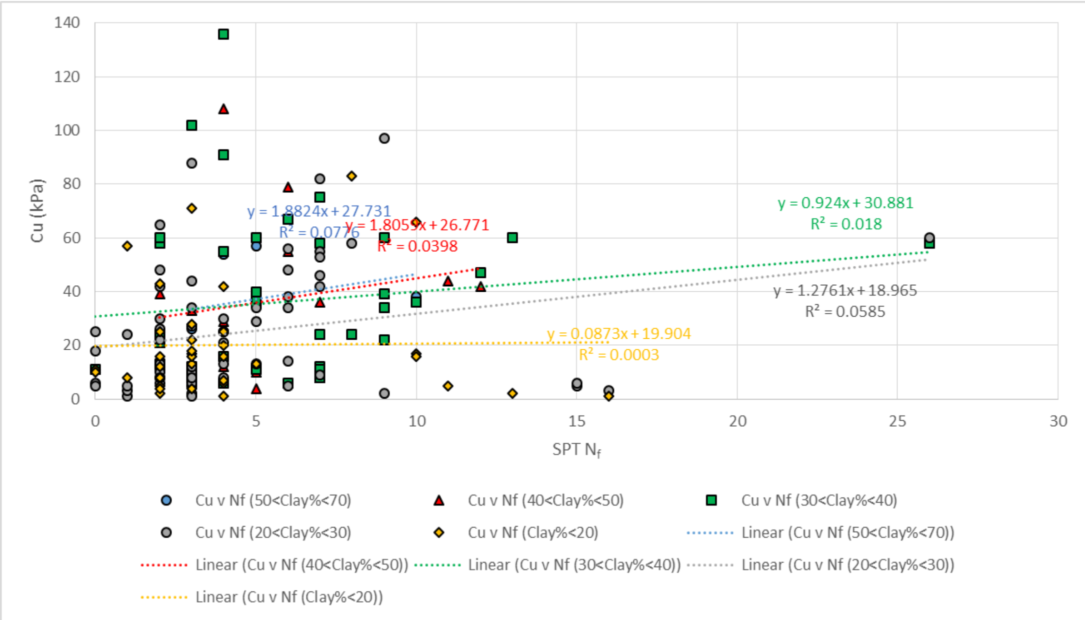

Figure 111-22: SPT N_{field} Vs undrained shear strength by triaxial UU tests (based on CC)

The effects of the variation of clay content (CC) on the relationship between SPT N_f and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to five sub categories based on their clay content as 50%<CC<70%, 40%<CC<50%, 30%<CC<40%, 20%<CC<30% and CC<20%.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure III-22* with aforesaid categories, categorized based on clay content.

6.4 C_u/SPT N Ratio against Clay Content.

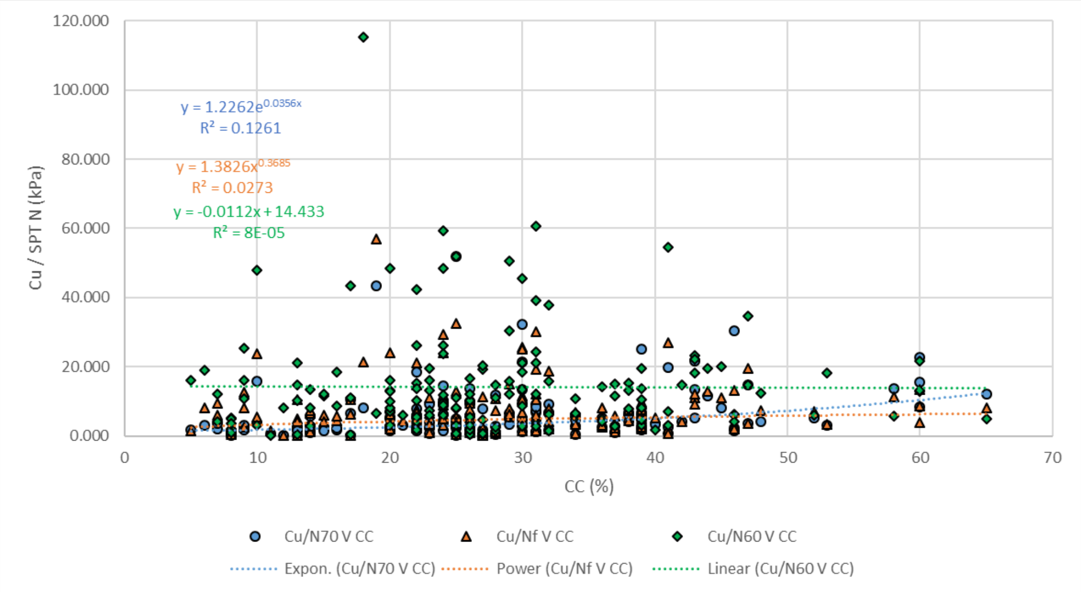

Figure III-23: Cu/SPT N Ratio against clay content.

To get an overall idea on the effects of the clay content on the undrained shear strength / SPT N'_{70} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by triaxial UU tests / SPT N'_{70} and undrained shear strength by triaxial UU tests / SPT N_f calculated factors were plotted against the respective clay content, given in the *Figure III-23*. The available data with SPT N_{field} value zero (0) were not considered for this analysis

7. Analysis based on the variation Sampling Depth.

7.1. SPT N'_{70} Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of sampling depth (SD) and the effects of the SPT Correction factors on the relationship between SPT N'_{70} and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to seven sub categories based on their sampling depth as 0.3m, 1.3m, 2.3m, 3.3m, 4.3, 5.3 to 6.3m, 7.3 to 13.3m.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-24* with aforesaid categories, categorized based on sampling depth.

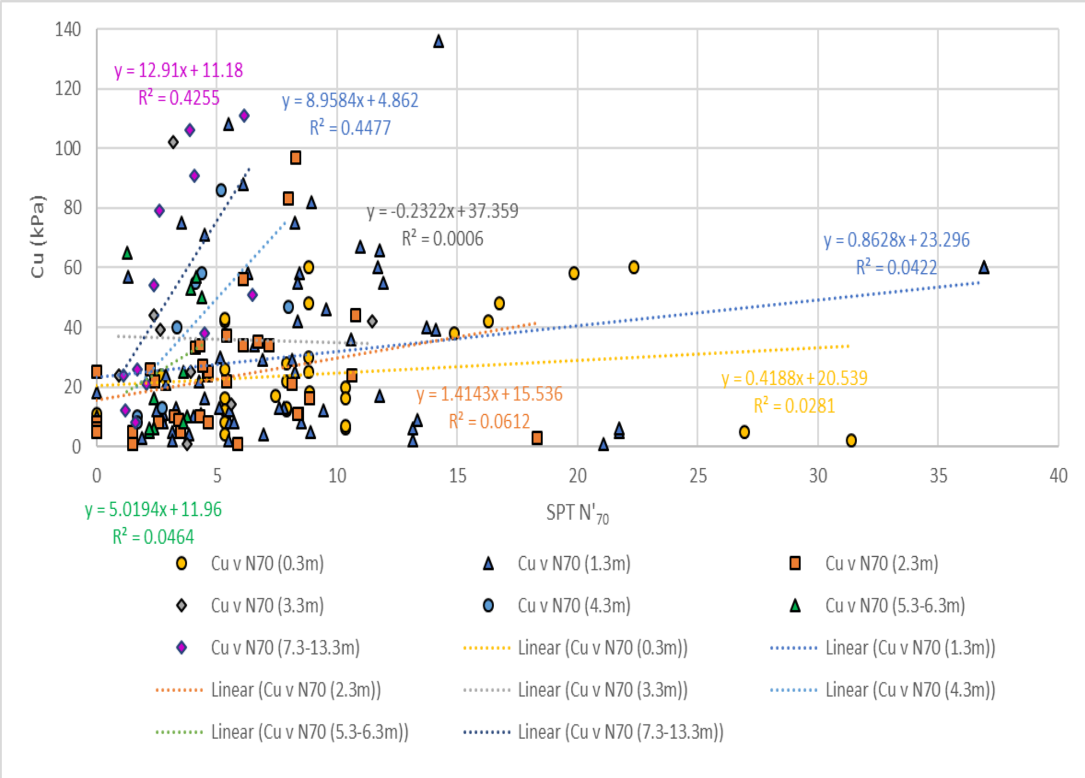

Figure III-24: SPT N’$_{70}$ Vs undrained shear strength by triaxial UU tests (based on sampling depth)

7.2 SPT N$_{60}$ Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of sampling depth (SD) and the effects of the SPT Correction factors on the relationship between SPT N$_{60}$ and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to seven sub categories based on their sampling depth as 0.3m, 1.3m, 2.3m, 3.3m, 4.3, 5.3 to 6.3m, 7.3 to 13.3m.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N$_{60}$ values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-25* with aforesaid categories, categorized based on sampling depth.

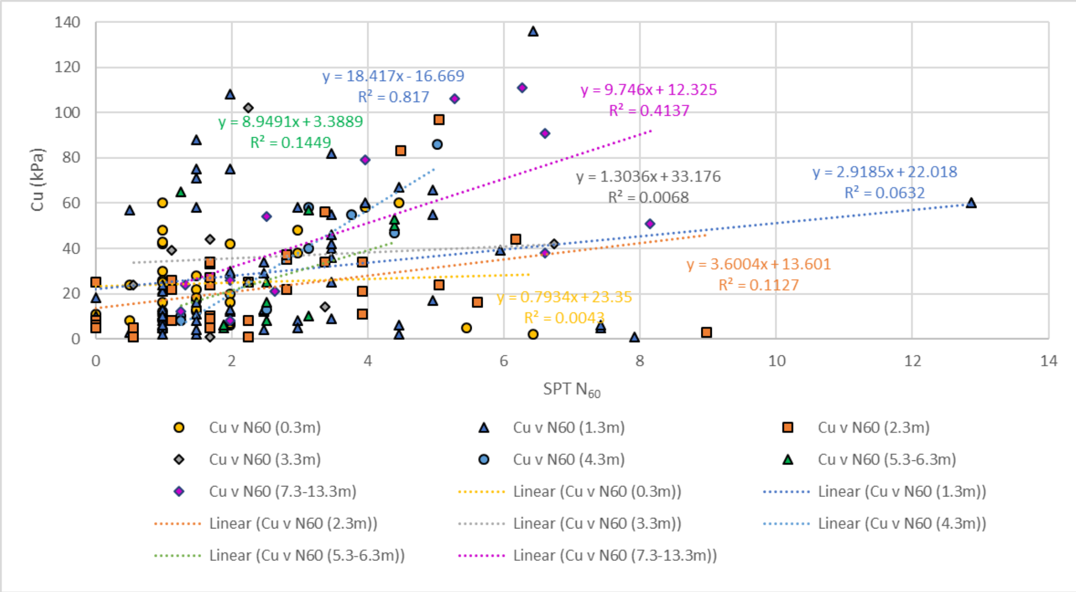

Figure III-25: SPT N_{60} Vs undrained shear strength by triaxial UU tests (based on sampling depth)

7.3 SPT N_f Vs Undrained Shear Strength by Triaxial UU Tests

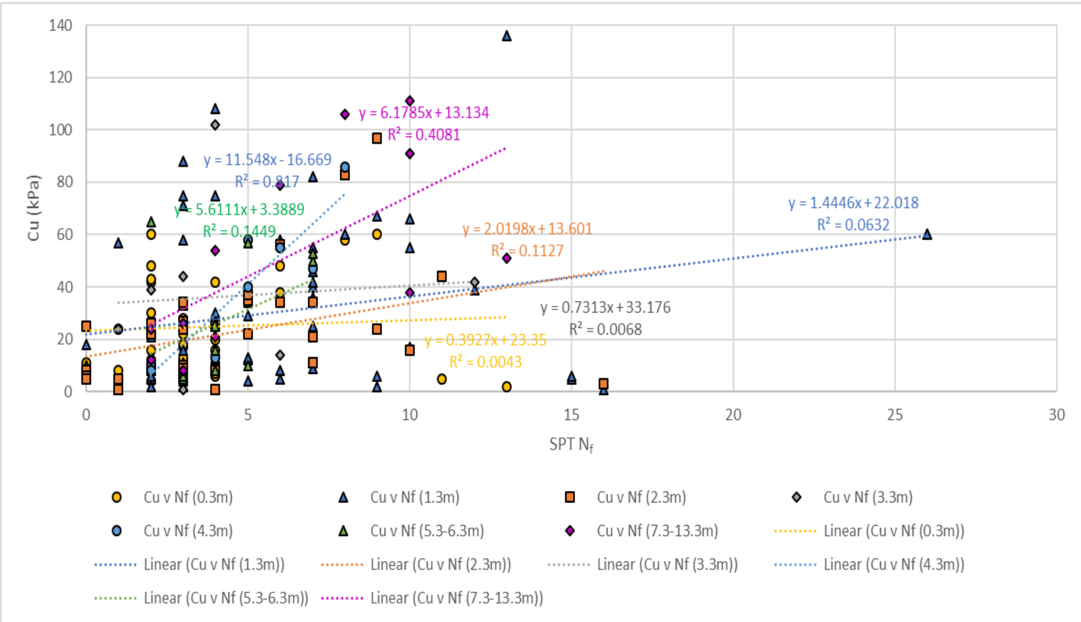

Figure III-26: SPT N_{field} Vs undrained shear strength by triaxial UU tests (based on sampling depth)

The effects of the variation of sampling depth (SD) on the relationship between SPT N_f and undrained shear strength by triaxial UU tests is studied in this section. Available data set was categorized in to seven sub categories based on their sampling depth as 0.3m, 1.3m, 2.3m, 3.3m, 4.3, 5.3 to 6.3m, 7.3 to 13.3m.

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_f values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-26* with aforesaid categories, categorized based on sampling depth.

7.4 C_u/SPT N Ratio against Sampling Depth.

To get an overall idea on the effects of the sampling depth on the undrained shear strength / SPT N'_{70} factor, undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by triaxial UU tests / SPT N'_{70}, undrained shear strength by triaxial UU tests / SPT N_{60} and undrained shear strength by triaxial UU tests / SPT N_f calculated factors were plotted against the respective sampling depth, given in the *Figure III-27*. The available data with SPT N_{field} value zero (0) were not considered for this analysis

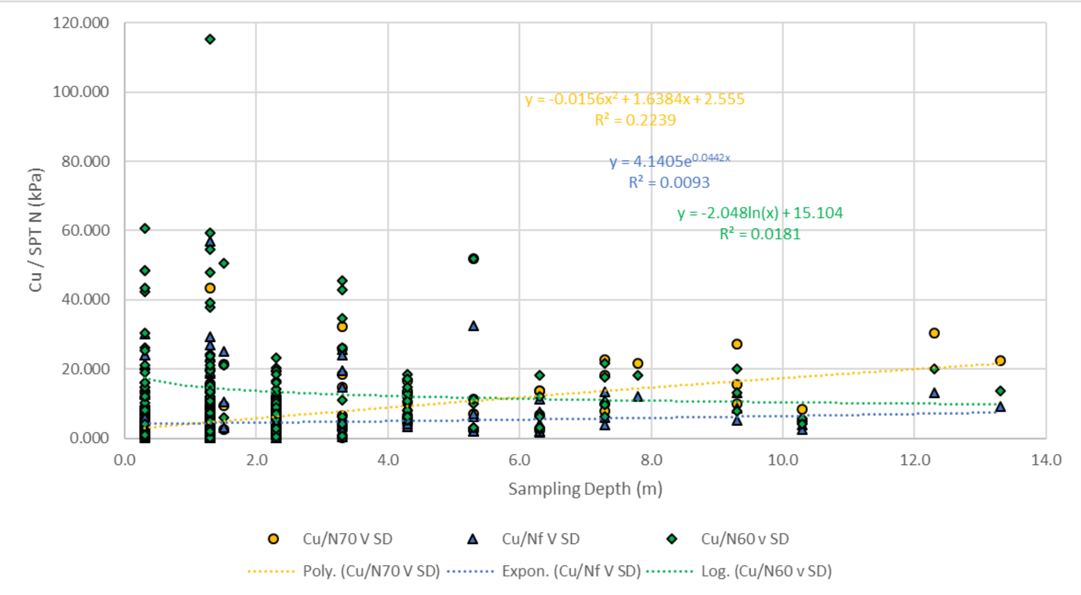

Figure III-27: C_u/SPT N Ratio against sampling depth.

8. Analysis based on the Unified Soil Classification System (USCS)

8.1. SPT N'_{70} Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of soil types on correlation between SPT N'_{70} and undrained shear strength by triaxial UU tests are studied in this section. unified soil classification system (USCS) is used for the classification of available fine grained soil samples and categorized in to four divisions as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) and low plastic silt (ML).

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-28* with aforesaid categories, categorized based on USCS.

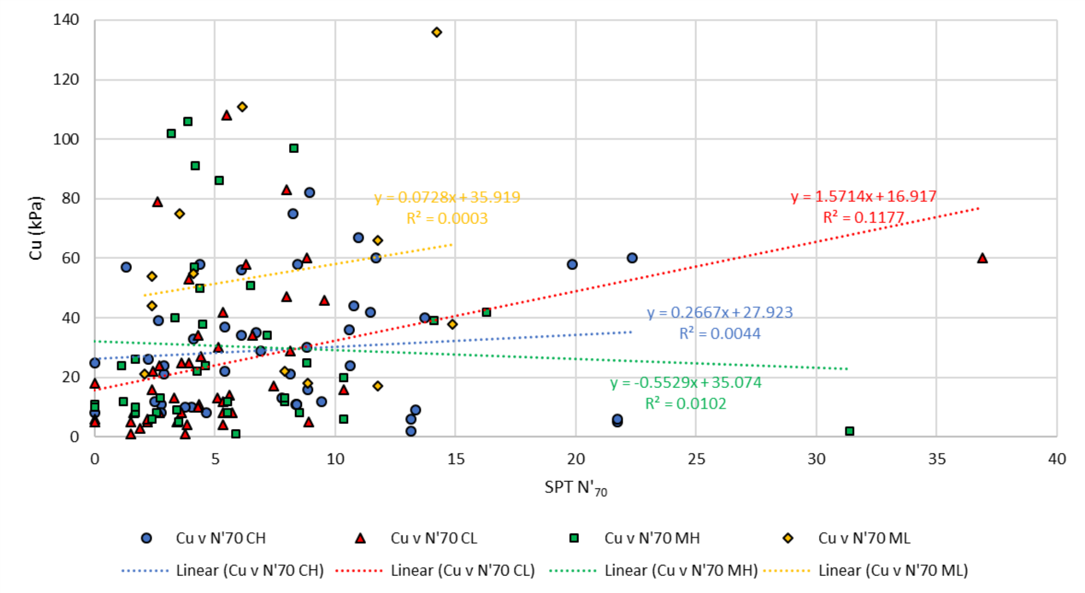

Figure III-28: SPT N'_{70} Vs undrained shear strength by triaxial UU tests (based on USCS)

8.2 SPT N_{60} Vs Undrained Shear Strength by Triaxial UU Tests

The effects of the variation of soil types on correlation between SPT N_{60} and undrained shear strength by triaxial UU tests are studied in this section. unified soil classification system (USCS) is used for the classification of available fine grained soil samples and categorized in to four divisions as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) and low plastic silt (ML).

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure III-29* with aforesaid categories, categorized based on USCS.

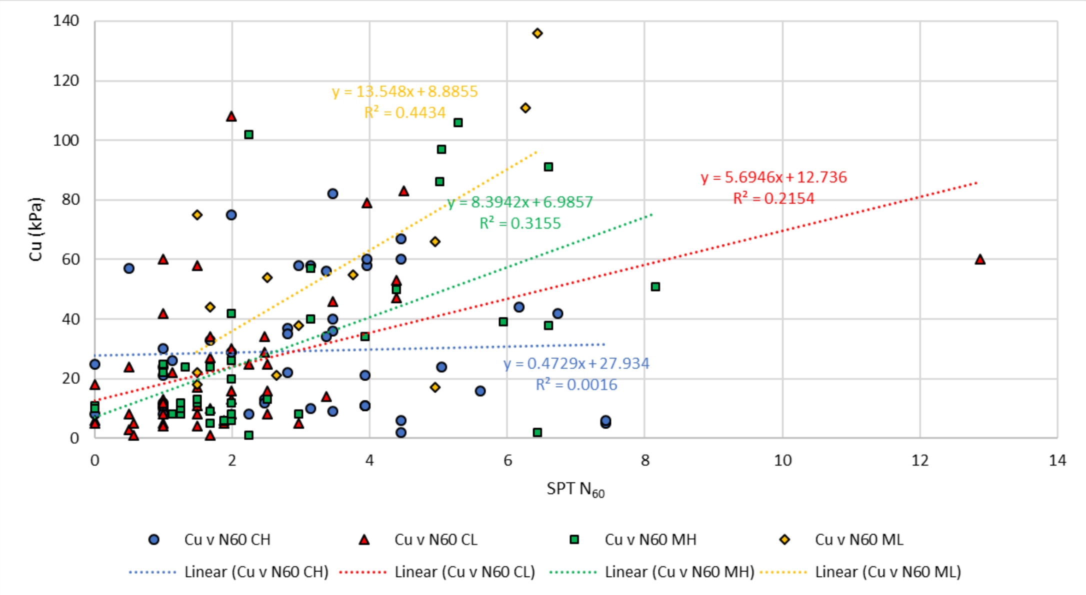

Figure III-29: SPT N_{60} Vs undrained shear strength by triaxial UU tests (based on USCS)

8.3 SPT N_{field} Vs Undrained Shear Strength by Triaxial UU Tests

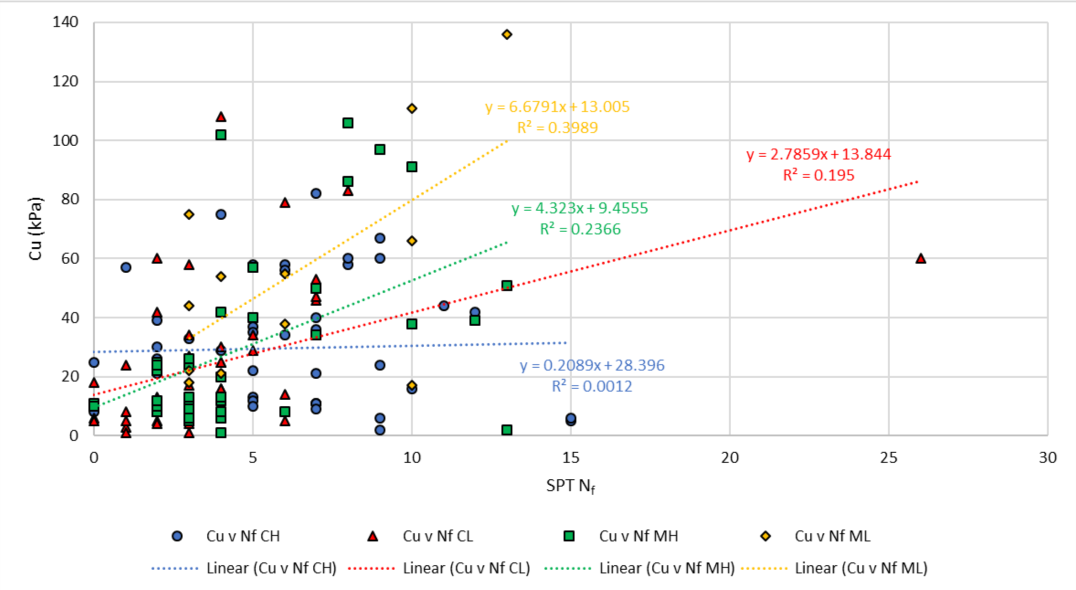

Figure III-30: SPT N_{field} Vs undrained shear strength by triaxial UU tests (based on USCS)

The effects of the variation of soil types on correlation between SPT N_{field} and undrained shear strength by triaxial UU tests are studied in this section. unified soil classification system (USCS) is used for the classification of available fine grained soil samples and categorized in to four divisions as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) and low plastic silt (ML).

Undrained shear strength values of undisturbed fine grained soil samples, determined with triaxial UU tests were plotted against the SPT N_{field} values, observed from the respective soil stratums at the field, is shown in the *Figure III-30* with aforesaid categories, categorized based on USCS.

Appendix IV : Graphs of Analysis using Undrained Shear Strength by Field Vane Shear Test.

1. Analysis on Fine Grained Soils, Complete Set.

1.1 SPT N'$_{70}$ Vs Undrained Shear Strength by Field Vane Shear Test. (Complete Set)

Soil samples of which more than 50 % percent by weight passing the No 200 sieve (75µm) were considered for the analysis without any divisions.

First the undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N'$_{70}$ values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-1*.

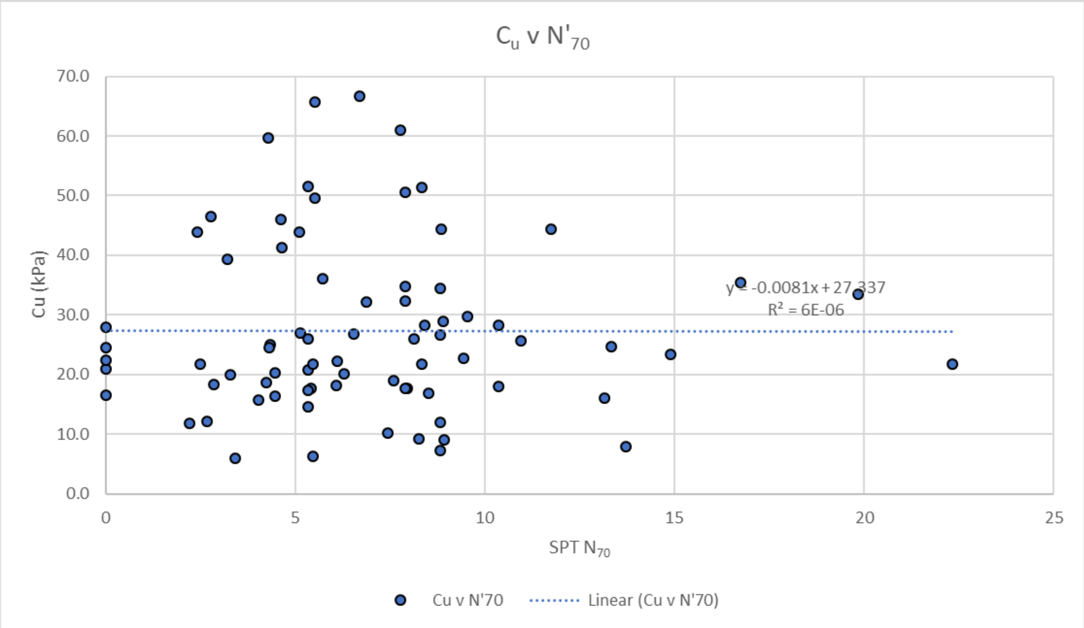

Figure IV-1: SPT N'$_{70}$ Vs undrained shear strength by field vane shear test (Complete Set)

Since the spread of the plotted data of SPT N'$_{70}$ Vs undrained shear strength for complete data set doesn't indicate any pattern, there are insufficient facts to get to a conclusion on a correlation between SPT N'$_{70}$ against the undrained shear strength of fine grained soils.

1.2 SPT N_{60} Vs Undrained Shear Strength by Field Vane Shear Test. (Complete Set)

It was decided to plot the undrained shear strength values of fine grained soil samples, determined with field vane shear test against the SPT N_{60} values, as shown in *Figure IV-2* to observe the spread before applying the correction factors on SPT N_{60}. Main purpose of this step is to negate the effects of the "Adjustment for effective overburden pressure P'$_o$" C_N, which makes a considerable impact of the SPT N'_{70} values, especially at shallow and very deep levels.

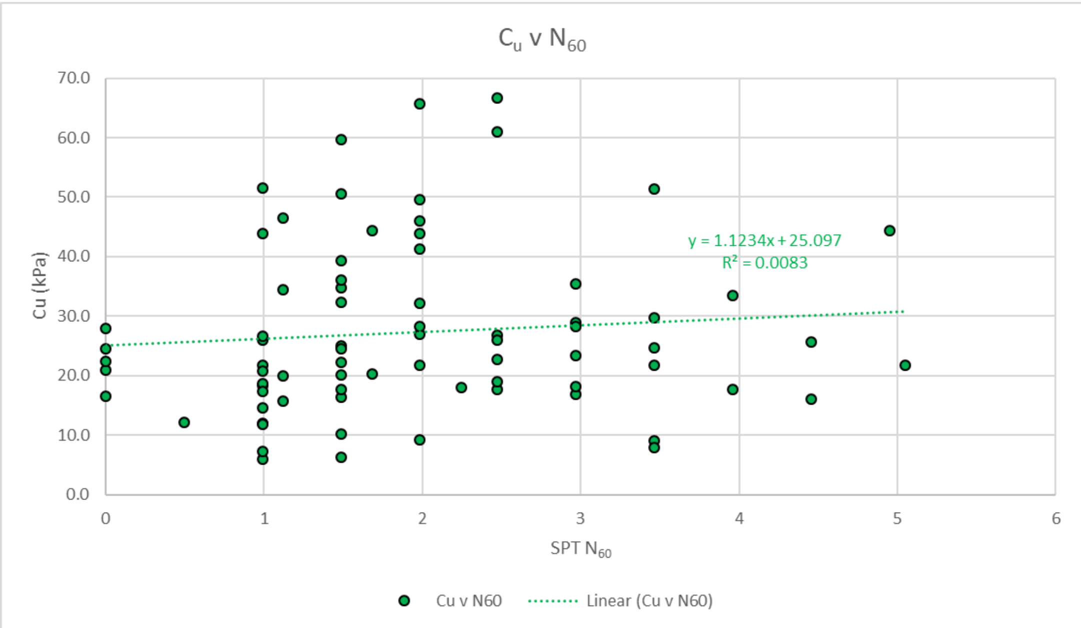

Figure IV-2: SPT N_{60} Vs undrained shear strength by field vane shear test (Complete Set)

1.3 SPT N_{field} Vs Undrained Shear Strength by field vane shear test (Complete Set)

It was decided to plot the undrained shear strength values of fine grained soil samples, determined with field vane shear test against the SPT N_{field} values, as shown in *Figure IV-3* to observe the spread before applying the correction factors on SPT N_{field}. Main purpose of this step is to negate the effects of the "Adjustment for effective overburden pressure P'$_o$" C_N, as well as the effects of correction factors which make a considerable impact of the SPT N'_{70} and SPT N_{60} values, especially at shallow and very deep levels.

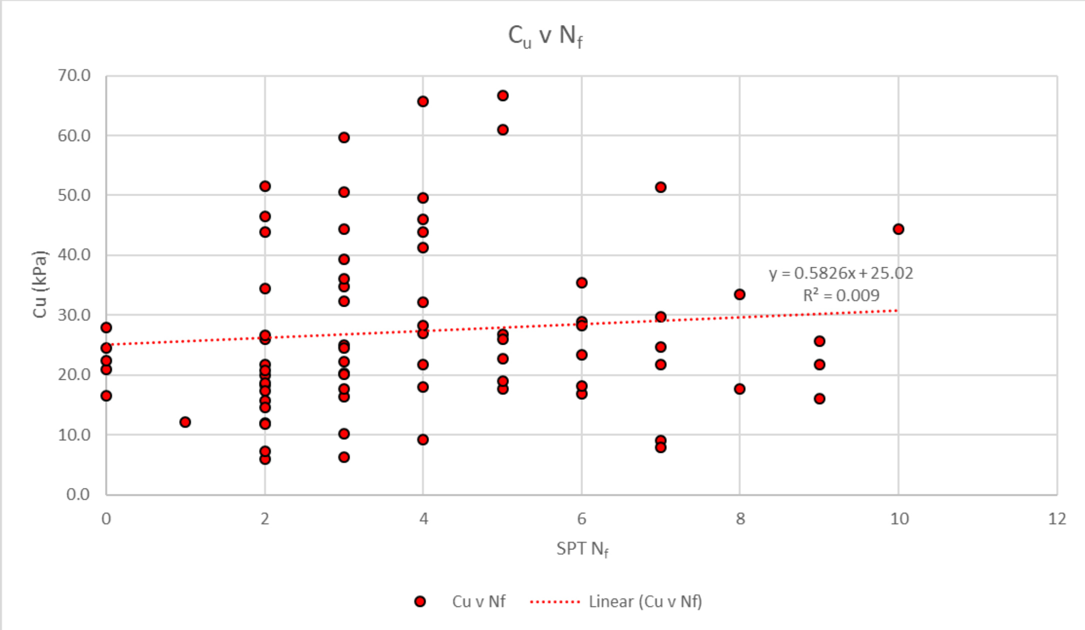

Figure IV-3: SPT N_{field} Vs undrained shear strength by field vane shear test (Complete Set)

2. Analysis based on the variation of Liquid Limit.

2.1 SPT N'$_{70}$ Vs Undrained Shear Strength by Field Vane Shear Tests.

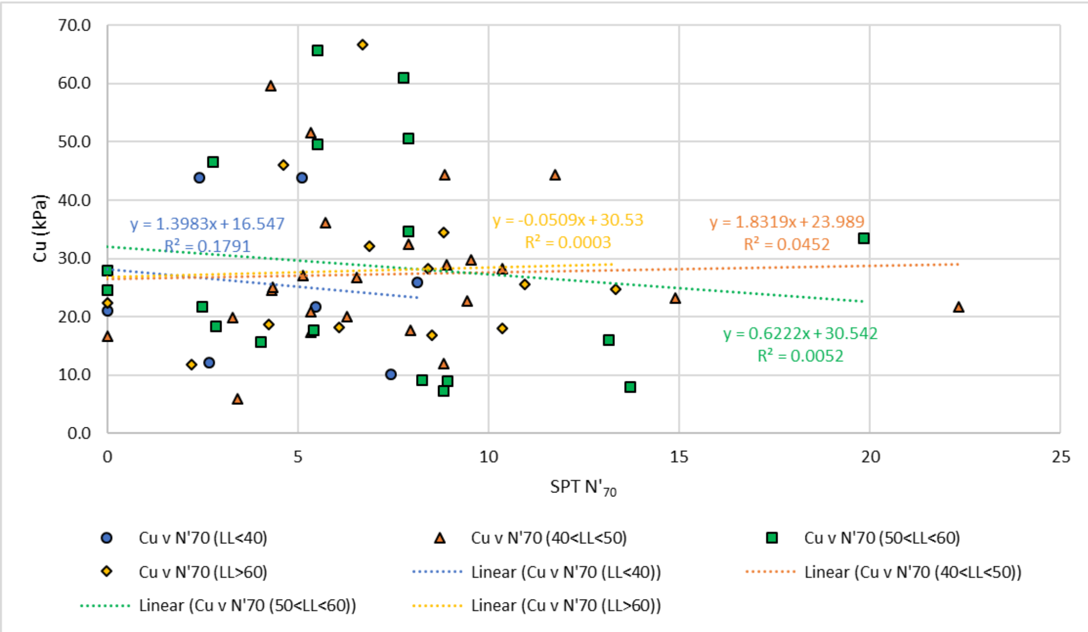

Figure IV-4: SPT N'$_{70}$ Vs undrained shear strength by field vane shear test (based on LL)

The effects of the variation of liquid limit (LL) on the relationship between SPT N'$_{70}$ and undrained shear strength by field vane shear test is studied in this section.

Available data set was categorized in to four sub categories based on their liquid limit as LL<40%, 40%<LL<50%, 50%<LL<60% and LL>60%.

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-4* with aforesaid categories, categorized based on liquid limit.

2.2 SPT N_{60} Vs Undrained Shear Strength by Field Vane Shear Tests.

The effects of the variation of liquid limit (LL) on the relationship between SPT N_{60} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to four sub categories based on their liquid limits as LL<40%, 40%<LL<50%, 50%<LL<60% and LL>60%.

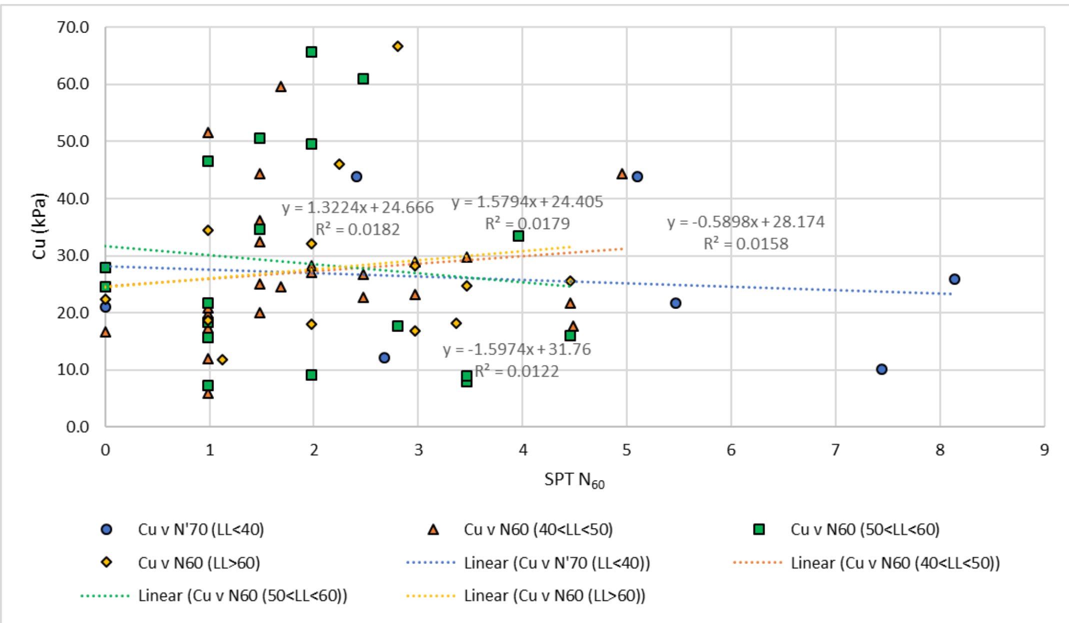

Figure IV-5: SPT N_{60} Vs undrained shear strength by field vane shear test (based on LL)

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-5* with aforesaid categories, categorized based on liquid limits.

2.3 SPT N_f Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of liquid limit (LL) on the relationship between SPT N_f and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to four sub categories based on their liquid limits as LL<40%, 40%<LL<50%, 50%<LL<60% and LL>60%.

Undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure IV-6* with aforesaid categories, categorized based on liquid limits

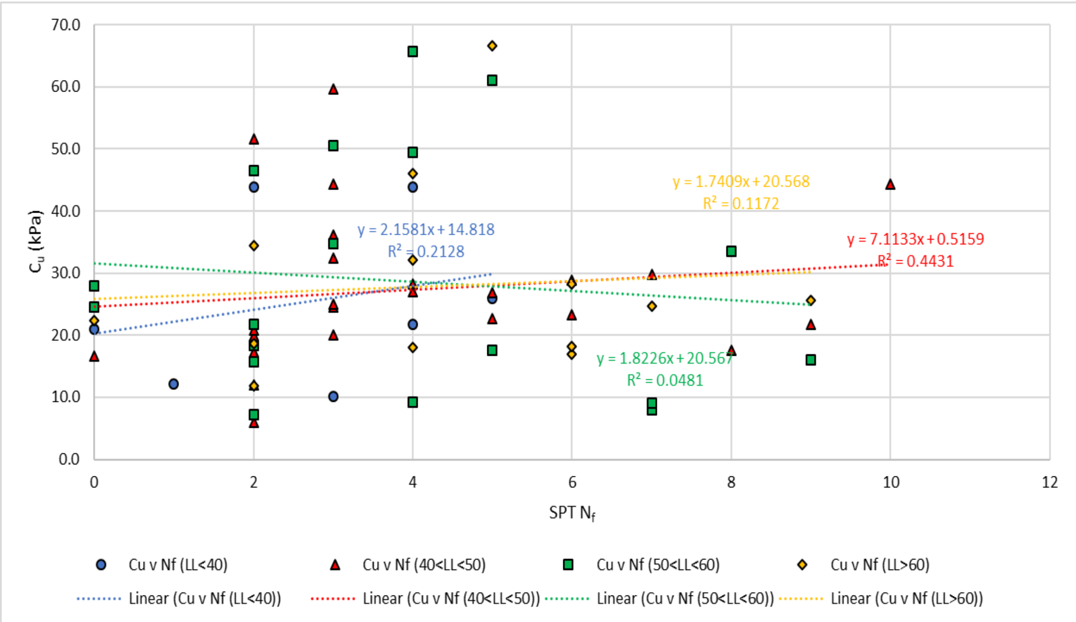

Figure IV-6: SPT N_f Vs undrained shear strength by field vane shear test (based on LL)

2.4 C_u/SPT N Ratio against Liquid Limit.

To get an overall idea on the effects of the liquid limit on the undrained shear strength / SPT N'_{70} factor, undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by field vane shear test / SPT N'_{70}, undrained shear strength by field vane shear test / SPT N_{60} and undrained shear strength by field vane shear test / SPT N_f calculated factors were plotted against the respective liquid limits, given in the *Figure IV-7*. The available data with SPT N_{field} value zero (0) were not considered for this analysis.

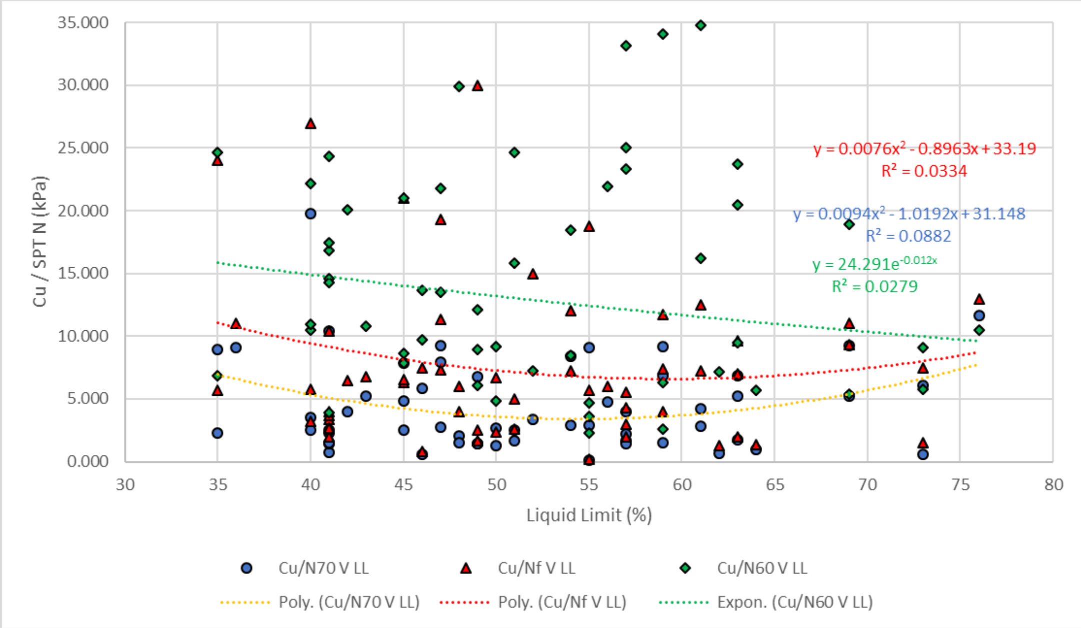

Figure IV-7: C_u/SPT N Ratio against liquid limit.

3 Analysis based on the variation of Plastic Limit

3.1 SPT N'$_{70}$ Vs Undrained Shear Strength by Field Vane Shear Tests

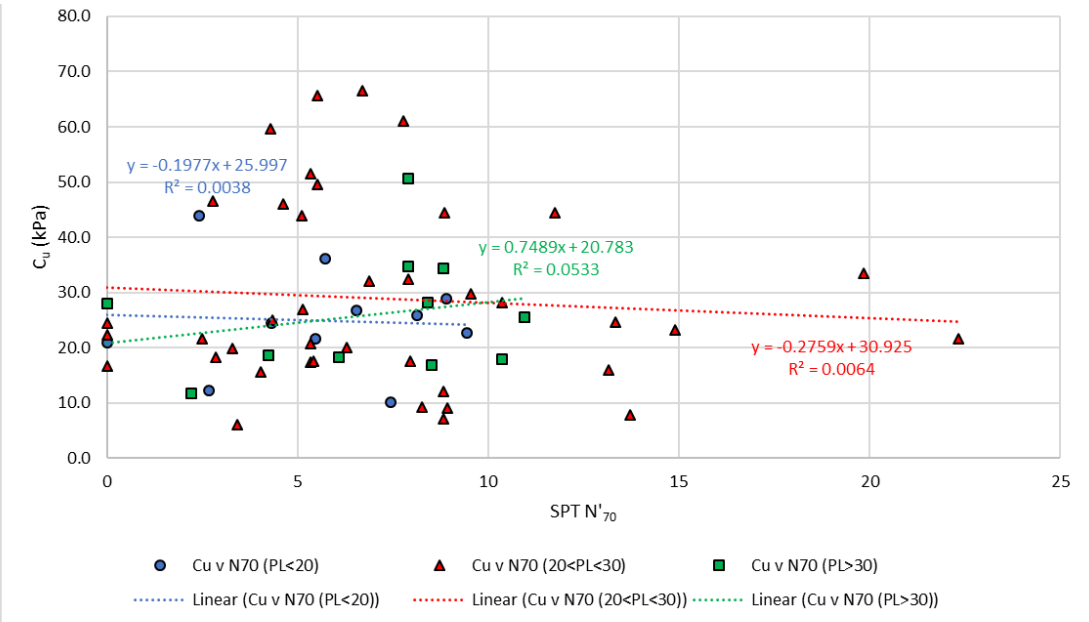

Figure IV-8: SPT N'$_{70}$ Vs undrained shear strength by field vane shear test (based on PL)

The effects of the variation of plastic limit (PL) on the relationship between SPT N'$_{70}$ and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to three sub categories based on their plastic limits as PL<20%, 20%<PL<30% and PL>30%.

Undrained Shear Strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-8* with aforesaid categories, categorized based on plastic limits.

3.2 SPT N_{60} Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of plastic limit (PL) on the relationship between SPT N_{60} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to three sub categories based on their plastic limits as PL<20%, 20%<PL<30% and PL>30%.

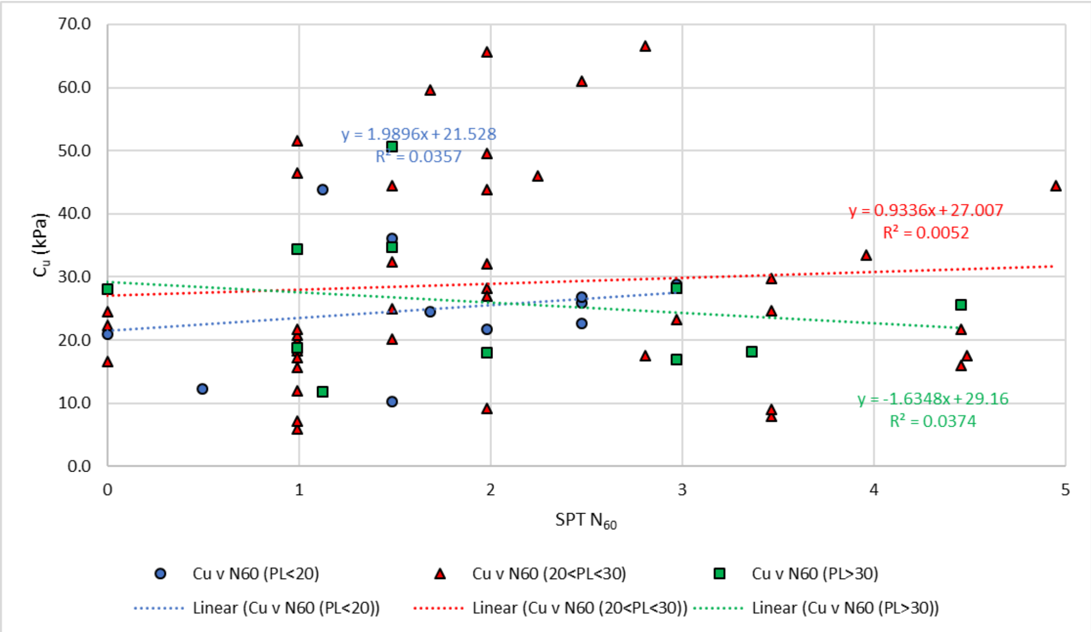

Figure IV-9: SPT N_{60} Vs undrained shear strength by field vane shear test (based on PL)

Undrained Shear Strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-9* with aforesaid categories, categorized based on plastic limits.

3.3 SPT N_f Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of plastic limit (PL) on the relationship between SPT N_f and undrained shear strength by field vane shear test is studied in this section.

Available data set was categorized in to three sub categories based on their plastic limits as PL<20%, 20%<PL<30% and PL>30%.

Undrained Shear Strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure IV-10* with aforesaid categories, categorized based on plastic limits.

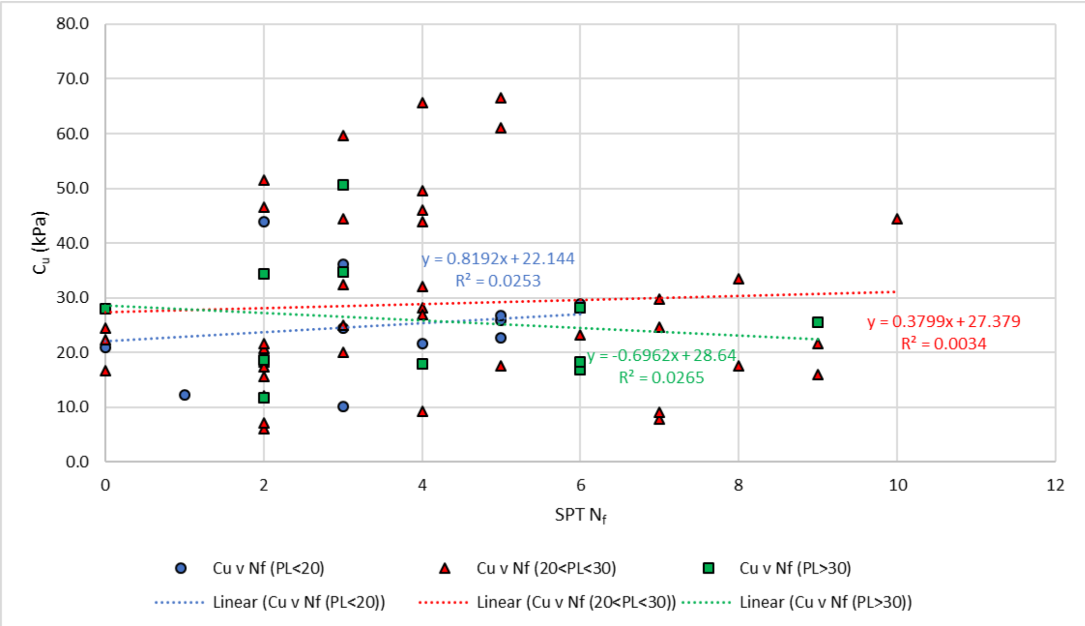

Figure IV-10: SPT N_{field} Vs undrained shear strength by field vane shear test (based on PL)

3.4 C_u/SPT N Ratio against Plastic Limit.

To get an overall idea on the effects of the plastic limit on the undrained shear strength / SPT N'_{70}, undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by field vane shear test / SPT N'_{70}, undrained shear strength by field vane shear test / SPT N_{60} and undrained shear strength by field vane shear test / SPT N_f calculated factors were plotted against the respective plastic limits, given in the *Figure IV-11*. The available data with SPT N_{field} value zero (0) were not considered for this analysis.

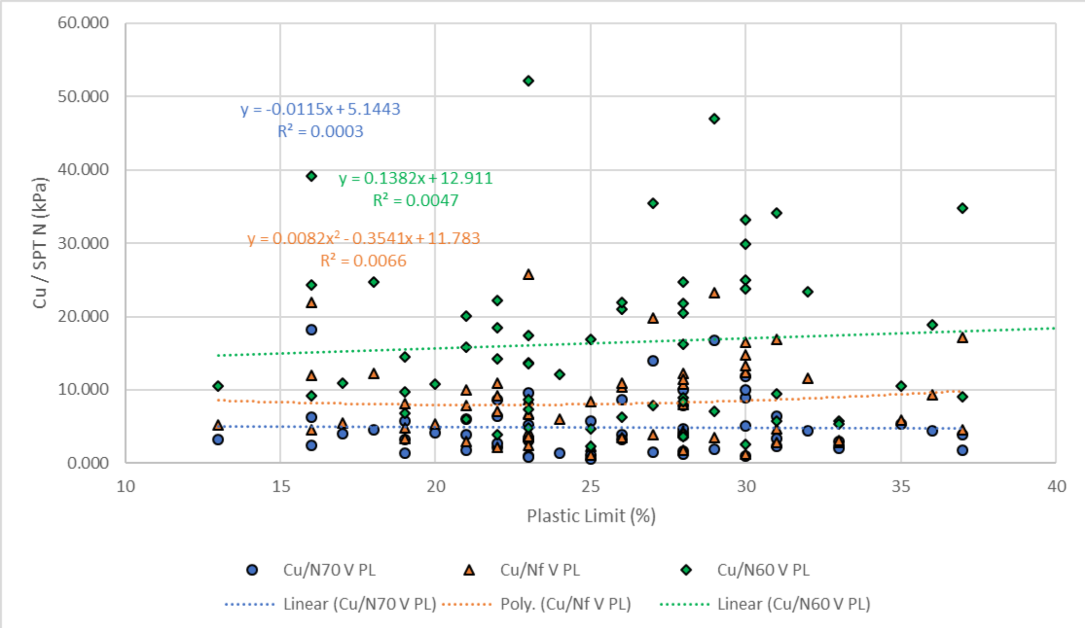

Figure IV-11: C_u/SPT N Ratio against plastic limit.

4. Analysis based on the variation of Plasticity Index

4.1. SPT N'$_{70}$ Vs Undrained Shear Strength by Field Vane Shear Tests

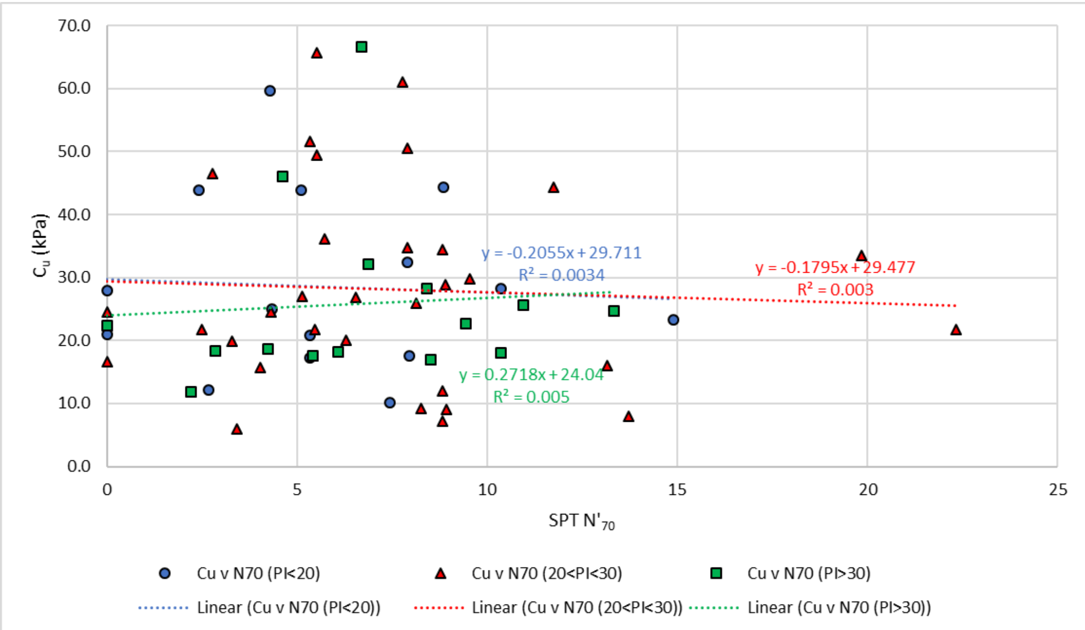

Figure IV-12: SPT N'$_{70}$ Vs undrained shear strength by field vane shear test (based on PI)

The effects of the variation of plasticity index (PI) on the relationship between SPT N'$_{70}$ and undrained shear strength by field vane shear test is studied in this section.

Available data set was categorized in to three sub categories based on their plasticity indexes as PI<20%, 20%<PI<30% and PI>30%.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N'$_{70}$ values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-12* with aforesaid categories, categorized based on plasticity indexes.

4.2 SPT N_{60} Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of plasticity index (PI) on the relationship between SPT N_{60} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to three sub categories based on their plasticity indexes as PI<20%, 20%<PI<30% and PI>30%.

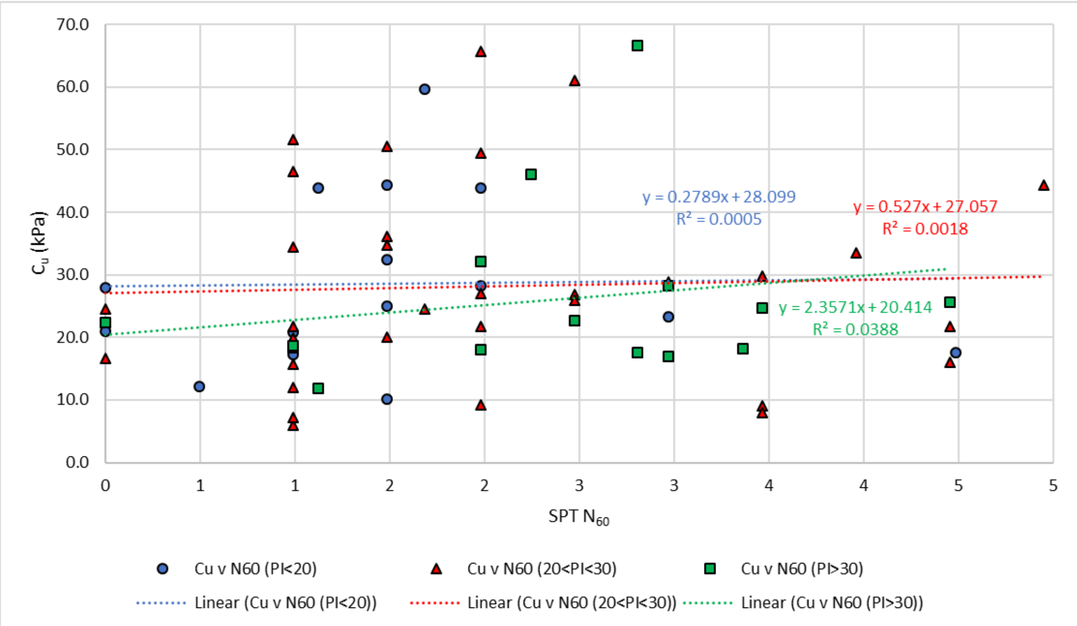

Figure IV-13: SPT N_{60} Vs undrained shear strength by field vane shear test (based on PI)

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-13* with aforesaid categories, categorized based on plasticity indexes.

4.3 SPT N_f Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of plasticity index (PI) on the relationship between SPT N_f and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to three sub categories based on their plasticity indexes as PI<20%, 20%<PI<30% and PI>30%.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure IV-14* with aforesaid categories, categorized based on plasticity indexes.

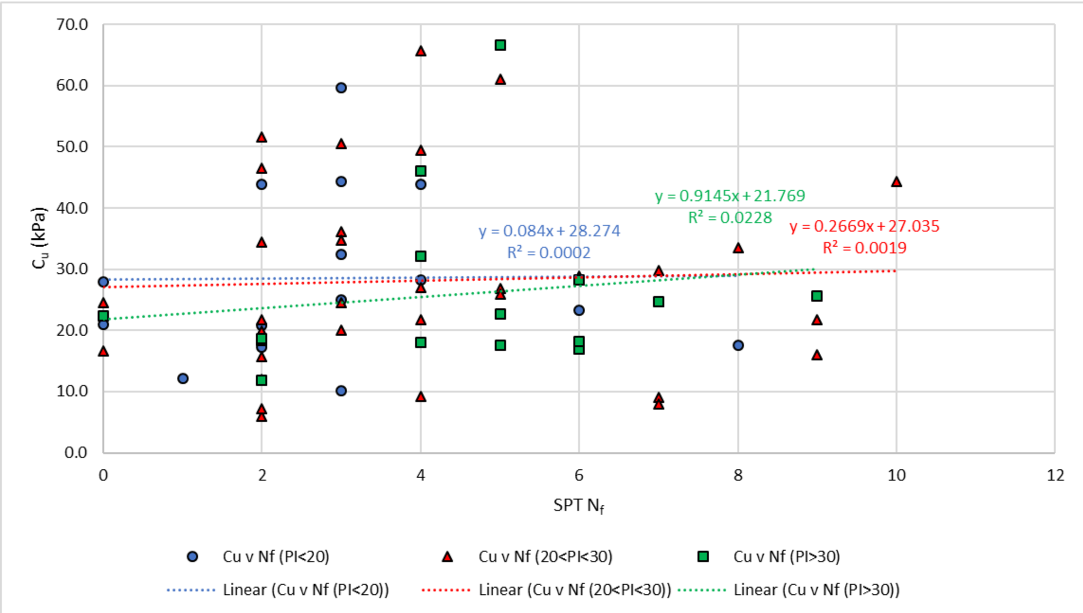

Figure IV-14: SPT N_{field} Vs undrained shear strength by field vane shear test (based on PI)

4.4 C_u/SPT N Ratio against Plasticity Index.

To get an overall idea on the effects of the plasticity index on the undrained shear strength / SPT N'_{70}, undrained shear strength / SPT N'_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by field vane shear test / SPT N'_{70}, undrained shear strength by field vane shear test / SPT N_{60} and undrained shear strength by field vane shear test / SPT N_f calculated factors were plotted against the respective plasticity index, given in the *Figure IV-15*. The available data with SPT N_{field} value zero (0) were not considered for this analysis.

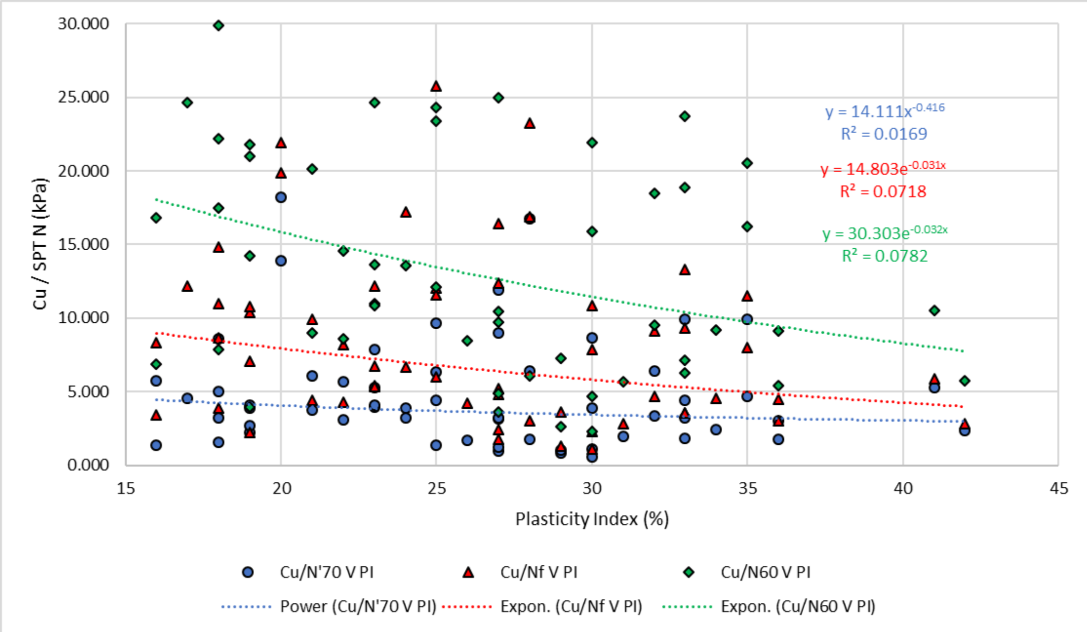

Figure IV-15: C_u/SPT N Ratio against plasticity index.

5. Analysis based on the variation Fines Content.

5.1 SPT N'_{70} Vs Undrained Shear Strength by Field Vane Shear Tests

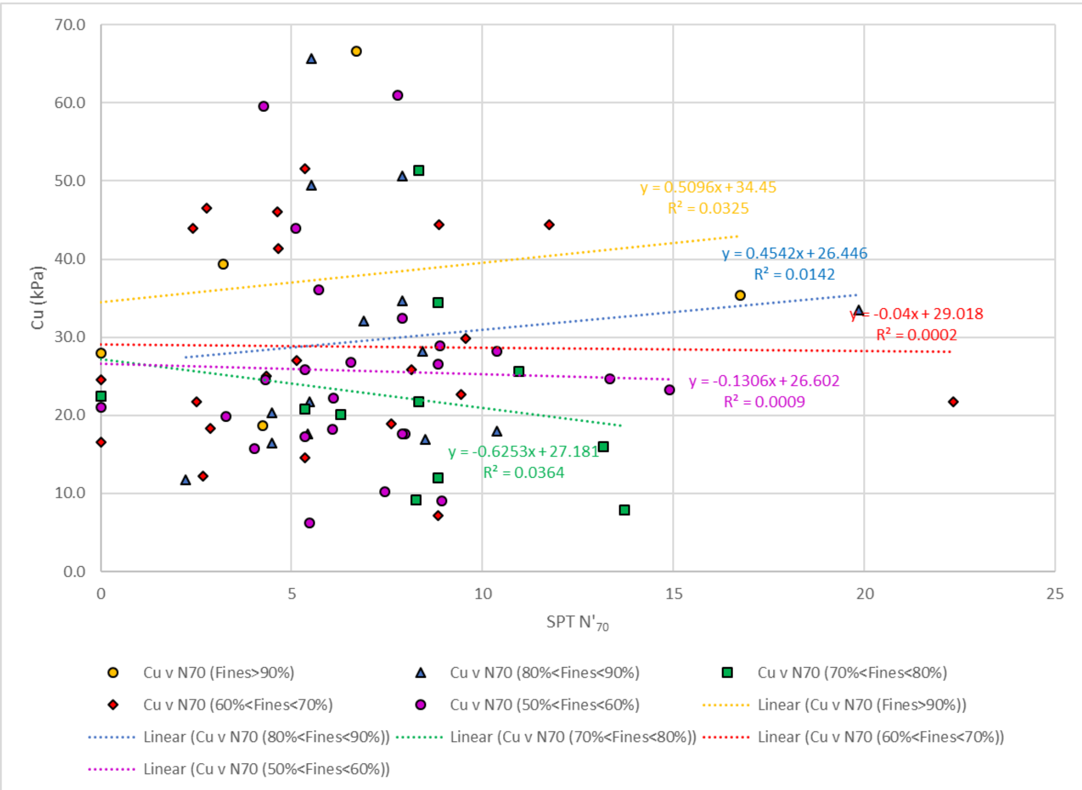

Figure IV-16: SPT N'_{70} Vs undrained shear strength by field vane shear test (based on fines content)

The effects of the variation of fines content (FC) on the relationship between SPT N'$_{70}$ and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to five sub categories based on their fines content as FC>90%, 90%<FC<80%, 80%<FC<70%, 70%<FC<60% and 60%<FC<50%.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N'$_{70}$ values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-16* with aforesaid categories, categorized based on fines content.

5.2 SPT N$_{60}$ Vs Undrained Shear Strength by Field Vane Shear Tests

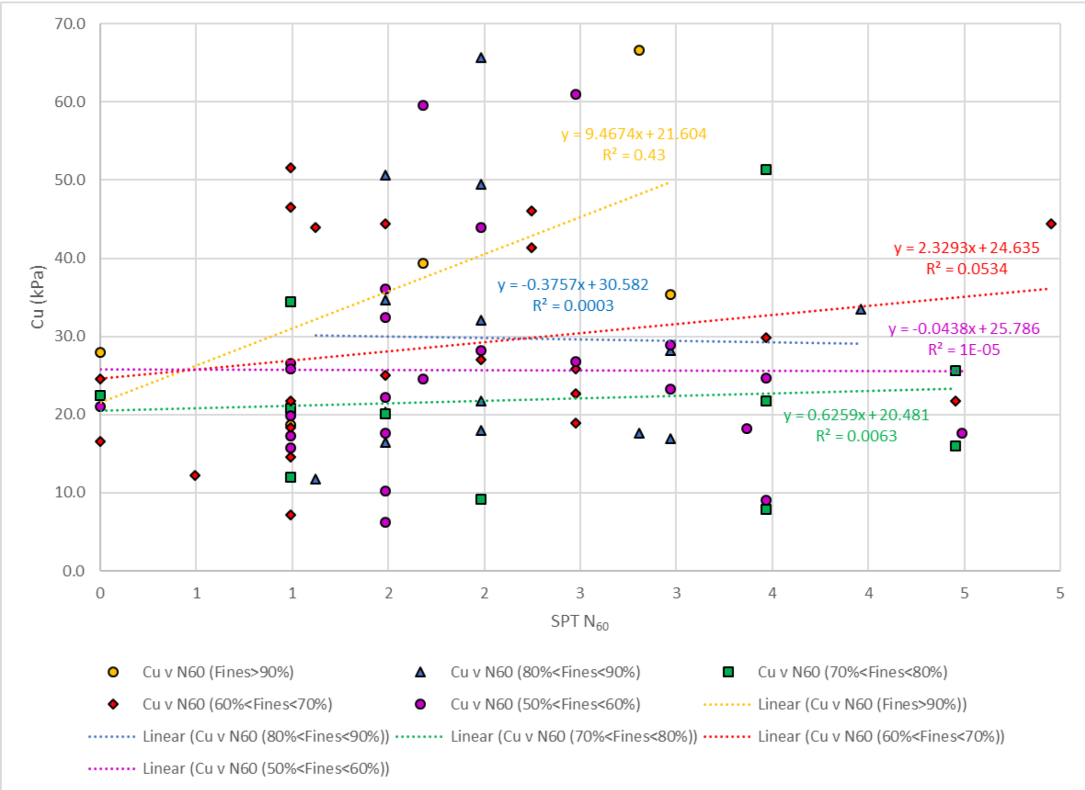

Figure IV-17: SPT N$_{60}$ Vs undrained shear strength by field vane shear test (based on fines content)

The effects of the variation of fines content (FC) on the relationship between SPT N$_{60}$ and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to five sub categories based on their fines content as FC>90%, 90%<FC<80%, 80%<FC<70%, 70%<FC<60% and 60%<FC<50%.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-17* with aforesaid categories, categorized based on fines content.

5.3 SPT N_f Vs Undrained Shear Strength by Field Vane Shear Tests

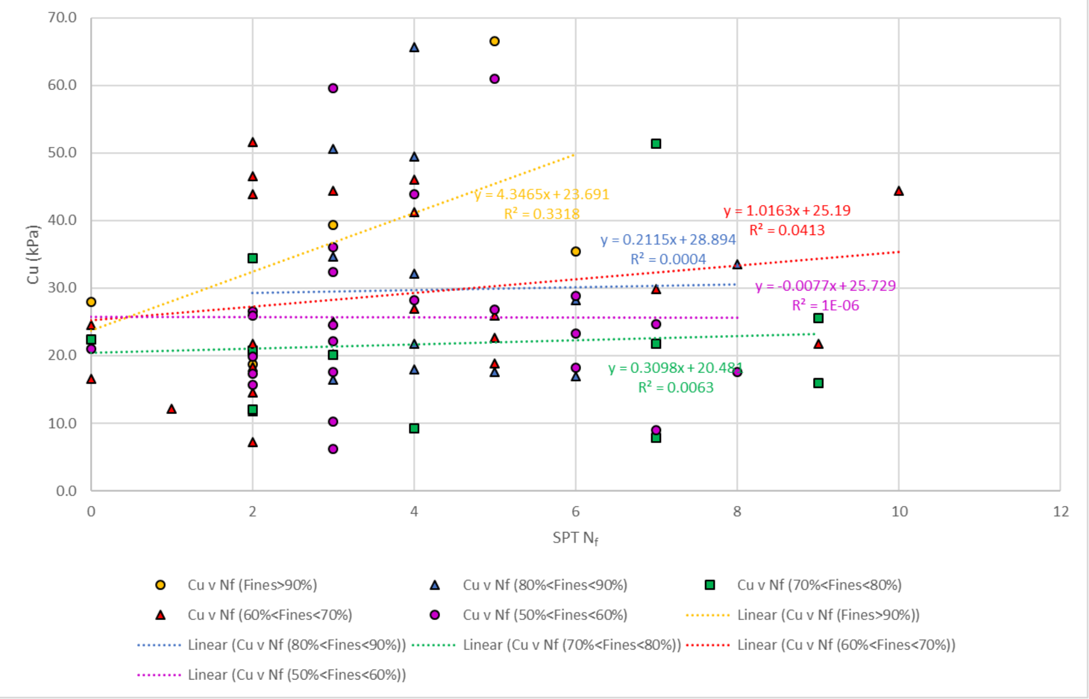

Figure IV-18: SPT N_{field} Vs undrained shear strength by field vane shear test (based on fines content)

The effects of the variation of fines content (FC) on the relationship between SPT N_f and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to five sub categories based on their fines content as FC>90%, 90%<FC<80%, 80%<FC<70%, 70%<FC<60% and 60%<FC<50%.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure IV-18* with aforesaid categories, categorized based on fines content.

5.4 C_u/SPT N Ratio against Fines Content.

To get an overall idea on the effects of the fines content on the undrained shear strength / SPT N'_{70} factor, the undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by field vane shear test / SPT N'_{70}, undrained shear strength by field vane shear test / SPT N_{60} and undrained shear strength by field vane shear test / SPT N_f calculated factors were plotted against the respective fines content, given in the *Figure IV-19*. The available data with SPT N_{field} value zero (0) were not considered for this analysis

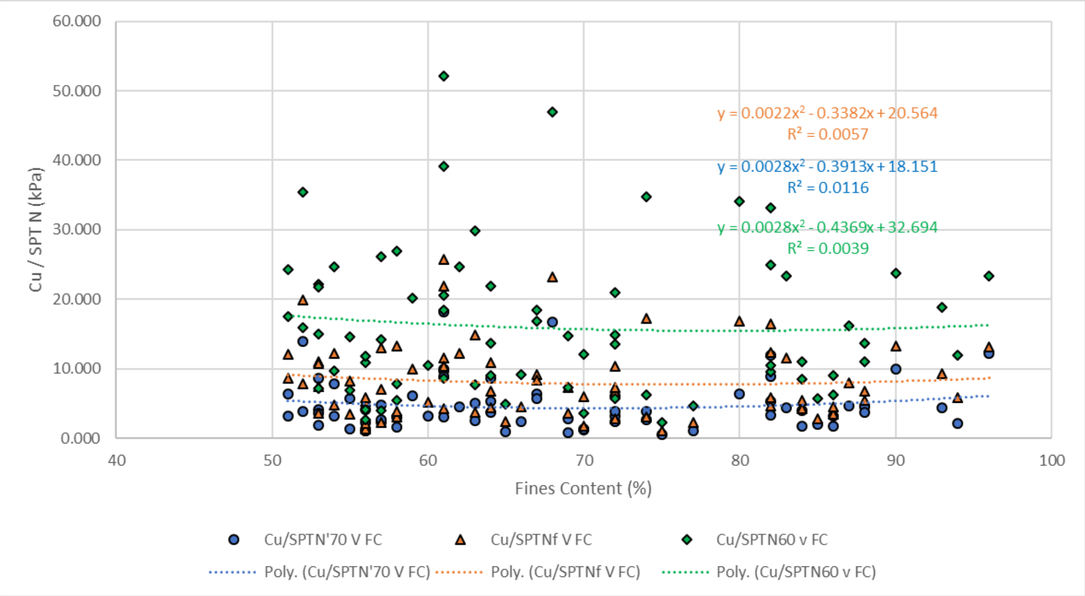

Figure IV-19: C_u/SPT N Ratio against fines content.

6. Analysis based on the variation Clay Content.

6.1 SPT N'_{70} Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of clay content (CC) on the relationship between SPT N'_{70} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to five sub categories based on their cay content as 50%<CC<70%, 40%<CC<50%, 30%<CC<40%, 20%<CC<30% and CC<20%.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-20* with aforesaid categories, categorized based on clay content.

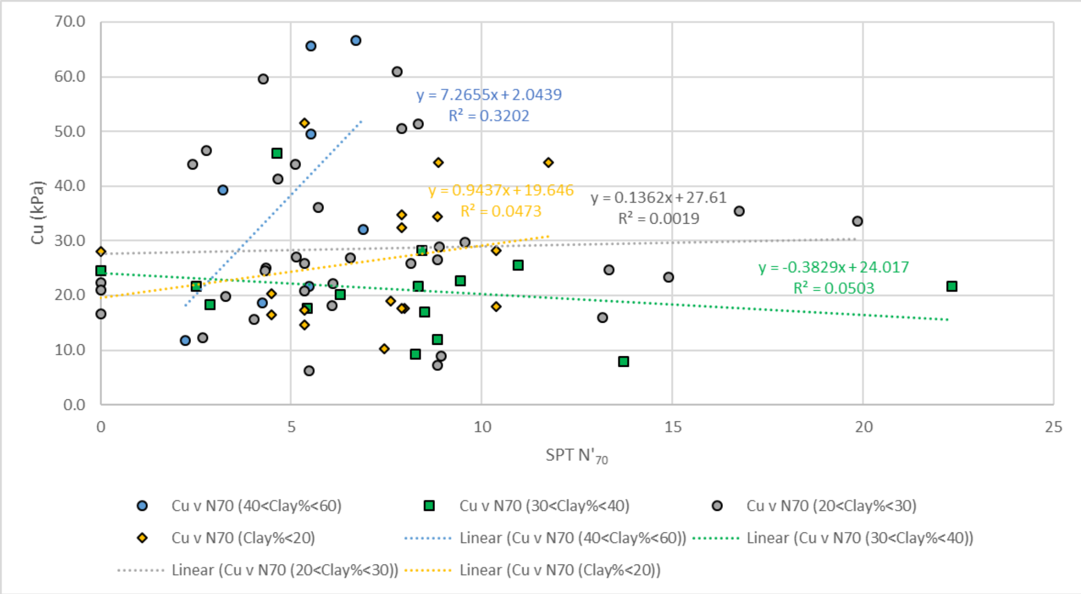

Figure IV-20: SPT N'$_{70}$ Vs undrained shear strength by field vane shear test (based on clay content)

6.2 SPT N$_{60}$ Vs Undrained Shear Strength by Field Vane Shear Tests

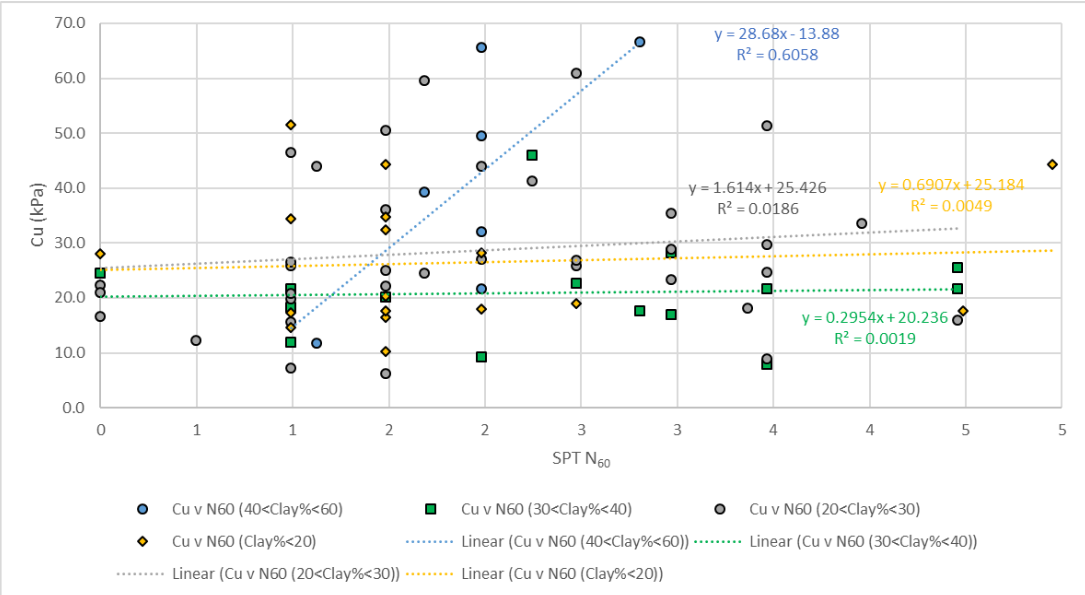

Figure IV-21: SPT N$_{60}$ Vs undrained shear strength by field vane shear test (based on cay content)

The effects of the variation of clay content (CC) on the relationship between SPT N$_{60}$ and undrained shear strength by Field Vane Shear Tests is studied in this section. Available data set was categorized in to five sub categories based on their clay content as 50%<CC<70%, 40%<CC<50%, 30%<CC<40%, 20%<CC<30% and CC<20%.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-21* with aforesaid categories, categorized based on clay content.

6.3 SPT N_f Vs Undrained Shear Strength by Field Vane Shear Tests

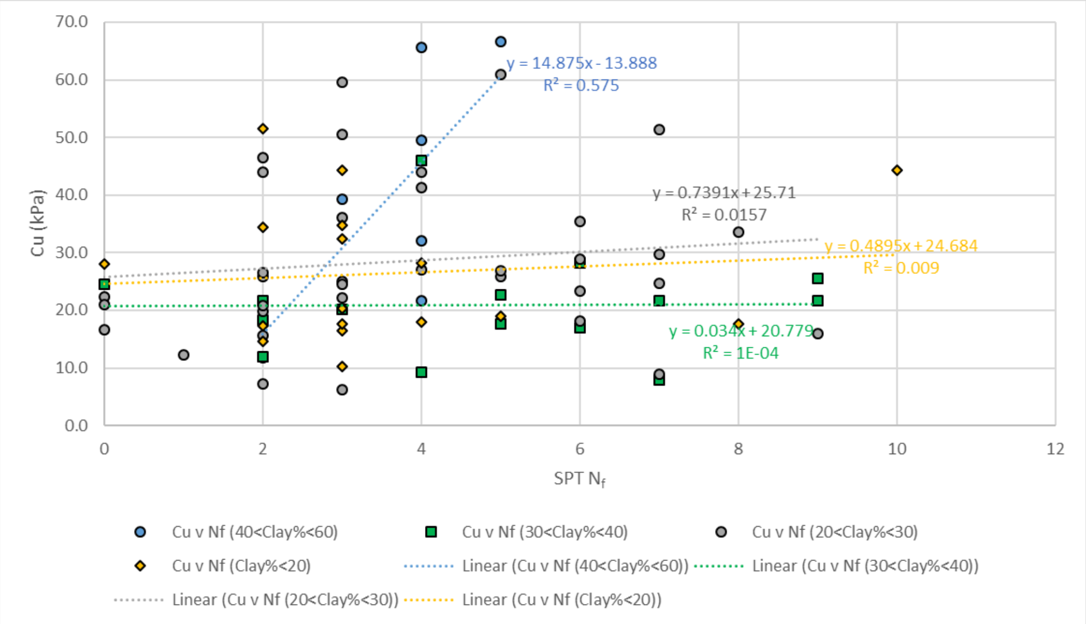

Figure IV-22: SPT N_{field} Vs undrained shear strength by field vane shear test (based on clay content)

The effects of the variation of clay content (CC) on the relationship between SPT N_f and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to five sub categories based on their clay content as 50%<CC<70%, 40%<CC<50%, 30%<CC<40%, 20%<CC<30% and CC<20%.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_f values, observed from the respective soil stratums at the field, is shown in the *Figure IV-22* with aforesaid categories, categorized based on clay content.

6.4 C_u/SPT N Ratio against Clay Content.

To get an overall idea on the effects of the clay content on the undrained shear strength / SPT N'_{70} factor, undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by field vane shear test / SPT N'_{70}, undrained shear strength by field vane shear test / SPT N_{60} and undrained shear strength by field vane shear test / SPT N_f calculated factors were plotted against the respective clay content, given in the *Figure IV-23*. The available data with SPT N_{field} value zero (0) were not considered for this analysis

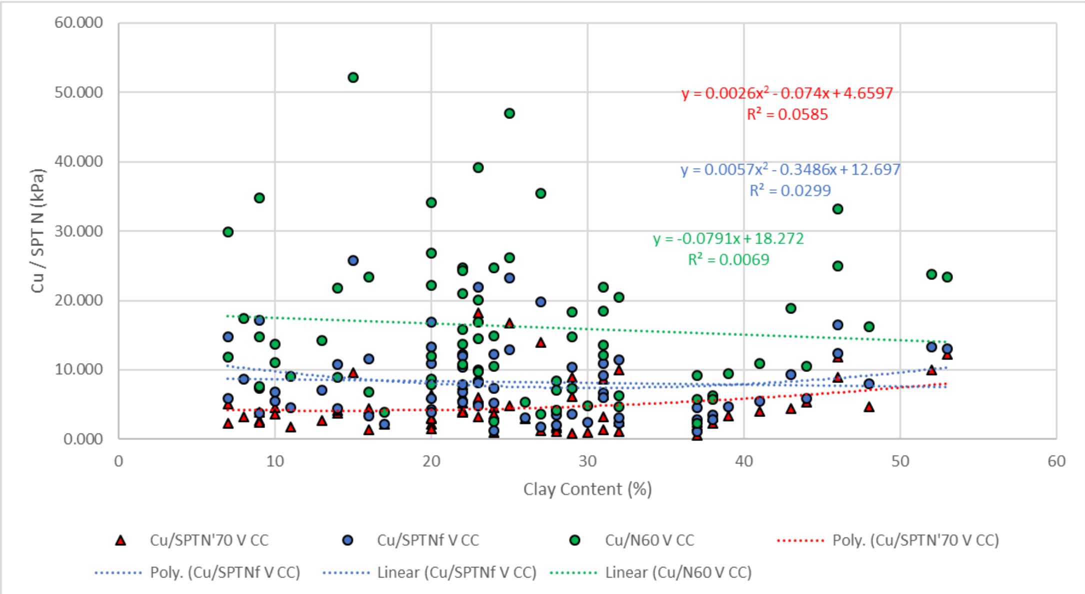

Figure IV-23: C_u/SPT N Ratio against clay content.

7. Analysis based on the variation Sampling Depth.

7.1. SPT N'$_{70}$ Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of sampling depth (SD) and the effects of the SPT Correction factors on the relationship between SPT N'_{70} and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to seven sub categories based on their sampling depth as 0.3m, 1.3m, 2.3m, 3.3m, 4.3, 5.3 to 6.3m, 7.3 to 13.3m.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-24* with aforesaid categories, categorized based on sampling depth.

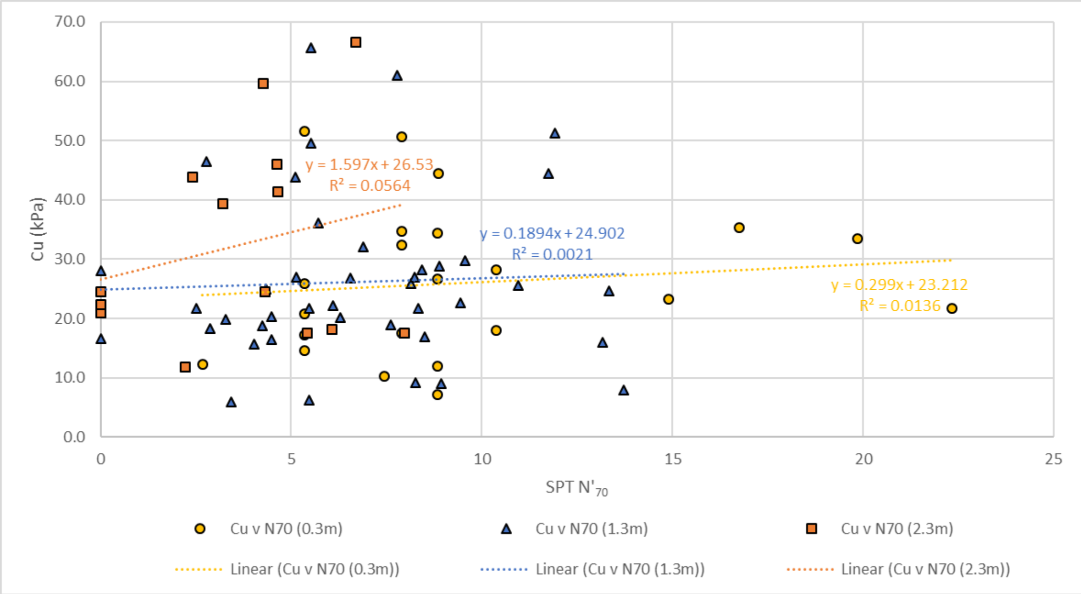

Figure IV-24: SPT N'$_{70}$ Vs undrained shear strength by field vane shear test (based on sampling depth)

7.2 SPT N$_{60}$ Vs Undrained Shear Strength by Field Vane Shear Tests

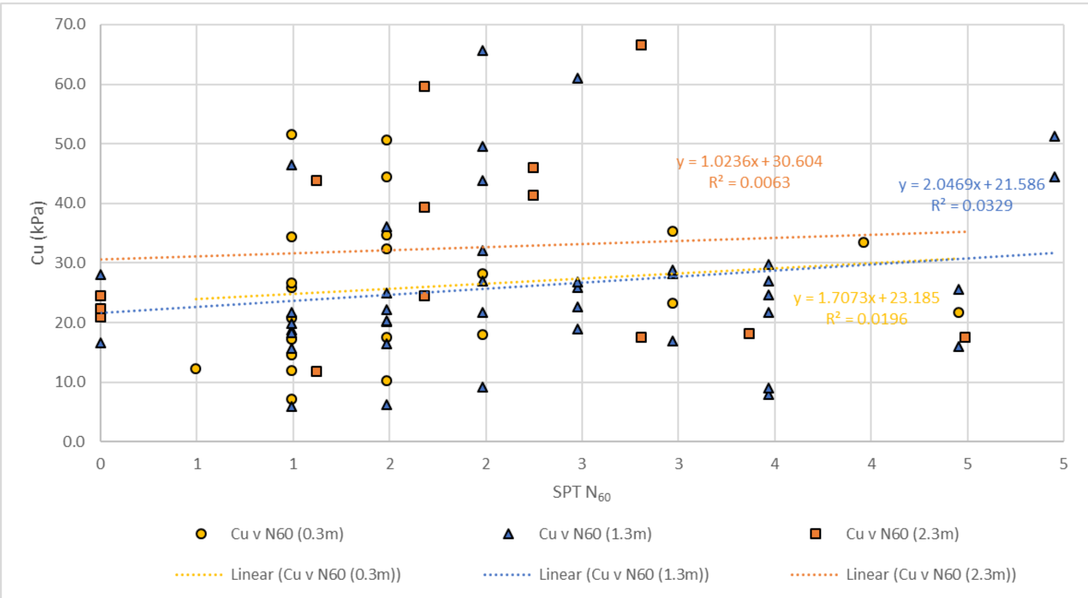

Figure IV-25: SPT N$_{60}$ Vs undrained shear strength by field vane shear test (based on sampling depth)

The effects of the variation of sampling depth (SD) and the effects of the SPT Correction factors on the relationship between SPT N$_{60}$ and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to seven sub categories based on their sampling depth as 0.3m, 1.3m, 2.3m, 3.3m, 4.3, 5.3 to 6.3m, 7.3 to 13.3m.

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-25* with aforesaid categories, categorized based on sampling depth.

7.3 SPT N_f Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of sampling depth (SD) on the relationship between SPT N_f and undrained shear strength by field vane shear test is studied in this section. Available data set was categorized in to seven sub categories based on their sampling depth as 0.3m, 1.3m, 2.3m, 3.3m, 4.3, 5.3 to 6.3m, 7.3 to 13.3m.

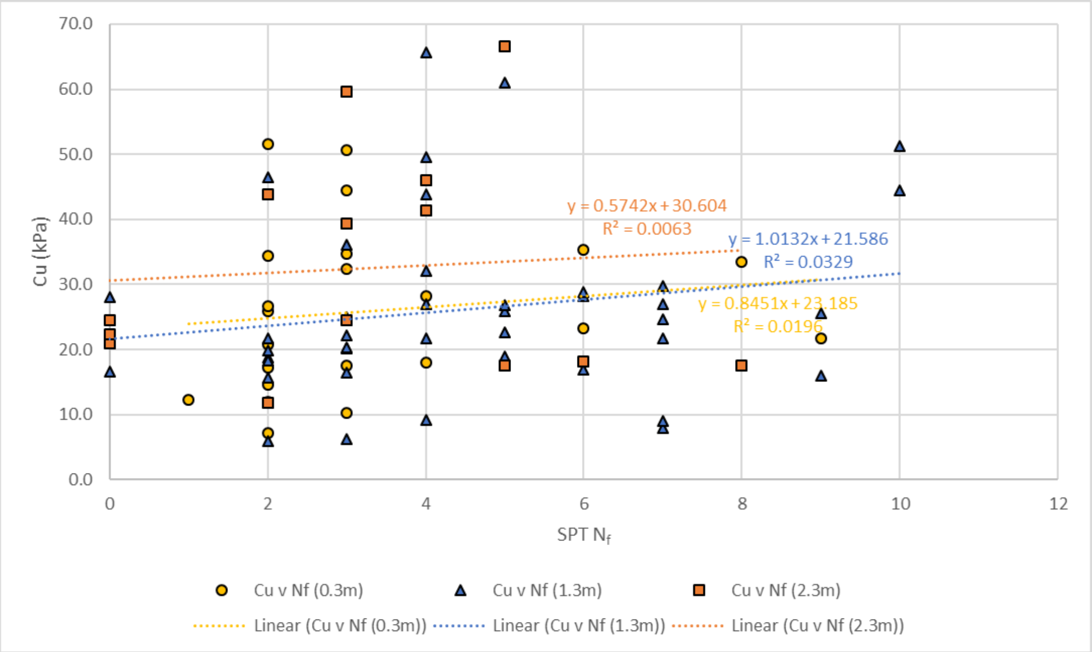

Figure IV-26: SPT N_{field} Vs undrained shear strength by field vane shear test (based on sampling depth)

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_f values, observed from the respective soil stratums at the field, after correction is shown in the *Figure IV-26* with aforesaid categories, categorized based on sampling depth.

7.4 Cu/SPT N Ratio against Sampling Depth.

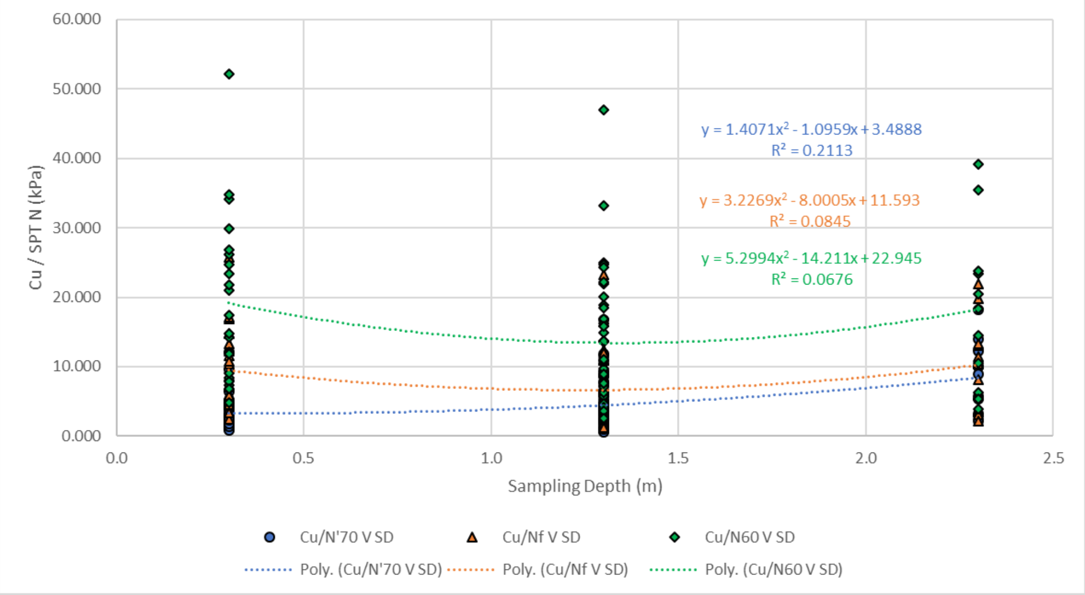

Figure IV-27: Cu/SPT N Ratio against sampling depth.

To get an overall idea on the effects of the sampling depth on the undrained shear strength / SPT N'_{70} factor, undrained shear strength / SPT N_{60} factor and undrained shear strength / SPT N_f factor, the undrained shear strength by field vane shear test / SPT $N'_{70,}$ undrained shear strength by field vane shear test / SPT N_{60} and undrained shear strength by field vane shear test / SPT N_f calculated factors were plotted against the respective sampling depth, given in the Figure *IV-27*. The available data with SPT N_{field} value zero (0) were not considered for this analysis

8. Analysis based on the Unified Soil Classification System (USCS)

8.1. SPT N'_{70} Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of soil types on correlation between SPT N'_{70} and undrained shear strength by field vane shear test are studied in this section. Unified soil classification system (USCS) is used for the classification of available fine grained soil samples and categorized in to four divisions as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) and low plastic silt (ML).

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N'_{70} values, observed from the respective soil stratums at the field, after correction is shown in the below *Figure IV-28* with aforesaid categories, categorized based on USCS.

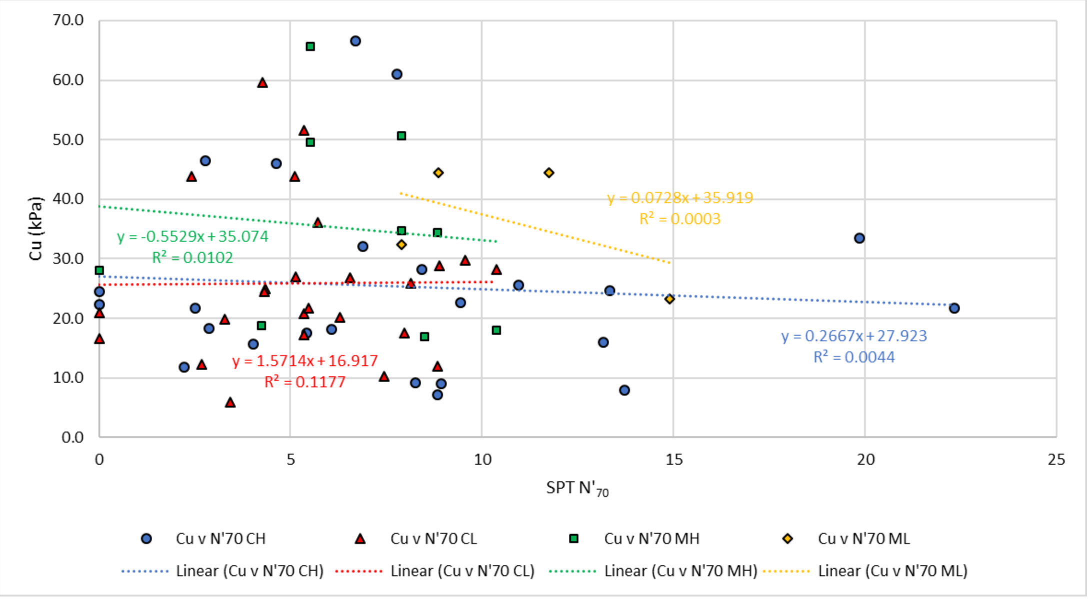

Figure IV-28: SPT N'$_{70}$ Vs undrained shear strength by field vane shear test (based on USCS)

8.2 SPT N_{60} Vs Undrained Shear Strength by Field Vane Shear Tests

The effects of the variation of soil types on correlation between SPT N_{60} and undrained shear strength by field vane shear test are studied in this section. Unified soil classification system (USCS) is used for the classification of available fine grained soil samples and categorized in to four divisions as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) and low plastic silt (ML).

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_{60} values, observed from the respective soil stratums at the field, after correction is shown in the below *Figure IV-29* with aforesaid categories, categorized based on USCS.

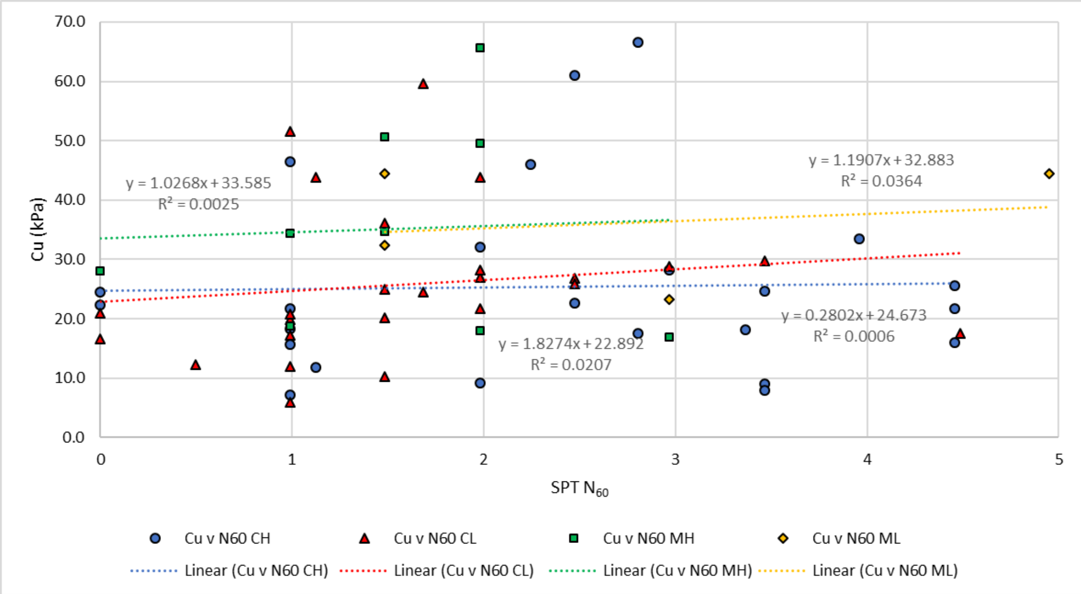

Figure IV-29: SPT N_{60} Vs undrained shear strength by field vane shear test (based on USCS)

8.3 SPT N_{field} Vs Undrained Shear Strength by Field Vane Shear Tests

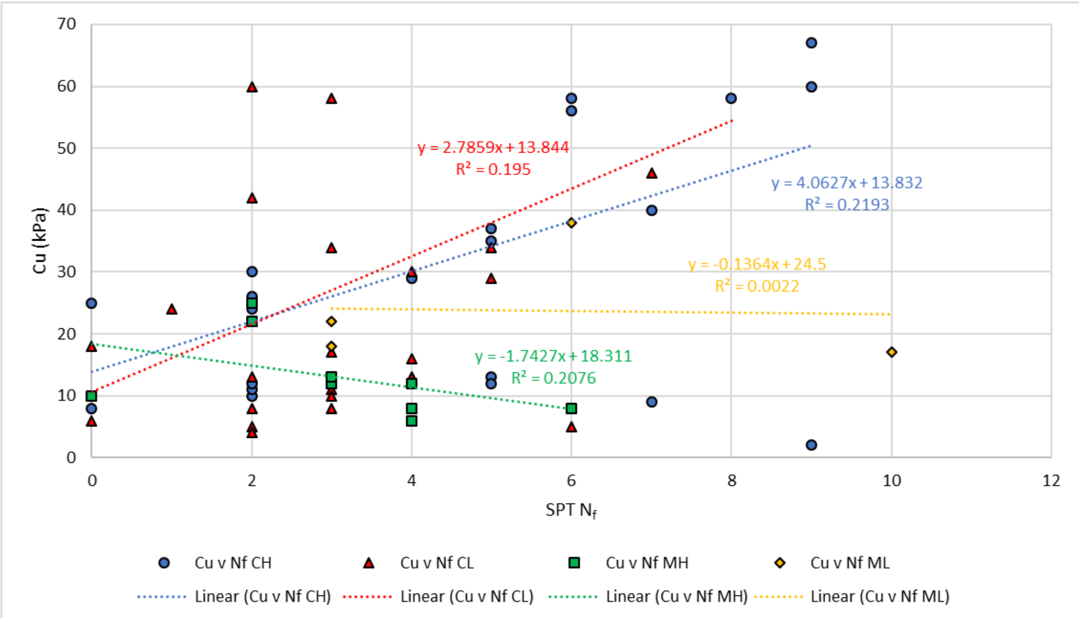

Figure IV-30: SPT N_{field} Vs undrained shear strength by field vane shear test (based on USCS)

The effects of the variation of soil types on correlation between SPT N_{field} and undrained shear strength by field vane shear test are studied in this section. Unified soil classification system (USCS) is used for the classification of available fine grained soil samples and categorized in to four divisions as high plastic clay (CH), low plastic clay (CL), high plastic silt (MH) and low plastic silt (ML).

undrained shear strength values of fine grained soil samples, determined with field vane shear test were plotted against the SPT N_{field} values, observed from the respective soil stratums at the field, is shown in the *Figure IV-30* with aforesaid categories, categorized based on USCS.

Appendix V: Reliable Data Set

Table V-1: Reliable data set

Borehole No	Water Table at (m)	Layer Depth (m)	Description	USCS	Avg SPT	Sample Depth (m)	Particle Size Distribution					Atterberg Limits			Specific Gravity	NMC (%)	Depth (m)	Unconsolidated Undrained TT			Vane Shear Test			Average Cu (kPa)	SPT Correction				Deviation Factor (%)
							Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	LL (%)	PL (%)	PI (%)				No of Samples	C_u (kPa)	Φ_u	Depth (m)	Peak S/S (kN/m^2)	Residual S/S (kN/m^2)		Depth	SPT N_f	SPT N'_{70}	SPT N_{60}	
BH 31881 N-L	0.35	0.0-0.9	sandy SILT with clay	M L	2	0.0	0	43	32	25	57	NP	NP	NP	2.62	32.1	0.50-1.00	1	26	0	0.50	25.9	13.9	26.0	0.3	2	5	1	0.2
BH 21135 N-L	0.70	0.7-1.8	sandy SILT with some clay	M L	3	1.0	0	12	78	10	88	NP	NP	NP	2.58	39.3	1.30-1.80	2	16	3	1.20	16.4	9.2	16.2	1.3	3	4	1	1.2
BH 32425 N-L	0.30	0.0-0.7	soft clayey SILT with sand	M L	0	0.0	1	22	40	37	77	NP	NP	NP	2.59	38.1	0.50-1.00	2	23	1	0.50	24	16.2	23.5	0.3	3	8	1	2.1
BH 23074 N-R	1.50	0.8-1.9	clayey SILT with sand	M L	7	1.0	0	28	43	29	72	NP	NP	NP	2.59	22.2	1.5-2.0	1	55	0	1.40	51.3	28.0	53.2	1.3	7	8	3	3.5
BH 32425 N-L	0.30	0.7-1.8	sandy lean CLAY	C L	0	1.0	3	30	39	28	67	49	24	25	2.62	43.6	1.00-1.50	2	18	0	1.00	16.6	8.3	17.3	1.3	0	0	0	4.0
BH 5339 N-L	0.65	0.0-0.9	sandy SILT with traces of clay	M L	2	0.0	2	29	60	9	69	NP	NP	NP	2.47	49.1	0.50-1.00	1	16	0	0.50	14.6	7.4	15.3	0.3	2	5	1	4.6
BH 31881 N-L	0.35	0.9-1.7	fat CLAY	C H	4	1.0	0	13	39	48	87	61	28	35	2.57	42.8	1.00-1.50	1	29	0	1.00	32.1	9.5	30.6	1.3	4	7	2	5.1
BH 14827-N-L	1.40	0.8-1.8	sandy SILT with clay	C L	4	1.0	2	34	42	22	64	46	23	23	2.63	46.9	1.00-1.50	1	30	0	1.40	27.0	13.4	28.5	1.3	4	5	2	5.3
BH 21534 N-R	1.10	1.8-3.0	clayey SILT with sand	C H	0	2.0	0	23	50	27	77	70	29	41	2.61	43.3	1.50-2.00	1	25	0	2.00	22.4	8.0	23.7	2.3	0	0	0	5.5
BH 5319 N-R	0.45	0.9-1.6	sandy lean CLAY	C L	5	1.0	2	38	36	24	60	40	13	27	2.60	29.3	1.00-1.50	1	29	0	1.00	25.9	21.2	27.5	1.3	5	8	2	5.6
BH 16398 N-C	0.00	0.7-2.9	elastic SILT	M H	2	1.0	0	7	50	43	93	69	36	33	2.73	57.8	1.00-1.50	2	22	5	1.00	18.7	11.5	20.4	1.3	2	4	1	8.1
BH 6796 N-R	0.40	0.6-1.6	sandy CLAY	C L	2	1.0	-	-	-	-	-	49	21	28	-	83.3	0.50-1.00	2	5	0	1.25	6.0	4.2	5.5	1.3	2	3	1	9.1
BH 23797 N-L	0.90	0.6-1.6	sandy SILT with clay	C L	5	1.0	0	44	34	22	56	43	20	23	2.59	37.4	1.0-1.5	1	34	0	1.10	26.8	17.1	30.4	1.3	5	7	2	11.8
BH 17986 N-R	0.90	0.6-2.5	sandy SILT with clay	C H	2	1.0	0	33	36	31	67	54	22	32	2.64	37.0	1.00-1.50	1	24	0	1.00	18.3	11.1	21.2	1.3	2	3	1	13.5
BH 23074 N-L	0.20	0.0-0.8	clayey SILT with traces of sand	M L	6	0.0	0	6	74	20	94	NP	NP	NP	2.55	50.9	0.5-1.0	2	48	0	0.50	35.4	23.3	41.7	0.3	6	17	3	15.1
BH 24945 N-C	0.00	0.0-0.8	sandy SILT with traces of clay	M H	2	0.0	0	26	65	9	74	61	37	24	2.48	81.7	0.5-1.0	1	25	0	0.50	34.4	19.4	29.7	0.3	2	9	1	15.8
BH 5339 N-L	0.65	0.9-1.8	sandy SILT with traces of clay	M L	5	1.0	0	37	54	9	63	NP	NP	NP	2.58	23.4	1.00-1.50	1	13	0	1.00	18.9	13.6	16.0	1.3	5	8	2	18.5
BH 24838 N-R	0.50	0.0-0.7	sandy SILT with some clay	M L	3	0.0	0	47	39	14	53	47	28	19	2.56	33.1	0.5-1.0	1	22	0	0.50	32.4	12.7	27.2	0.3	3	8	1	19.1
BH 24214 N-R	0.50	1.0-1.6	sandy SILT with clay	C L	2	1.0	0	41	36	23	59	42	21	21	2.59	42.8	1.0-1.5	1	13	0	1.00	19.9	9.7	16.5	1.3	2	3	1	21.0
BH 14867-N-L	1.00	0.5-1.8	sandy SILT with clay with traces of gravel	C L	7	1.0	4	35	41	20	61	45	23	22	2.66	47.2	1.50-2.00	2	46	5	1.50	29.8	0.7	37.9	1.3	7	10	3	21.4
BH 29110-N-C	0.08	0.6-1.6	sandy SILT with clay	C H	2	1.0	4	44	30	22	52	51	21	30	2.60	29.5	1.00-1.50	2	10	0	1.50	15.7	14.6	12.9	1.3	2	4	1	22.2
BH 5319 N-R	0.45	0.0-0.9	sandy SILT with traces of clay	M L	3	0.0	2	42	49	7	56	NP	NP	NP	2.51	45.5	0.50-1.00	1	28	0	0.50	17.6	13.4	22.8	0.3	3	8	1	22.8
BH 24838 N-L	0.80	0.0-1.0	sandy SILT with clay	M L	6	0.0	1	41	38	20	58	45	27	18	2.56	41.2	0.5-1.0	1	38	0	0.50	23.3	9.2	30.7	0.3	6	15	3	24.0
BH 32375 N-R	1.00	0.7-2.5	lean CLAY with sand	M L	4	2.0	0	39	32	29	61	NP	NP	NP	2.64	35.3	1.50-2.00	1	25	0	2.00	41.3	20.1	33.2	2.3	4	5	2	24.6
BH 5339 N-R	0.40	0.0-0.8	sandy lean CLAY	C L	3	0.0	0	45	39	16	55	35	19	16	2.55	27.4	0.50-1.00	1	17	0	0.50	10.2	9.5	13.6	0.3	3	7	1	25.0
BH 23636 N-L	0.30	0.0-0.8	clayey SILT with sand	C H	8	0.0	0	16	56	28	84	54	28	26	2.54	35.5	0.5-1.0	1	58	0	0.70	33.5	23.6	45.8	0.3	8	20	4	26.8
BH 26968-N-C	0.00	1.8-2.8	sandy CLAY with silt	C L	7	2.0	1	47	25	27	52	47	27	20	2.66	30.2	1.5-2.0	2	34	1	1.60	59.6	39.8	46.8	2.3	3	4	2	27.4
BH 5319 N-L	0.70	0.0-0.8	sandy lean CLAY	C L	4	0.0	2	41	44	13	57	41	22	19	2.52	35.9	0.50-1.00	2	16	2	0.50	28.2	19.4	22.1	0.3	4	10	2	27.6
BH 19264 N-R	0.00	0.0-1.7	sandy SILT with clay	M L	2	0.0	1	41	38	20	58	NP	NP	NP	2.59	40.8	0.00-0.50	1	48	0	0.50	26.6	12.7	37.3	0.3	2	9	1	28.7
BH 16220 N-C	1.20	1.0-1.6	sandy fat CLAY	C H	2	1.0	1	35	33	31	64	56	26	30	2.67	51.1	1.00-1.50	1	12	0	1.00	21.7	15.2	16.9	1.3	2	3	1	28.8
BH 24945 N-C	0.00	0.8-1.8	sandy CLAY with silt	C H	5	1.0	1	33	29	37	66	50	16	34	2.57	36.3	1.0-1.5	1	12	0	1.00	22.7	14.3	17.4	1.3	5	9	2	30.8
BH 23074 N-L	0.20	1.8-3.0	silty CLAY with some sand	C H	5	2.0	0	10	38	52	90	63	30	33	2.62	48.6	2.0-2.5	1	35	0	2.00	66.6	32.4	50.8	2.3	5	7	3	31.1
BH 32425 N-R	0.30	0.0-0.9	sandy lean CLAY	C L	1	0.0	0	38	38	24	62	35	18	17	2.62	31.1	0.50-1.00	1	24	0	0.50	12.2	6.9	18.1	0.3	1	3	0	32.6
BH 14867-N-L	1.00	1.8-3.9	sandy SILT with clay	C L	2	3.0	1	38	38	23	61	36	16	20	2.65	38.6	2.50-3.00	1	22	0	2.00	43.9	29.8	33.0	2.3	2	2	1	33.2

Borehole No	Water Table at (m)	Layer Depth (m)	Description	USCS		Avg SPT	Sample Depth (m)	Particale Size Distribution					Atterberg Limits			Specific Gravity	NMC (%)	Depth (m)	Unconsolidated Undrained TT			Vane Shear Test			Average Cu (kPa)	SPT Correction				Deviation Factor (%)
								Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	LL (%)	PL (%)	PI (%)				No of Samples	C_u (kPa)	Φ_u	Depth (m)	Peak S/S (kN/m²)	Residual S/S (kN/m²)		Depth	SPT N_f	SPT N'_{70}	SPT N_{60}	
BH 32375 N-R	1.00	0.0-0.7	soft lean CLAY with sand	C	L	4	0.0	0	28	50	22	72	45	26	19	2.56	44.2	0.50-1.00	2	42	3	0.50	20.8	12.9	31.4	0.3	2	5	1	33.8
BH 17743 N-L	0.70	0.7-1.4	fat CLAY with sand	C	H	6	1.0	4	14	43	39	82	63	31	32	2.62	44.3	1.00-1.50	1	58	0	1.50	28.2	12.7	43.1	1.3	6	8	3	34.6
BH 21295 N-C	1.30	0.6-2.8	clayey SILT with sand	C	H	4	2.0	0	14	48	38	86	59	26	33	2.64	31.6	1.50-2.00	2	37	3	2.00	17.6	6.7	27.3	2.3	5	5	3	35.5
BH 27100-N-R	0.80	1.2-1.8	clayey SILT with some sand	M	H	6	1.0	1	14	48	37	85	64	33	31	2.60	39.8	1.0-1.5	2	8	1	1.25	16.9	6.9	12.5	1.3	6	9	3	35.7
BH 16220 N-C	1.20	1.6-2.8	fat CLAY with sand	C	H	2	2.0	1	17	38	44	82	76	35	41	2.70	63.5	1.50-2.00	1	26	0	1.50	11.8	6.0	18.9	2.3	2	2	1	37.6
BH 27100-N-L	0.80	0.6-1.7	sandy SILT with clay	C	L	3	1.0	0	33	44	23	67	41	25	16	2.67	32.8	1.0-1.5	2	11	0	1.25	25.0	20.3	18.0	1.3	3	4	1	38.9
BH 32425 N-L	0.30	0.7-1.8	sandy lean CLAY	C	L	0	2.0	5	40	32	23	55	41	19	22	2.68	38.8	1.50-2.00	2	10	2	2.00	24.5	15.9	17.3	2.3	3	4	2	42.0
BH 24214 N-L	0.20	0.0-1.0	sandy SILT with clay	M	L	3	0.0	0	37	56	7	63	48	30	18	2.51	53.9	0.5-1.0	2	18	0	0.50	44.4	19.7	31.2	0.3	3	9	1	42.3
BH 16320 N-C	1.50	0.8-1.6	clayey SILT with sand and traces of clay	M	L	7	1.0	5	21	42	32	74	NP	NP	NP	2.60	41.9	1.00-1.50	1	55	0	1.00	21.7	15.9	38.4	1.3	7	8	3	43.4
BH 26426 N-C	1.50	0.6-2.6	sandy SILT with clay	M	L	9	1.0	3	30	50	14	64	49	28	21	2.64	34.4	1.0-1.5	1	17	0	1.10	44.4	27.7	30.7	1.3	10	12	5	44.6
BH 3624 N-R	1.20	0.7-1.5	fat CLAY with sand	C	H	9	1.0	2	26	34	38	72	73	31	42	2.54	32.4	1.00-1.50	1	67	0	1.50	25.6	25.6	46.3	1.3	9	11	4	44.7
BH 27310-N-R	0.59	0.0-0.7	sandy SILT with traces of clay	M	H	3	0.0	0	17	67	16	83	57	32	25	2.59	36.1	0.5-1.0	1	13	0	0.50	34.7	19.7	23.9	0.3	3	8	1	45.5
BH 26968-N-C	0.00	1.0-1.8	sandy CLAY with silt	C	H	7	1.0	1	46	25	28	53	62	29	33	2.64	26.1	1.0-1.5	2	9	3	1.10	24.7	12.7	16.9	1.3	7	13	3	46.6
BH 20865 N-R	1.60	0.0-0.8	sandy SILT with clay	C	H	9	0.0	0	35	35	30	65	50	23	27	2.68	29.1	0.50-1.00	1	60	0	0.50	21.7	9.0	40.9	0.3	9	22	4	46.9
BH 8500 L	0.50	0.0-1.4	clayey SILT with traces of sand	M	H	0	0.0	0	7	83	10	93	60	41	19	2.46	70.6	0.50-1.00	3	10	1.33	1.00	28.0	12.5	19.0	1.3	0	0	0	47.4
BH 32375 N-L	0.00	1.0-2.0	lean CLAY with sand	C	L	3	1.0	0	28	41	31	72	47	23	24	2.59	39.0	1.00-1.50	1	58	0	1.00	20.1	9.7	39.1	1.3	3	6	1	48.5
BH 27100-N-R	0.80	0.0-1.2	sandy SILT with some clay	M	H	4	0.0	0	14	75	11	86	73	37	36	2.58	29.1	0.5-1.0	2	6	0	0.75	18.0	13.6	12.0	0.3	4	10	2	50.0
BH 26868-N-C	0.50	1.7-2.9	sandy SILT with clay	C	H	0	2.0	1	30	39	30	69	51	24	27	2.62	57.4	1.5-2.0	1	8	0	1.50	24.5	24.5	16.3	2.3	0	0	0	50.8
BH 16320 N-C	1.50	1.6-2.8	sandy fat CLAY with gravel	C	H	6	2.0	21	21	32	26	58	69	33	36	2.65	21.9	1.50-2.00	1	56	0	1.50	18.2	9.5	37.1	2.3	6	6	3	50.9
BH 5110 N-C	0.20	1.0-1.6	sandy CLAY with silt	M	L	3	1.0	4	40	28	28	56	NP	NP	NP	2.60	30.7	1.00-1.50	2	2	0	1.50	6.2	0.0	4.1	1.3	3	5	1	51.2
BH14867-N-R	1.20	0.7-1.6	sandy SILT with clay	C	L	4	1.0	4	43	33	20	53	40	22	18	2.69	33.3	1.00-1.50	2	13	5	1.50	43.9	11.3	28.5	1.3	4	5	2	54.3
BH 21135 N-L	0.70	0.7-1.8	sandy SILT with some clay	M	L	3	1.0	0	12	78	10	88	NP	NP	NP	2.58	39.3	0.80-1.30	1	71	0	0.60	20.3	10.0	45.7	1.3	3	4	1	55.5
BH 27068-N-C	0.49	1.8-2.8	sandy SILT with clay	C	L	0	2.0	2	45	30	23	53	36	17	19	2.67	32.5	1.5-2.0	1	6	0	1.50	21.0	15.5	13.5	2.3	0	0	0	55.6
BH 23074 N-R	1.50	1.9-2.8	silty CLAY	M	L	3	2.0	0	4	43	53	96	NP	NP	NP	2.54	45.8	2.0-2.5	2	10	5	1.90	39.3	31.9	24.7	2.3	3	3	2	59.4
BH 19264 N-R	0.00	0.0-1.7	sandy SILT with clay	M	L	2	1.0	0	47	29	24	53	NP	NP	NP	2.60	31.5	0.50-1.00	1	88	0	1.20	22.2	14.3	55.1	1.3	3	6	1	59.7
BH 23034 N-R	0.90	1.0-1.8	silty CLAY with sand	M	H	4	1.0	0	18	36	46	82	57	30	27	2.55	42.2	1.0-1.5	1	12	0	1.00	49.5	22.2	30.8	1.3	4	6	2	61.0
BH 32187 N-R	0.00	0.0-0.8	sandy fat CLAY	C	H	2	0.0	0	31	40	29	69	52	23	29	2.67	34.7	0.50-1.00	1	30	0	0.50	7.2	1.8	18.6	0.3	2	9	1	61.3
BH 23636 N-R	0.30	0.0-0.8	clayey SILT with sand	M	H	3	0.0	0	20	60	20	80	59	31	28	2.51	42.6	0.5-1.0	2	12	4	0.50	50.6	26.8	31.3	0.3	3	8	1	61.7
BH 17887 N-C	1.00	1.2-1.8	sandy SILT with clay	C	H	2	1.0	1	31	43	25	68	57	29	28	2.61	37.7	1.00-1.50	1	11	0	1.00	46.5	17.3	28.8	1.3	2	3	1	61.7
BH 4935 N-R	0.30	0.0-1.0	sandy lean CLAY	C	L	2	0.0	1	48	43	8	51	41	23	18	2.54	41.4	0.50-1.00	2	4	0	0.50	17.3	9.2	10.7	0.3	2	5	1	62.4
BH 5200 N-C	0.15	0.7-2.8	sandy lean CLAY	C	L	3	1.0	1	48	29	22	51	41	16	25	2.62	21.3	1.00-1.50	3	8	0	1.50	36.1	22.4	22.1	1.3	3	6	1	63.7
BH 26268-N-L	0.45	0.8-1.6	sandy SILT with clay	C	H	5	1.0	1	45	32	22	54	51	28	23	2.64	29.4	1.0-1.5	2	13	0	1.00	61.0	32.8	37.0	1.3	5	8	2	64.9
BH 26426 N-C	1.50	0.6-2.6	sandy SILT with clay	C	L	9	2.0	2	41	40	17	57	41	22	19	2.66	32.3	2.0-2.5	1	83	0	2.20	17.6	6.9	50.3	2.3	8	8	4	65.0
BH 32375 N-R	1.00	0.7-2.5	lean CLAY with sand	C	L	4	1.0	0	16	43	41	84	40	17	23	2.60	52.0	1.00-1.50	1	108	0	1.00	21.7	10.6	64.9	1.3	4	5	2	66.5
BH 32187 N-L	0.00	0.0-0.9	sandy lean CLAY	C	L	2	0.0	0	30	39	31	70	49	24	25	2.67	35.9	0.50-1.00	1	60	0	0.50	12.0	5.5	36.0	0.3	2	9	1	66.7
BH 32187 N-R	0.00	0.8-1.5	fat CLAY with sand	C	H	7	1.0	0	25	38	37	75	55	25	30	2.67	35.0	1.00-1.50	1	40	0	1.00	7.9	3.5	24.0	1.3	7	14	3	67.0

Borehole No	Water Table at (m)	Layer Depth (m)	Description	USCS	Avg SPT	Sample Depth (m)	Particale Size Distribution					Atterberg Limits			Specific Gravity	NMC (%)	Depth (m)	Unconsolidated Undrained TT			Vane Shear Test			Average Cu (kPa)	SPT Correction				Deviation Factor (%)
							Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	LL (%)	PL (%)	PI (%)				No of Samples	C_u (kPa)	Φ_u	Depth (m)	Peak S/S (kN/m^2)	Residual S/S (kN/m^2)		Depth	SPT N_f	SPT N'_{70}	SPT N_{60}	
BH 26740 N-R	0.96	1.5-2.7	sandy fat CLAY	C H	4	2.0	4	35	29	32	61	63	28	35	2.62	49.1	2.00-2.50	2	8	0	2.00	46.0	16.4	27.0	2.3	4	5	2	70.4
BH 23817 N-R	0.40	0.7-1.5	sandy SILT with clay	C L	6	1.0	0	46	31	23	54	46	19	27	2.64	32.0	1.0-1.5	1	5	0	1.00	28.9	13.2	17.0	1.3	6	9	3	70.5
BH 17835 N-C	1.30	0.0-0.9	sandy SILT with clay	C L	2	0.0	1	38	46	15	61	48	23	25	2.58	25.9	0.50-1.00	1	8	0	0.50	51.6	19.3	29.8	0.3	2	5	1	73.2
BH 26868-N-C	0.50	0.8-1.7	sandy SILT with clay	C H	9	1.0	1	29	43	27	70	55	28	27	2.63	48.4	1.0-1.5	1	2	0	1.00	16.0	7.9	9.0	1.3	9	13	4	77.8
BH 32187 N-L	0.00	0.9-1.8	fat CLAY with sand	C H	4	1.0	0	23	45	32	77	55	25	30	2.73	33.1	1.00-1.50	1	75	0	1.00	9.2	1.6	42.1	1.3	4	8	2	78.1
BH 23034 N-R	0.90	1.0-1.8	silty CLAY with sand	M H	4	1.0	0	18	36	46	82	57	30	27	2.55	42.2	1.5-2.0	1	8	0	1.75	65.7	28.4	36.9	1.3	4	6	2	78.3
BH 20865 N-L	1.00	0.8-2.0	sandy SILT with clay	C H	7	1.0	0	44	32	24	56	59	30	29	2.75	34.0	1.00-1.50	1	82	0	1.30	9.0	5.1	45.5	1.3	7	9	3	80.2

NP – Non plastic

ML – Low plastic silt

MH – High plastic silt

CL – Low plastic clay

CH – High plastic clay