



**ADDIS ABABA UNIVERSITY  
ADDIS ABABA INSTITUTE OF TECHNOLOGY  
DEPARTMENT OF CIVIL ENGINEERING**

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**CORRELEATION BETWEEN STANDARD PENETRATION TEST  
WITH UNCONFINED COMPRESSIVE STRENGTH AND INDEX  
PROPERTIES OF FINE-GRAINED SOIL**

**BY: ADDIS KEBEDE**

An Independent Project Submitted to School of Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Engineer in Civil Engineering under Geotechnical Engineering.

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**ADDIS ABABA UNIVERSITY**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF GRADUATE STUDIES**

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# TABLE OF CONTENT

<b>1. INTRODUCTION</b> .....	<b>1</b>
1.1. GENERAL .....	1
1.2. IMPORTANCE .....	1
1.3. STATEMENT OF THE PROBLEM.....	2
1.4. OBJECTIVE .....	2
1.4.1. <i>General Objective</i> .....	2
1.4.2. <i>Specific Objective</i> .....	2
1.5. METHODOLOGY.....	2
1.6. DATA ORGANIZATION: .....	3
1.7. ORGANIZATION OF THE INDEPENDENT PROJECT .....	3
<b>2. LITERATURE REVIEW</b> .....	<b>4</b>
2.1. PROPERTIES OF FINE GRAINED SOILS.....	4
2.1.1. <i>Silts</i> .....	4
2.1.2. <i>Clays</i> .....	4
2.2. CONSISTENCY OF FINE GRAINED SOILS .....	5
2.2.1. <i>Consistency of clay soil</i> .....	5
2.2.2. <i>Atterberg Limits</i> .....	5
2.2.3. <i>Liquidity Index IL</i> .....	7
2.2.4. <i>Modified liquid limit (WLM) and Modified plasticity index (ILM)</i> .....	8
2.3. STANDARD PENETRATION TEST (SPT) .....	9
2.3.1. <i>Correction of SPT N Value</i> .....	12
2.4. UNCONFINED COMPRESSION TEST .....	12
2.5. EXISTING CORRELATIONS .....	14
2.5.1. <i>Correlations of SPT with undrained shear strength</i> .....	14
2.5.2. <i>Correlation of undrained shear strength with Liquidity index</i> .....	15

<b>3. DATA FILTERING AND SELECTING.....</b>	<b>17</b>
3.1. BACKGROUND.....	17
3.1.1. Location.....	17
3.2. FILTERING OF DATA.....	18
<b>4. ANALYSIS OF DATA AND DISCUSSION.....</b>	<b>21</b>
4.1. DATA ANALYSIS METHODS.....	21
4.1.1. Scatter Plot and Best-Fit Curve.....	21
4.2. REGRESSION ANALYSIS OF SPT WITH UNDRAINED SHEAR STRENGTH, PLASTIC INDEX, AND LIQUIDITY INDEX OF FINE GRAINED SOILS.....	21
4.2.1. Silty Clay and Sandy Silt Soil.....	21
4.2.2. Regression Analysis for fine grained soils separately.....	28
4.3. REGRESSION ANALYSIS BETWEEN UNDRAINED SHEAR STRENGTH ( $C_u$ ) WITH LIQUIDITY INDEX ( $I_L$ ) AT DIFFERENCE DEGREE OF SATURATION.....	34
4.4. REGRESSION ANALYSIS OF SPT WITH INDEX PROPERTY OF FINE GRAINED SOILS	35
4.4.1. Silty Clay Soil.....	35
4.4.2. Sandy Silt soil.....	44
<b>5. SUMMARY OF THE REGRESSION ANALYSIS AND COMPARISON WITH EXISTING CORRELATION.....</b>	<b>52</b>
5.1. CORRELATION OF STANDARD PENETRATION NUMBERS (SPT) WITH UCS ( $C_u$ ), $I_L$	52
5.1.1. Silty Clay soil.....	52
5.1.2. Sandy Silt soil.....	52
5.2. CORRELATION OF STANDARD PENETRATION NUMBERS (SPT) WITH THE INDEX PROPERTIES.....	52
5.2.1. Silty Clay soil.....	52
5.2.2. Sandy Silt soil.....	53

5.3.	COMPARISON THE RESULTING WITH EXISTING CORRELATION .....	53
5.3.1.	<i>Comparison for correlation of SPT (<math>N'_{70}</math>) Vs. <math>q_u</math> in the general form .....</i>	53
5.3.2.	<i>Comparison for correlation of <math>C_U</math> Vs. <math>I_L</math> based on the observation of Wroth &amp; Wood, (1978) eq (2.51) [22]:.....</i>	53
5.3.3.	<i>The best fit equation for the correlation of <math>I_L</math> vs. SPT.....</i>	56
<b>6.</b>	<b>CONCLUSION AND RECOMMENDATION .....</b>	<b>57</b>
6.1.	CONCLUSION .....	57
6.2.	RECOMMENDATION .....	58
<b>APPENDIX A-1: SINGLE LINEAR REGRESSION ANALYSIS DATA</b>		
<b>APPENDIX A-2: SOIL STRATIFICATION PROFILE</b>		

## LIST OF TABLE

<b>Table 1</b> Different states through which soil sample passes with the decrease in the moisture content .....	6
<b>Table 2</b> Values of $I_L$ according to consistency of soil .....	8
<b>Table 3</b> Consistency and unconfined compression strength of clays .....	13
<b>Table 4</b> Relation between $N_{cor}$ and $q_u$ [7] .....	14
<b>Table 5</b> Consistency of saturated cohesive soils [5] .....	15
<b>Table 6</b> Single linear regression of Standard penetration number (SPT) with UCS ( $C_u$ ), $I_L$ and PI, for Silty clay and Sandy silt together (at depth 2.5m-3.0m).....	22
<b>Table 7</b> Correlation of Standard penetration number (SPT) with UCS ( $C_u$ ), $I_L$ and PI, for Silty clay and Sandy silt together (at depth 2.5m-3.0m).....	25
<b>Table 8</b> Correlation between Standard penetration numbers (SPT) with UCS ( $C_u$ ), $I_L$ and PI, for Silty Clay soil (at depth 2.5m-3.0m).....	28
<b>Table 9</b> Correlation between Standard penetration numbers (SPT) with UCS ( $C_u$ ), $I_L$ and PI, for Sandy Silt soil (at depth 2.5m-3.0m).....	31
<b>Table 10</b> Correlation between Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for Silty Clay soil (at depth 1.5m- 5.1m).....	36
<b>Table 11</b> Correlation between Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for Silty Clay soil (at depth 1.5m- 2.1m).....	38
<b>Table 12</b> Correlation between Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for Silty Clay soil (at depth 3.1m- 3.7m).....	40
<b>Table 13</b> Correlation between Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for Silty Clay soil (at depth 4.5m- 5.1m).....	42
<b>Table 14</b> Correlation between Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for Sandy Silt soil (at depth 1.5m-5.1m) .....	44
<b>Table 15</b> Correlation between Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for sandy silt soil (at depth 1.5m- 2.1m).....	46
<b>Table 16</b> Correlation between Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for sandy silt soil (at depth 3.1m- 3.7m).....	48
<b>Table 17</b> Correlation between Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for sandy silt soil (at depth 4.5m-5.1m).....	50

## LIST OF FIGURE

<b>Figure 1</b> Schematic diagrams of the three commonly used hammers [5].....	10
<b>Figure 2</b> Unconfined compression strength. ....	13
<b>Figure 3</b> Location map of the condominium site [12].....	18
<b>Figure 4</b> Soil stratification profile .....	20
<b>Figure 5</b> Scatter plot and best-fit curve of undrained Shear Strength and SPT for Silty clay and Sandy silt together .....	22
<b>Figure 6</b> Scatter plot and best-fit curve of Liquidity index and Undrained shear strength for Silty clay and Sandy silt together .....	23
<b>Figure 7</b> Scatter plot and best-fit curve of liquidity index and SPT for Silty clay and Sandy silt together .....	23
<b>Figure 8</b> Scatter plot and best-fit curve of plasticity Index and SPT for Silty clay and Sandy silt together .....	24
<b>Figure 9</b> Scatter plot and best-fit curve of undrained Shear Strength and SPT for Silty clay and Sandy silt together .....	25
<b>Figure 10</b> Scatter plot and best-fit curve of liquidity index and Undrained shear strength for Silty clay and Sandy silt together .....	26
<b>Figure 11</b> Scatter plot and best-fit curve of liquidity index and SPT for Silty clay and Sandy silt together .....	26
<b>Figure 12</b> Scatter plot and best-fit curve of plasticity Index and SPT for Silty clay and Sandy silt together .....	27
<b>Figure 13</b> Scatter plot and best-fit curve of undrained Shear Strength and SPT for Silty Clay soil .....	28
<b>Figure 14</b> Scatter plot and best-fit curve of Liquidity index and Undrained shear strength for Silty Clay soil .....	29
<b>Figure 15</b> Scatter plot and best-fit curve of liquidity index and SPT for Silty Clay soil .....	29
<b>Figure 16</b> Scatter plot and best-fit curve of plasticity index and SPT for Silty Clay soil .....	30
<b>Figure 17</b> Scatter plot and best-fit curve of undrained Shear Strength and SPT for Sandy Silt soil .....	31
<b>Figure 18</b> Scatter plot and best-fit curve of liquidity index and Undrained shear strength for Sandy Silt soil .....	32
<b>Figure 19</b> Scatter plot and best-fit curve of liquidity index and SPT for Sandy Silt soil .....	32
<b>Figure 20</b> Scatter plot and best-fit curve of plasticity index and SPT for Sandy Silt soil .....	33

<b>Figure 21</b> Correlation between undrained Shear strength ( $C_u$ ) with liquidity index at degree of saturation above 85% for Silty Clay and Sandy Silt soil.....	34
<b>Figure 22</b> Correlation between undrained Shear strength ( $C_u$ ) with liquidity index at degree of saturation below 85% for Silty Clay and Sandy Silt soil .....	35
<b>Figure 23</b> Scatter plot and best-fit curve of Liquidity Index and SPT for Silty Clay soil (at 1.5m-5.1m) .....	36
<b>Figure 24</b> Scatter plot and best-fit curve of Modified Plasticity index and SPT for Silty Clay soil (at 1.5m-5.1m) .....	37
<b>Figure 25</b> Scatter plot and best-fit curve of plasticity Index and SPT for Silty Clay soil (at 1.5m-5.1m) .....	37
<b>Figure 26</b> Scatter plot and best-fit curve of liquidity Index and SPT for Silty Clay soil (at 1.5m-2.1m) .....	38
<b>Figure 27</b> Scatter plot and best-fit curve of Modified Plasticity index and SPT for Silty Clay soil (at 1.5m-2.1m) .....	39
<b>Figure 28</b> Scatter plot and best-fit curve of plasticity Index and SPT for Silty Clay soil (at 1.5m-2.1m) .....	39
<b>Figure 29</b> Scatter plot and best-fit curve of liquidity Index and SPT for Silty Clay soil (at 2.m-3.7m) .....	40
<b>Figure 30</b> Scatter plot and best-fit curve of Modified Plasticity index and SPT for Silty Clay soil (at 2.m-3.7m) .....	41
<b>Figure 31</b> Scatter plot and best-fit curve of plasticity Index and SPT for Silty Clay soil (at 2.m-3.7m) .....	41
<b>Figure 32</b> Scatter plot and best-fit curve of liquidity Index and SPT for Silty Clay soil (at 4.5m-5.1m) .....	42
<b>Figure 33</b> Scatter plot and best-fit curve of Modified Plasticity index and SPT for Silty Clay soil (at 4.5m-5.1m) .....	43
<b>Figure 34</b> Scatter plot and best-fit curve of plasticity Index and SPT for Silty Clay soil (at 4.5m-5.1m) .....	43
<b>Figure 35</b> Scatter plot and best-fit curve of liquidity Index and SPT for Sandy Silt soil (at 1.5m-5.1m) .....	44
<b>Figure 36</b> Scatter plot and best-fit curve of Modified Plasticity index and SPT for Sandy Silt soil (at 1.5m-5.1m) .....	45
<b>Figure 37</b> Scatter plot and best-fit curve of plasticity Index and SPT for Sandy Silt soil (at 1.5m-5.1m) .....	45
<b>Figure 38</b> Scatter plot and best-fit curve of liquidity Index and SPT for Sandy Silt soil (at 1.5m-2.1m) .....	46

<b>Figure 39</b> Scatter plot and best-fit curve of Modified plasticity Index and SPT for Sandy Silt soil (at 1.5m-2.1m).....	47
<b>Figure 40</b> Scatter plot and best-fit curve of plasticity Index and SPT for Sandy Silt soil (at 1.5m-2.1m).....	47
<b>Figure 41</b> Scatter plot and best-fit curve of liquidity Index and SPT for Sandy Silt soil (at 3.1m- 3.7m).....	48
<b>Figure 42</b> Scatter plot and best-fit curve of Modified Plasticity index and SPT for Sandy Silt soil (at 3.1m- 3.7m).....	49
<b>Figure 43</b> Scatter plot and best-fit curve of Plasticity index and SPT for Sandy Silt soil (at 3.1m- 3.7m).....	49
<b>Figure 44</b> Scatter plot and best-fit curve of liquidity index and SPT for Sandy Silt soil (at 4.5m- 5.1m).....	50
<b>Figure 45</b> Scatter plot and best-fit curve of Modified Plasticity index and SPT for Sandy Silt soil (at 4.5m- 5.1m).....	51
<b>Figure 46</b> Scatter plot and best-fit curve of plasticity Index and SPT for Sandy Silt soil (at 4.5m- 5.1m).....	51
<b>Figure 47</b> Comparison of the correlation for $C_U$ vs $I_L$ based on the observation of Wroth & Wood, (1978) proposed equation.....	54
<b>Figure 48</b> Comparison of the correlation of $C_U$ vs. $I_L$ with normal coordinate and semi-logarithmic.....	55
<b>Figure 49</b> The best fit equation for the correlation of $I_L$ vs. SPT .....	56

## **ABSTRACT**

The properties of soil play an important role in many practices for geotechnical engineering. To determine the real values of these properties special techniques should be followed such as undisturbed samples and initial overburden pressures should be taken into consideration. Actually, it is difficult to obtain 100 % undisturbed samples due to handling, transportation, release of overburden pressure and poor laboratory conditions. So, prediction of some properties such as shear strength parameters ( $c_u$ ) for hard and dry silty clay and sandy silt soil with the help of standard penetration test (SPT) and index properties provides a good opportunity to obtain these parameters without great using of more laboratory tests. Standard penetration tests (SPT), rough measure the strength of soil. The merit of this test and the main reason for its widespread use is that it is simple and inexpensive. The shear strength parameters which can be indirect are approximate, but may give a useful guide in ground conditions where it may not be possible to obtain borehole samples of adequate quality like clay containing sand or gravel. This study was undertaken in order to study the reliability of using standard penetration test (SPT) and index properties ( $I_L$ ,  $I_{LM}$ , PI and PL) in predicting some properties, ( such as shear strength parameters ( $q_u$  &  $c_u$ ) of silty clay and sandy silt. For purpose of this investigation I utilized the borehole samples data that have been carried out for Addis Ababa Housing Development Program office at Bole Arabsa Condominium Building site 6. The results of the research indicated that the undrained shear strength of fine grained soil strongly related with the SPT number and liquidity index. Empirical equations to identify the shear strength parameters of fine grained soil using corrected SPT number ( $N'_{70}$ ) and liquidity index have been proposed.

**Keyword:** Silty clay & sandy silt, ( $q_u$  &  $c_u$ ), **LL**, **PL**, **PI**,  **$I_L$** , **Modified Plasticity Index** from laboratory result & **SPT** from the field

AAiT	Addis Ababa Institute of Technology
AAU	Addis Ababa University
AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society of Testing and Materials
CH	Inorganic clays of high plasticity
CL	Inorganic clays of low to medium plasticity
FC	Fine content (percentage of soil passing No. 200 sieve)
FS	Free Swell
Gs	Specific gravity
LL	Liquid Limit
IL	Liquidity Index
NMC	Natural Moisture Content
ML	Inorganic silts of low plasticity
MH	Inorganic silts of high plasticity
N	Number of sample
OH	Organic clays of medium of high plasticity.
OL	Organic silts of low plasticity
PI	Plastic Index
PL	Plastic Limit
$w_s$	Shrinkage Limit
$I_L$	Liquidity Index
$C_u$	Undrained Shear strength
$I_{LM}$	Modified Plasticity index
$W_{LM}$	Modified Liquidity index
$R^2$	Correlation Coefficient
SPT	Standard Penetration Test

USCS Unified Soil Classification System

$\gamma_{\text{wet}}$  Maximum wet unit weight

$\gamma_{\text{dry}}$  Maximum dry unit weight

## **1. Introduction**

### **1.1. General**

Every man made structure resting on the surface and sub-surface needs safe and stable soil. To attain this safety and stability requirements the engineering properties of the soil beneath the structure or on the structure must be identified. However, obtaining these engineering properties of soils requires relatively more time and money. Numerous methods have been developed for determination the soil properties. These methods include the field and laboratory tests. Also, to determine the real values of these properties, special techniques should be followed such as undisturbed samples and initial overburden pressures should be taken into consideration. On the other hand, field test such as SPT does not depend on undisturbed sample because it is carried out in original field soil. Most problems in soils and construction involve either the strength of the in-situ soil or the compressibility of the soil mass on the other hand the investigating of index properties for a soil is much easier than investigating other engineering properties; in terms of time, money, and effort. Moreover, most engineering properties of soils depend up on their index properties. Therefore, by obtaining the index property of soils that involves simpler and quicker method of testing, the engineering properties can be predicted satisfactorily from empirical correlations.

### **1.2. Importance**

Correlations are important to estimate engineering properties of soils particularly for project where there is a financial limitation, lack of test equipment or limited time, and correlations are commonly used in the preliminary stage of any project. Many attempts have been made to obtain a relation between the field test (SPT) and the laboratory test results of fine-grain soils. The correlation equations for fine-grained soils relate Standard penetration result (SPT) with unconfined compression strength ( $q_u$ ) and index properties.

### **1.3. Statement of the Problem**

Unconfined compression strength ( $q_u$ ) and index properties are usually determined by conducting specified method of testing in the laboratory, and the test results are utilized in the field to ensure the quality of construction for the desired purposes. However, when the extent of construction is very large (such as mass construction of Addis Ababa Housing Development Program office of Condominium Building) number of unconfined compression strength ( $q_u$ ) and index properties tests has to be performed. Obtaining the properties of fine-grained soil requires relatively elaborated laboratory procedures and it is time consuming. Thus, it is very important to obtain the index property parameters that involve simpler, quicker, and cheaper method of testing and the strength characteristics can be predicted satisfactorily from empirical correlations with standard penetration test result from the field

### **1.4. Objective**

#### **1.4.1. General Objective**

The objective of this study is to obtain applicable relationship between standard penetration result and unconfined compressive strength, Index properties of fine grained soils from laboratory and field data performed for Bole A rabsa Condominium Building site.

#### **1.4.2. Specific Objective**

1. To establish relevant relationships between standard penetration tests results (SPT), unconfined compressive strength and Index properties of fine grained soils and to develop appropriate empirical correlations among the corresponding soil parameters.
2. To examine the validity of the correlations with previous study, and to draw appropriate conclusions on the relationships of each empirical equations.

### **1.5. Methodology**

Primarily, in order to address the intended objectives of the study, basic theories and descriptions of correlation in general and in relation to field test and laboratory result of silty clay and sandy silt soil is reviewed. Subsequently, previous works of

different researchers with regard to the relation of SPT value and basic soil index properties from unconfined compressive strength were assessed.

### **1.6. Data organization:**

In order to have satisfactory data to seek the correlations, for this independent project as primary data of 112 out of 244 boreholes were selected by cluster random sampling method from the soil investigation of Addis Ababa House Development project at Bole Arabsa site 6.

Spread sheet data analyses were carried out by filtering with the type of soil according to the stratification and correlations were developed and also analyzed to find the best relation. Under the discussions of the obtained results the suitability of the developed correlations were examined and compared with previously conducted research. Finally, a generalized conclusion and recommendation was made.

### **1.7. Organization of the Independent Project**

In the first Chapter, importance of the study, statement of the problem, general objective and specific objective of the study, methodology and data organization were discussed as an introduction. In second Chapter, review of the literature has been done for studying the accepted theories and previously established relation stated. In Chapter three, data filtering and selecting, location of the boreholes and stratification of the soils are discussed. In chapter four, analyses of data, results, and interpretations are presented. In chapter five and six, summary of the results and comparison, conclusions and recommendations are treated.

## 2. Literature Review

### 2.1. Properties of Fine grained soils

Properties of fine-grained soils exhibit considerable changes with change of water content. Dry clay may be suitable as a foundation for heavy loads as long as it remains dry, but may turn into swamp when wet [1]. Many of the fine grained soils shrink on drying and expand on wetting, which may adversely affect structures founded on them. The properties of fine grained soils may vary considerably between their natural condition in the ground and their state after being disturbed, even if moisture content does not change [1].

#### 2.1.1. Silts

Silt is a fine-grained soil with little or no plasticity. The least plastic varieties generally consist of more or less equi-dimensional grains of quartz and are sometimes called rock flour; whereas the most plastic types contain an appreciable percentage of flake-shaped particles and are referred to as plastic silt. Because of its smooth texture, silt is often mistaken for clay, but it may be readily distinguished from clay without laboratory testing. If shaken in the palm of the hand, a pat of saturated inorganic silt expels enough water to make its surface appear glossy. If the pat is bent between the fingers, its surface again becomes dull. This procedure is known as the shaking test. After the pat has dried, it is brittle and dust can be detached by rubbing it with the finger.

#### 2.1.2. Clays

Clay is an aggregate of microscopic and submicroscopic particles derived from the chemical decomposition of rock constituents. It is plastic within a moderate to wide range of water content. Dry specimens are very hard, and no powder can be detached by rubbing the surface of dried pats with the fingers. The permeability of clay is extremely low.

They have low resistance to deformation when wet, but become hard cohesive masses when they dry. Clays are virtually impervious, difficult to compact when wet, and impossible to drain by ordinary means. Large expansion and contraction with changes in water content are characteristics of clays.

Field differentiation among clays is accomplished by the toughness test in which the moist soil is molded and rolled into threads until crumbling occurs and by the dry strength test which measures the resistance of the clay to breaking and pulverizing. The higher the liquid limit and thus the plasticity index the more cohesive is the clay [1].

## **2.2. Consistency of Fine grained soils**

### **2.2.1. Consistency of clay soil**

Consistency is a term used to indicate the degree of firmness of cohesive soils. The consistency of natural cohesive soil deposits is expressed qualitatively by such terms as very soft, soft, stiff, very stiff and hard. The physical properties of clays greatly differ at different water contents. A soil which is very soft at a higher percentage of water content becomes very hard with a decrease in water content. However, it has been found that at the same water content, two samples of clay of different origins may possess different consistency. Clay sample at one place may be relatively soft while the other may be hard. Further, a decrease in water content may have little effect on one sample of clay but may transform the other sample from almost a liquid to a very firm condition. Water content alone, therefore, is not an adequate index of consistency for engineering and many other purposes. Consistency of a soil can be expressed in terms of Atterberg limits and unconfined compressive strength [2]:

### **2.2.2. Atterberg Limits**

Atterberg, a Swedish scientist, considered the consistency of soils in 1911, and proposed a series of tests for defining the properties of cohesive soils. These tests indicate the range of the plastic state (plasticity is defined as the property of cohesive soils which possess the ability to undergo changes of shape without rupture) and other states. He showed that if the water content of a thick suspension of clay is gradually reduced, the clay water mixture undergoes changes from a liquid state through a plastic state and finally into a solid state.

The different states through which the soil sample passes with the decrease in the moisture content are depicted in Table 1. The water contents corresponding to the transition from one state to another are termed as

Atterberg Limits, and the tests required for determining the limits are the Atterberg Limit Tests. The testing procedures of Atterberg limits were subsequently improved by A. Casagrande (1932) [3].

States	Limit	Consistency	Volume change
Liquid		Very soft	
..... LL	Liquid limit .....	Soft	↑
Plastic		Stiff	
..... PL	Plastic limit .....	Very stiff	↓
Semi solid			
..... SL	Shrinkage limit .....	Extremely stiff	
Solid		Hard	Constant volume

**Table 1** Different states through which soil sample passes with the decrease in the moisture content

The transition state from the liquid state to a plastic state is called the liquid limit, where at this stage all soils possess certain small shear strength. This arbitrarily chosen shear strength is probably the smallest value that is feasible to measure in a standardized procedure. The transition from the plastic state to the semisolid state is termed the plastic limit, PL. At this state the soil rolled into threads of about 3 mm diameter just crumbles. Further decrease of the water contents of the same will lead finally to the point where the sample can decrease in volume no further. At this point the sample begins to dry at the surface, saturation is no longer complete, and further decrease in water in the voids occurs without change in the void volume. The color of the soil begins to change from dark to light. This water content is called

the shrinkage limit, SL. The limits expressed above are all expressed by their percentages of water contents.

The range of water content between the liquid and plastic limits, which is an important measure of plastic behavior, is called the plasticity index,  $I_p$ , i.e.

$$PI = LL - PL$$

Where, PI is the plasticity index, LL is liquidity limit and PL plasticity limit

### 2.2.3. Liquidity Index $I_L$

The Atterberg limits are found from tests on remolded soil samples. This limits us from finding out about the consistency of the in-situ conditions of soils. The index that is used to indicate the consistency of undisturbed soils is called the liquidity index. The liquidity index is expressed as [2]

$$I_L = \frac{W_n - PL}{PI}$$

Where;  $W_n$  is the natural moisture content of the soil in the undisturbed state. The liquidity index of undisturbed soils can vary from less than zero to greater than 1. The value of  $I_L$  varies according to the consistency of the soil as in Table 2. The liquidity index indicates the state of the soil in the field. If the natural moisture content of the soil is closer to the liquid limit the soil can be considered as soft, and the soil is stiff if the natural moisture content is closer to the plastic limit. There are some soils whose natural moisture contents are higher than the liquid limits. Such soils generally belong to the montmorillonite group and possess a brittle structure. A soil of this type when disturbed by vibration flows like a liquid. The liquidity index values of such soils are greater than one.

Consistency	$I_L$
Semisolid or solid state	Negative
Very stiff state ( $W_n = PL$ )	0
Very soft state ( $W_n = PL$ )	1
Liquid state (when disturbed)	>1

**Table 2** Values of  $I_L$  according to consistency of soil

#### 2.2.4. Modified liquid limit (WLM) and Modified plasticity index (ILM)

The Atterberg limits are usually conducted for soil fraction passing 425 microns. The values thus obtained may not be true representation of the entire soil. The presence of coarse particles only dilutes the physico-chemical potential of the soil proportionately (Muthy V.N.S. 1987) [2]. Accordingly the modified liquid limit ( $W_{LM}$ ) and modified plasticity index ( $I_{LM}$ ) are defined to analyze the test results. The modified liquid limit is defined as [4].

$$W_{LM} = LL \times F$$

And modified plasticity index is

$$I_{LM} = PL \times F$$

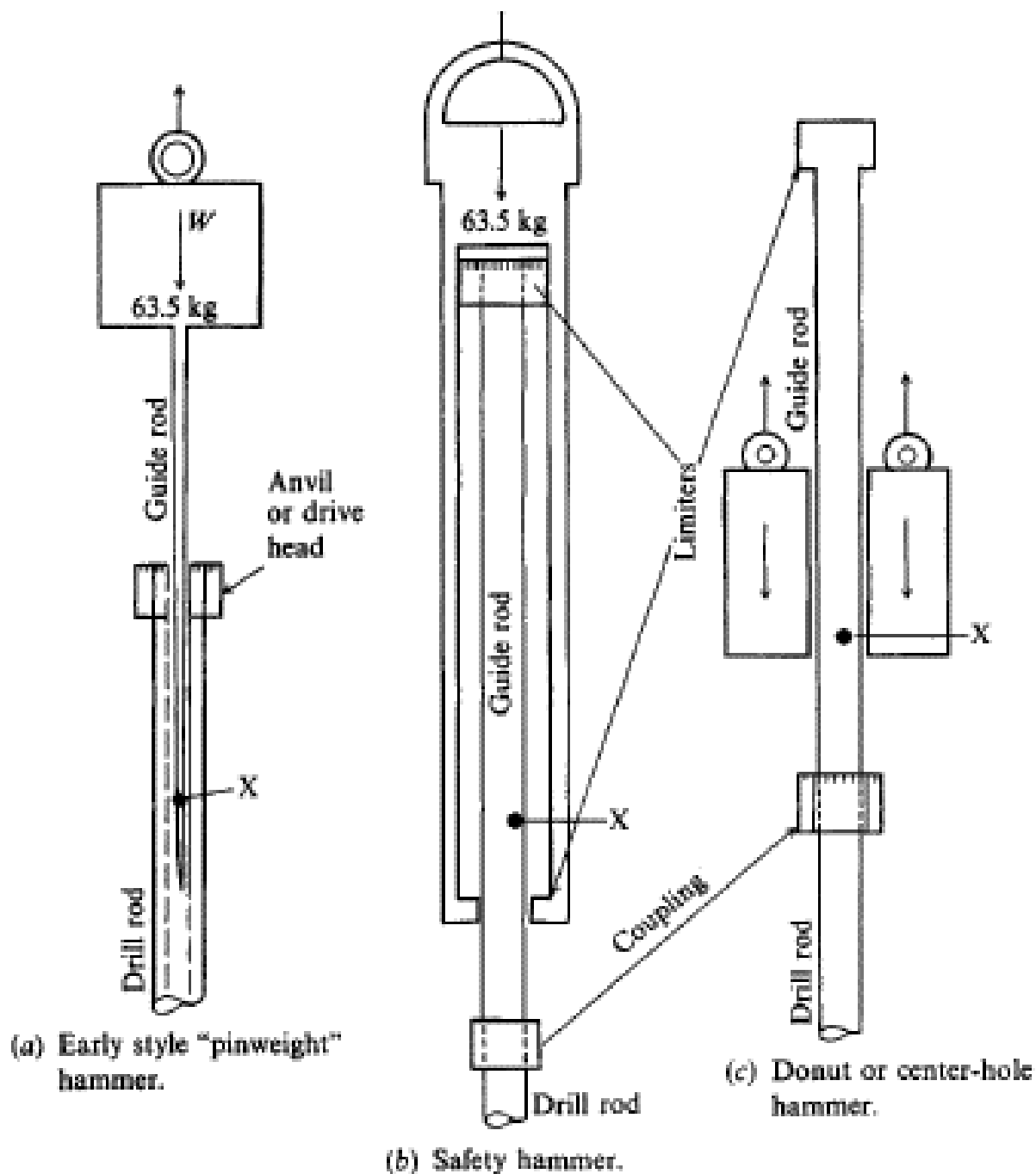
Where, F is fraction passing through 425 microns,  $I_{LM}$  is the modified plasticity index,  $W_{LM}$  is the modified plasticity index, LL is the Liquid Limit and PL is the Plasticity Limit.

### **2.3. Standard penetration test (SPT)**

The standard penetration test, developed around 1927, is currently the most popular and economical means to obtain subsurface information (both on land and offshore). This test is also widely used in other geographic regions. The method has been standardized as ASTM D 1586 since 1958 with periodic revisions to date. The test consists of the following [5]:

- i) Driving the standard split-barrel sampler of dimensions a distance 460 mm into the soil at the bottom of the boring. Using a 63.5-kg driving mass (or hammer) falling "free" from a height of 760 mm.
- ii) Counting the number of blows to drive the sampler the last two 150 mm distances (total = 300 mm) to obtain the N number.

SPT is important on all projects, especially those involving soft clays, loose sands and/or sands below the water table, due to the difficulty of obtaining representative samples suitable for laboratory testing. For each test included, a brief description of the equipment, the test method, and the use of the data is presented [13].



**Figure 1** Schematic diagrams of the three commonly used hammers [5].

Hammer (b) is used about 60 percent; (a) and (c) about 20 percent each in the United States. Hammer (c) is commonly used outside the United States. Note that the user must be careful with (b) and (c) not to contact the limiter and "pull" the sampler out of the soil. Guide rod X is marked with paint or chalk for visible height control when the hammer is lifted by rope off the cathead (power takeoff) [5].

The exposed drill rod is referenced with three chalk marks 150 mm apart, and the guide rod (see Fig. 1) is marked at 760 mm (for manual hammers). The assemblage is then seated on the soil in the borehole (after cleaning it of loose cuttings). Next the sampler is driven 150 mm to seat it on undisturbed soil, with this blow count being recorded (unless the system mass sinks the sampler so no N can be counted). The sum of the blow counts of the next two 150-mm increments is used as the penetration count N, unless the last increment cannot be completed. In this case the sum of the first two 150-mm penetrations is recorded as N.

The boring log shows refusal and the test is halted if

1. 50 blows are required for any 150-mm increment.
2. 100 blows are obtained (to drive the required 300 mm)
3. 10 successive blows produce no advance.

When the full test depth cannot be obtained, the boring log will show a ratio a 70/100 or 50/100 indicating that 70 (or 50) blows resulted in a penetration of 100 mm. Excessive equipment wear, as well as greatly reduced daily drilling meterage, results when blow counts are high, Standardization of refusal at 100 blows allows all drilling organizations to standardize cost so that higher blow counts result in a negotiation for a higher cost/length of boring or requirement for some type of coring operation.

SPT testing prior to about 1967 (according to ASTM) [11] only required the sampler to be seated and then driven 300 mm. This stipulation could reduce the N count nearly 50 percent since the first 150 mm of required seating produces substantial friction resistance on the sampler for the next 300 mm. It is unfortunate that many current SPT correlations are based on N values from this earlier procedure.

### 2.3.1. Correction of SPT N Value

The SPT N-values/300mm should be adjusted for different factors before employing them for computing the allowable bearing pressure. The SPT N-values are converted to  $N_{70}$  standard energy ratio value (Bowles, 1988) using [5]:

$$N'_{70} = C_N \times N \times n_1 \times n_2 \times n_3 \times n_4$$

$$N'_{70} = \text{adjusted N}$$

$$C_N = \text{adjustment for overburden pressure } (p''_o/p'_o)^{1/2}$$

$$p'_o = \text{overburden pressure}$$

$$P''_o = \text{reference overburden pressure (95.76kPa or } 1.0\text{kg/cm}^2\text{)}$$

$$n_1 = E_r/E_{rb} \text{ (where } E_r \text{ is average energy ratio that depends on the drill system and } E_{rb} \text{ is the standard energy ratio).}$$

$$n_2 = \text{Rod length correction;}$$

$$\text{Rod length } > 10 \text{ m} = 1, \text{ Rod length } 6\text{-}10 \text{ m} = 0.95, \\ \text{Rod length } 4\text{-}6 \text{ m} = 0.85, \text{ Rod length } 0\text{-}4 \text{ m} = 0.75$$

$$n_3 = \text{sampler correction (1.00 in this case)}$$

$$n_4 = \text{borehole diameter correction (1.00 in this case)}$$

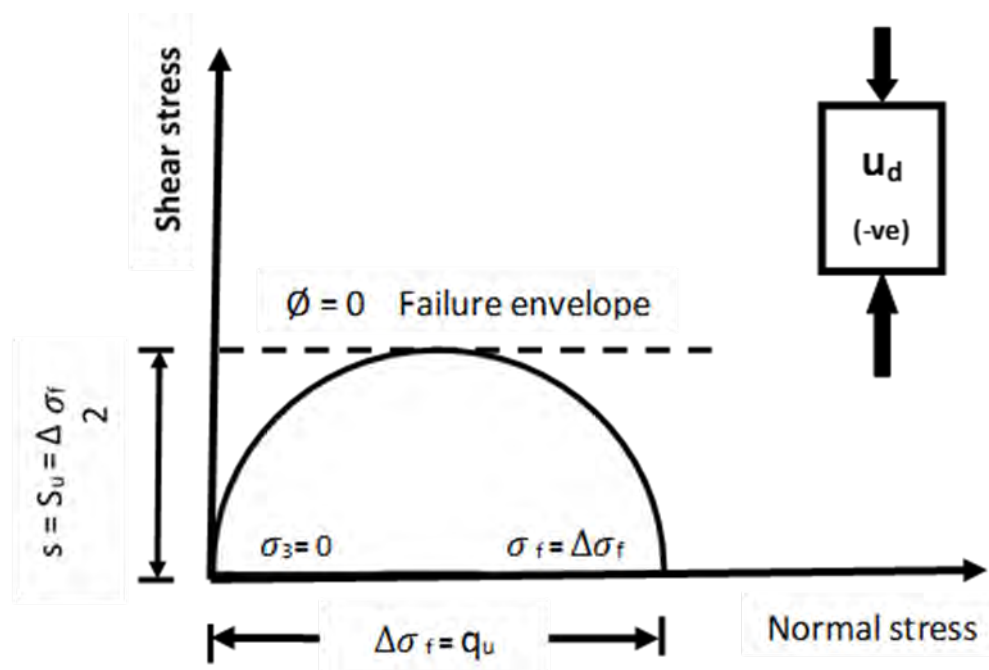
### 2.4. Unconfined compression test

The unconfined compression test is a special case of the unconsolidated undrained triaxial test. In this case no confining pressure to the specimen is applied (i.e.,  $\sigma_3 = 0$ ). For such conditions, for saturated clays, the pore water pressure in the specimen at the beginning of the test is negative (capillary pressure). Axial stress on the specimen is gradually increased until the specimen fails (Figure 2.0). At failure,  $\sigma_3 = 0$  and so [6]

$$\sigma_1 = \Delta\sigma_f = q_u$$

Where,  $q_u$  is the unconfined compression strength.

Theoretically, the value of  $\sigma_f$  of saturated clay should be the same as that obtained from unconsolidated undrained tests using similar specimens.



**Figure 2** Unconfined compression strength.

Consistency	$q_u$ (kN/m <sup>2</sup> )
Very soft	0–24
Soft	24–48
Medium	48–96
Stiff	96–192
Very stiff	192–383
Hard	>383

**Table 3** Consistency and unconfined compression strength of clays

Thus  $s = S_u = q_u / 2$ . However, this seldom provides high-quality results. The general relation between consistency and unconfined compression strength of clays is given in Table 3

## 2.5. Existing Correlations

### 2.5.1. Correlations of SPT with undrained shear strength

The first study to determine the  $q_u$ -N relationship was conducted by Terzaghi & Peck (1967). Their study was done on a variety of fine-grained soils that only examined  $q_u$  and N (SPT) without considering other parameters.

Table 4 shows a summary of their study, After Terzaghi and Peck (1967) many studies were done in this field. Sanglerat (1972) was the first researcher that presented  $q_u$ -N (SPT) correlation according to the type of fine-grained soils, by considering plasticity index of clay soils, and thus he divided soils into two categories of clay and silty clay [7].

Consistency	$N_{cor}$	$q_u$ (kN/m <sup>2</sup> )
Very soft	0-2	<25
Soft	2-4	25-50
Medium	4-8	50-100
Stiff	8-15	100-200
Very Stiff	15-30	200-400
Hard	>30	>400

**Table 4** Relation between  $N_{cor}$  and  $q_u$  [7]

Where;  $q_u$  is the unconfined compressive strength.

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

**Table 5** Consistency of saturated cohesive soils [5]

A correlation for N versus  $q_u$  is in the general form of [8]

$$q_u = KN$$

Where, the value of k tends to be site-dependent; However, a value of  $k = 12$  has been used Correlations for  $N_{70}$  and consistency of cohesive soil deposits (soft, stiff, hard, etc.) are given in Table 5.

### 2.5.2. Correlation of undrained shear strength with Liquidity index

The undrained strength of clays has been widely related to the liquidity index  $I_L$ , defined by equation (2.52) [9]:

$$I_L = \frac{W_n - PL}{PI} \quad \text{Eq. (2.52)}$$

Based on this observation, Wroth & Wood, (1978) proposed equation (2.53) [11]:

$$C_u = 170e^{-4.6I_L} = 1.7 \times 10^2(1-I_L)Kpa \quad \text{Eq. (2.53)}$$

This equation implies that the undrained shear strength of soil should be 1.7 kPa at the liquid limit and 170kPa at the plastic limit.

### Semi-logarithmic relationship

Worth & Wood (1978) relates liquidity index to the undrained shear strength. It is possible that the improvement when using the power model as opposed to the traditional semi-logarithmic model for individual soil test data is not as marked when analyzing the entire database. The semi-logarithmic relationship equation 2.54:

$$C_U = C_L R_{MW}^{(1-I_L)} \quad \text{Eq. (2.54)}$$

Where,  $R_{MW}$  is the ratio of strengths at the liquid and plastic limit,  $C_L$  strength of soil at liquid limit (taken as 1.7kPa in this paper)

Regressions are constructed by plotting liquidity index against the logarithm of undrained shear strength for the entire dataset.

The resulting regression equation is:

$$I_L = 1.150 - 0.283 \ln (C_u)Kpa \quad \text{Eq. (2.55)}$$

The regression line was adjusted such that it passes through  $C_u$  equal to 1.7 kPa at liquid limit: this did not reduce the coefficient of determination by any significant amount.

### **3. Data Filtering and Selecting**

#### **3.1. Background**

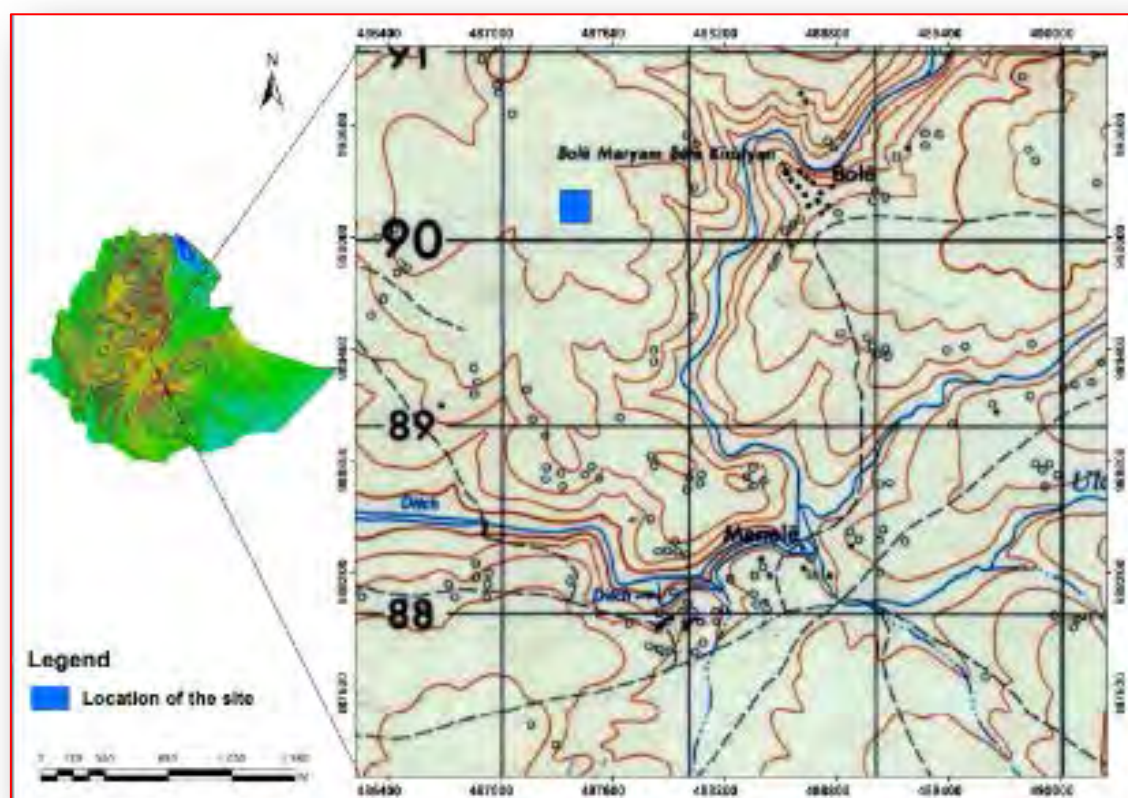
The Ababa Ababa Housing Development Program Office has conducted soil investigation for Bole Arabsa Condominium Building site 6. This building site is subdivided into different parcels; accordingly two hundred forty four boreholes were sunk in total of 16 Parcels building area to a maximum depth of 10.00m and 15.00 meters below the natural ground for G+4 and G+7 buildings respectively [12].

##### **3.1.1. Location**

The project site is located in the eastern part of Addis Ababa, Bole Sub-City, around Bole Arabsa locality. These project site are characterized by undulating topography with an average elevation of 2300m a.s.l.

The geotechnical investigations comprise core drilling, in-situ tests such as Standard Penetration Tests (SPT), monitoring of groundwater, collection of representative samples, and subsequent laboratory tests on representative samples to determine the engineering properties of the sub-surface materials. Moreover, the coordinates of each borehole was provided by the client and the ground elevation data were acquired using hand held GPS [12].

The field investigation was conducted from January 15 to January 21, 2015.



**Figure 3** Location map of the condominium site [12]

### 3.2. Filtering of Data

In order to have satisfactory data for utilizing the correlations, for the independent project, from 244 Boreholes 112 boreholes are selected by cluster random sampling method (selecting the data with the same soil stratification and depth). In these boreholes the upper part, the intermediate and the lower part of the soil profile mainly contained silty clay and sandy silt soil type as it is clearly shown in the soil stratification profiles (Figure 4 and Appendix A-2).

For the analysis in this independent project, the silty clay and sandy soil layers are selected with their respective thickness (0.0-1.5m, 1.5-2.10m, 2.5m-3.0m, 3.1-3.7m and 4.5m-5.1m in depth) as shown in the soil stratification profiles (Figure 4).

The soil stratification of the field investigation are categorized in seven layers with their soil type and depth.

**Layer 1:** Soft, dark grey, highly plastic CLAY

**Layer 2:** Medium stiff to stiff, greenish grey, highly plastic Silty CLAY

**Layer 3:** Medium stiff to stiff, yellowish brown Sandy SILT with few gravel

**Layer 4:** Medium dense to dense, yellowish to brownish grey Silty SAND

**Layer 5:** Very Stiff to hard, grayish to light reddish brown Silty CLAY

**Layer 6:** Dense, light brownish grey, Clayey Silty SAND (Highly weathered to completely decomposed BASALT).

**Layer 7:** Basalt

This independent project utilized a total of fifty two laboratory and field test results (at depth 2.5m to 3.0m) to relate undrained shear strength and Index properties with SPT. On the other hand one hundred eighty six laboratory and field tests results are used (at depth 1.5m to 5.1m) to relate the index properties with SPT of silty clay and sand soil.

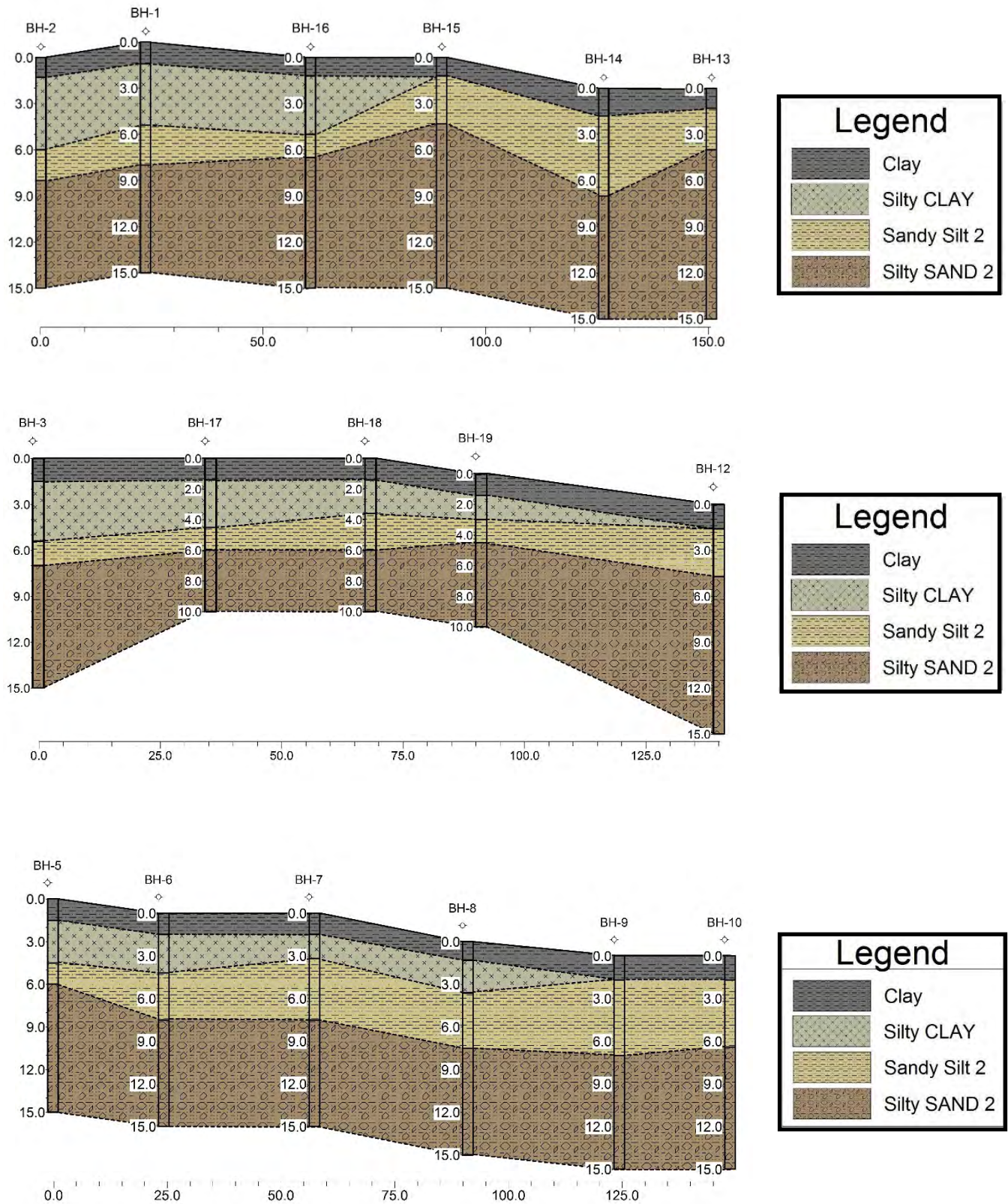


Figure 4 Soil stratification profile

## 4. Analysis of Data and Discussion

### 4.1. Data Analysis Methods

There are many methods that we can use to check the validity of the relationships between two or more variables. However, in this study the two common methods are used, namely: scatter plot and linear regression analysis. Before the application of the analysis methods some important terms are discussed below.

**Correlation coefficient or coefficient of regression (R):** Are the measures of how well the least-square regression line (best fit line) fits the sample data. Value of  $R=1$  or  $-1$  ( $R^2=1$ ) shows that there is a perfect linear correlation and also perfect linear regression. On the other hand  $R = 0$  or approaches to zero shows no valid relationship can be obtained between the variables

#### 4.1.1. Scatter Plot and Best-Fit Curve

Generally, in an analysis procedures of this independent project, the values of undrained shear strength ( $C_u$ ) are considered as the dependent variable whereas the standard penetration number, liquidity index and Index properties (SPT,  $I_L$ ,  $I_{LM}$ , and PI) are the independent (Predictor) variables.

In carrying out the statistical analysis, MS excel spreadsheet is used to determine the scatter plot, correlation and regression. The MS excel spreadsheet is found to be the most powerful and manageable tool for scatter plot analysis and determination of correlation between two variables.

### 4.2. Regression Analysis of SPT with undrained shear strength, plastic index, and liquidity index of fine grained soils

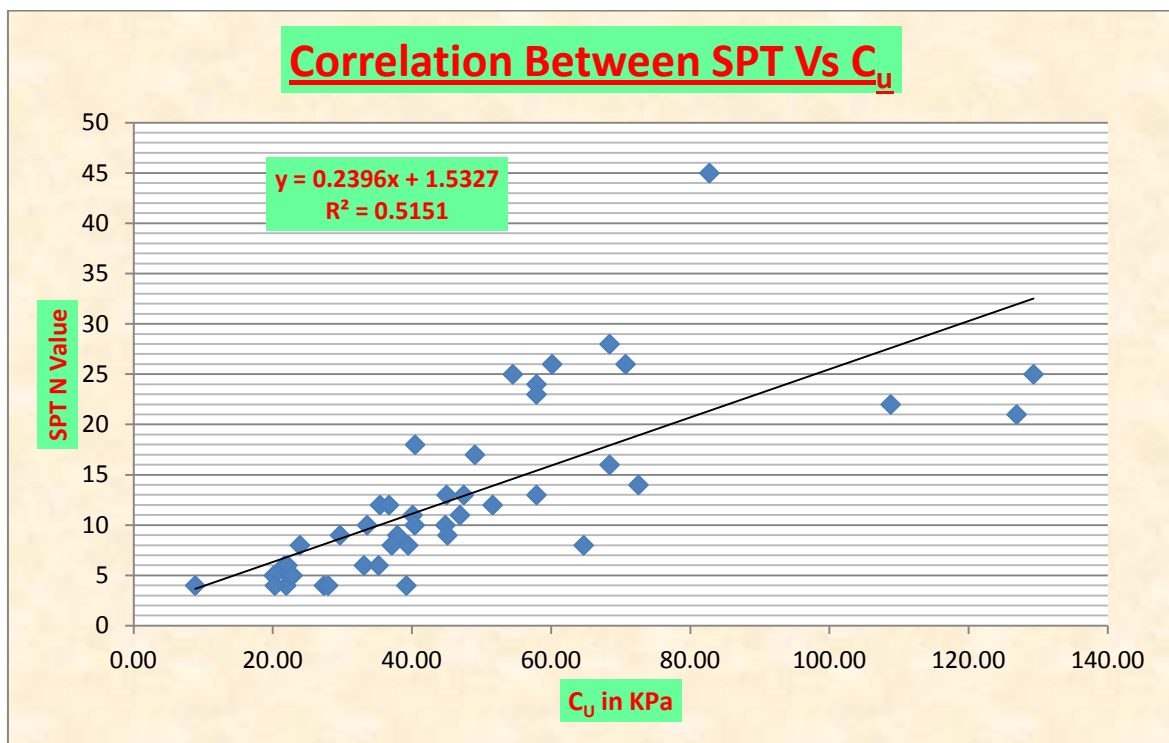
#### 4.2.1. Silty Clay and Sandy Silt Soil

##### **Model 1: Correlation of Standard penetration numbers (SPT) with UCS ( $C_u$ ), $I_L$ and PI, for Silty clay and Sandy silt together (at depth 2.5m-3.0m)**

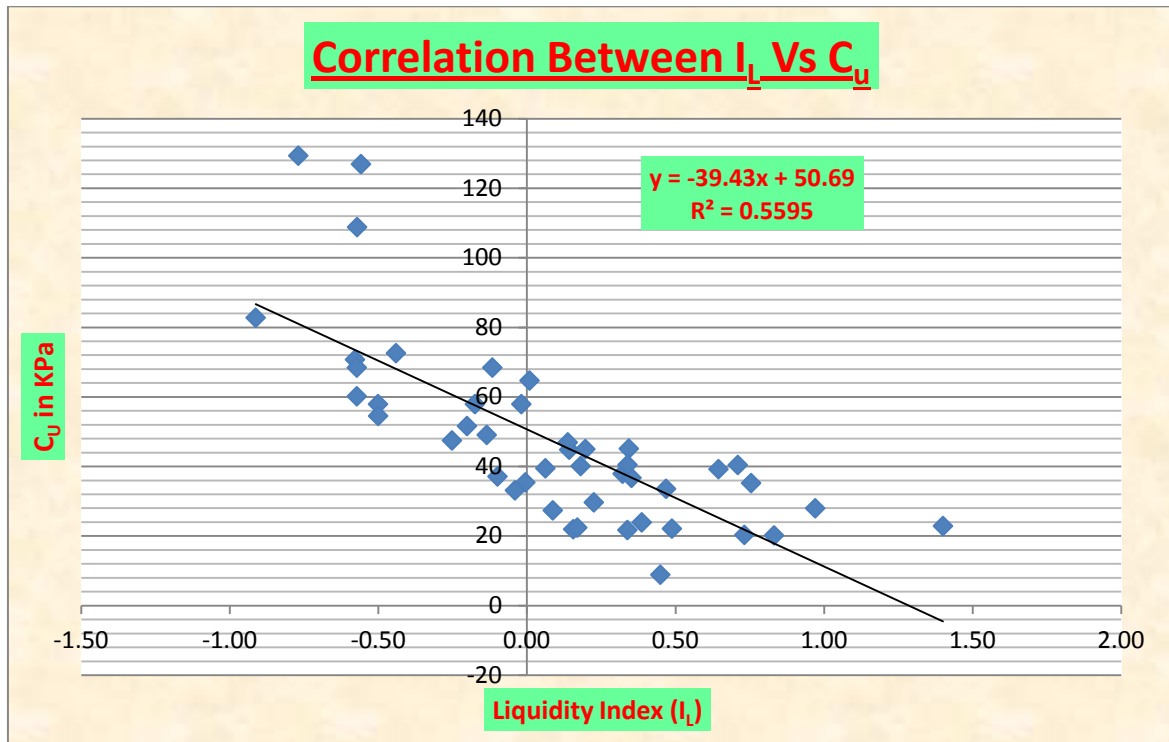
The resulting regression analysis after correlating **SPT** with **UCS**,  $I_L$  and **PI** for 45 available data of silty clay and sandy silt soil is expressed by the respective single linear equation in Table 6 with its corresponding correlation coefficients:

Variable	No. of Data	Single Linear Equation	Coefficient of Regression ( $R^2$ )
SPT Vs UCS	45	$N = 0.2396 \cdot C_U + 1.5327$	$R^2 = 0.5151$
UCS Vs $I_L$	45	$C_U = -39.43 \cdot I_L + 50.69$	$R^2 = 0.5595$
SPT Vs $I_L$	45	$N = -13.997 I_L + 14.071$	$R^2 = 0.6324$
SPT Vs PI	45	$N = -0.4832 \cdot PI + 25.602$	$R^2 = 0.3956$

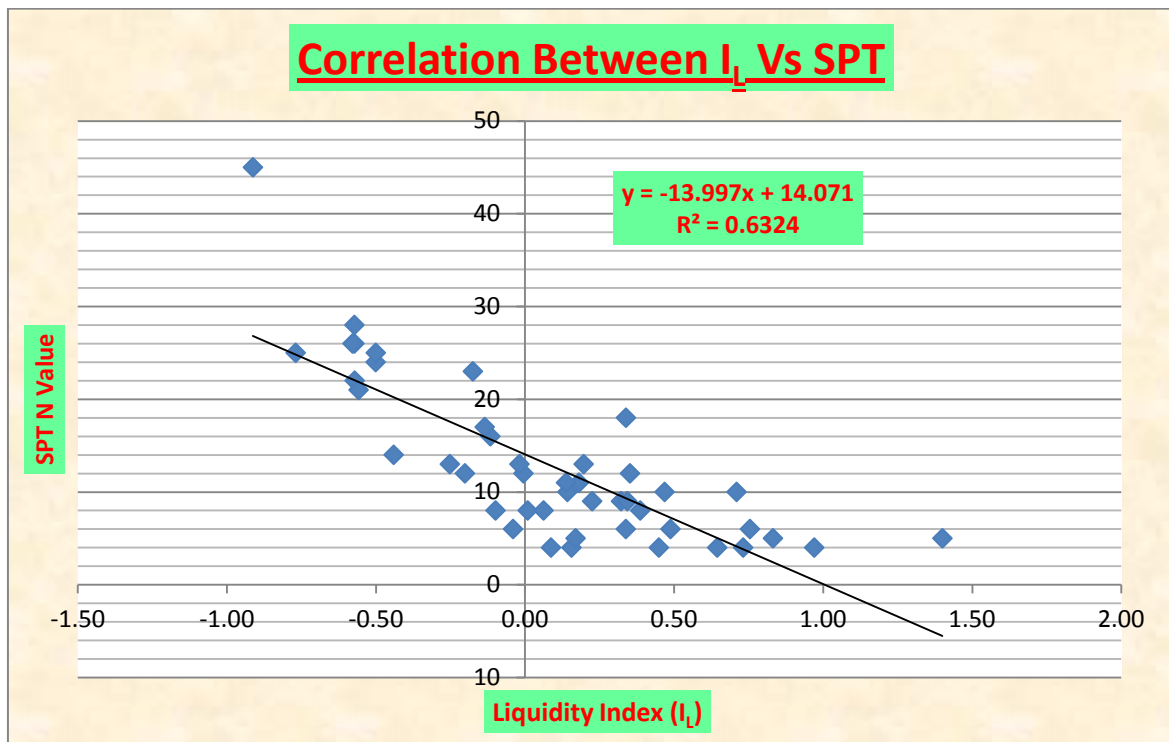
**Table 6** Single linear regression of Standard penetration number (SPT) with UCS ( $C_U$ ),  $I_L$  and PI, for Silty clay and Sandy silt together (at depth 2.5m-3.0m)



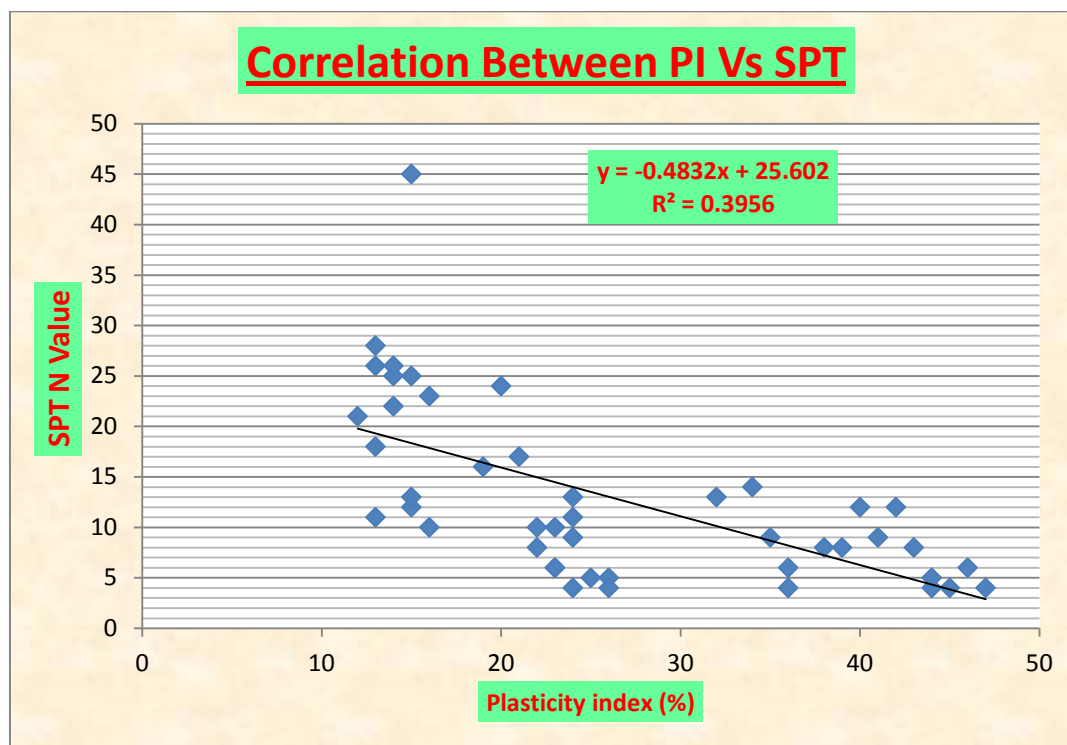
**Figure 5** Scatter plot and best-fit curve of undrained Shear Strength and SPT for Silty clay and Sandy silt together



**Figure 6** Scatter plot and best-fit curve of liquidity index and Undrained shear strength for Silty clay and Sandy silt together



**Figure 7** Scatter plot and best-fit curve of liquidity index and SPT for Silty clay and Sandy silt together



**Figure 8** Scatter plot and best-fit curve of plasticity Index and SPT for Silty clay and Sandy silt together

In Figure 5, 7 & 8, the dependent variable is SPT, and the independent variables are undrained shear strength, plasticity index, and liquidity index. Note that in predicting the undrained shear strength variable in the regression analysis there are two variables may be involved at a time. However, in the scatter plot (Figure 6), show the relationship between the undrained shear strength with liquidity index.

The Undrained shear strength has reasonably a linear correlation with liquidity index ( $R^2 = 0.5559$ ) value than standard penetration number. On the other hand, as shown in Figure 5 the relationship between undrained shear strength with standard penetration number has a correlation coefficient ( $R^2 = 0.5151$ ).

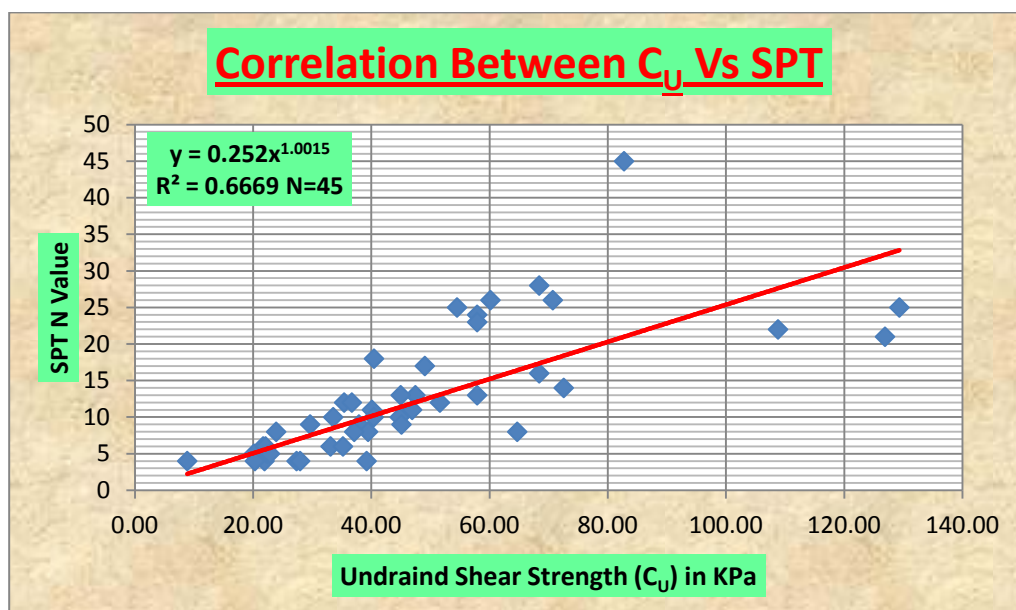
In general, it can be observed that for preliminary soil investigation the undrained shear strength of fine grained soils (silty clay and sandy silt), can be predicted from liquidity index with significant errors.

To find out the maximum coefficient of regression and best regression equation, in this study tried to see different regression stage in exponential, power and logarithmic

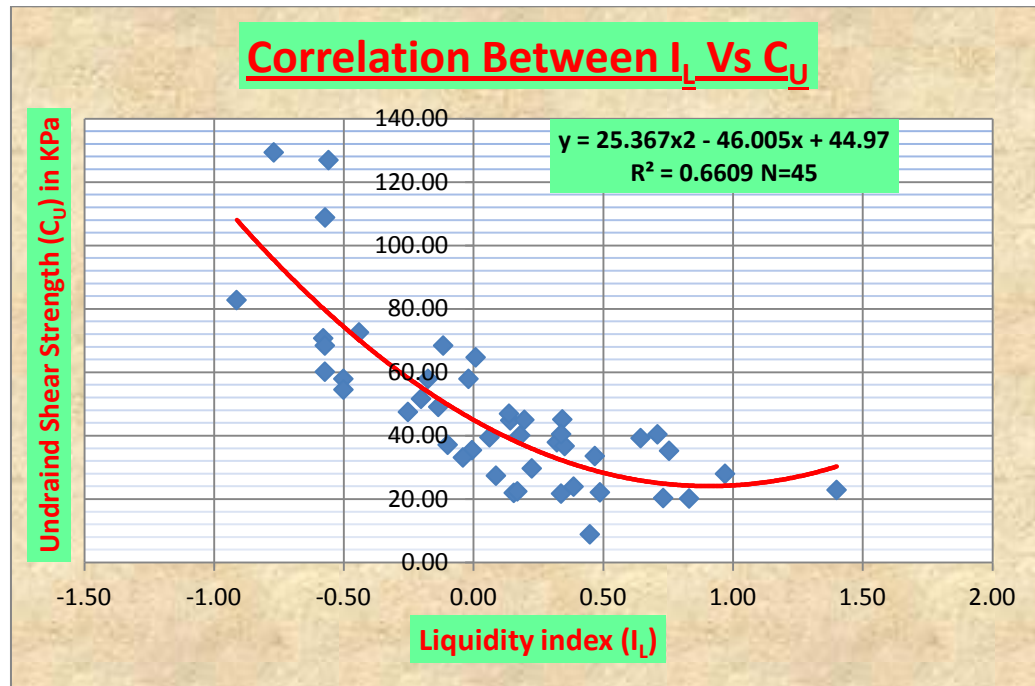
The resulting regression analysis after correlating **SPT** with **UCS**, **I<sub>L</sub>** and **PI** for 45 available data of silty clay and sandy silt soil is expressed by the respective regression equation with its corresponding correlation coefficients (Table 7):

Variable	No. of Data	Regression Equation	Coefficient of Regression (R <sup>2</sup> )
SPT Vs UCS	45	$N = 0.252 C_u^{1.0015}$	R <sup>2</sup> = 0.6669
UCS Vs I <sub>L</sub>	45	$C_u = 25.367 I_L^2 - 46.005 I_L + 44.97$	R <sup>2</sup> = 0.6609
SPT Vs I <sub>L</sub>	45	$N = 10.335 I_L^2 - 16.675 I_L + 11.74$	R <sup>2</sup> = 0.7834
SPT Vs PI	45	$N = 280.97 PI^{-1.035}$	R <sup>2</sup> = 0.4966

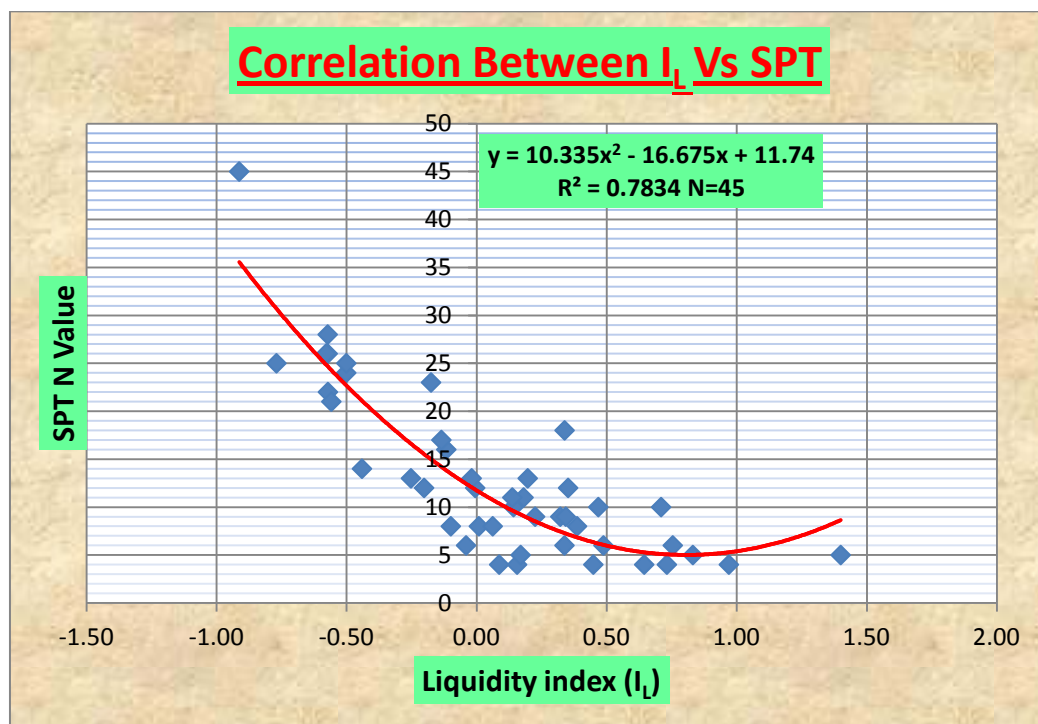
**Table 7** Correlation of Standard penetration number (SPT) with UCS (C<sub>u</sub>), I<sub>L</sub> and PI, for Silty clay and Sandy silt together (at depth 2.5m-3.0m)



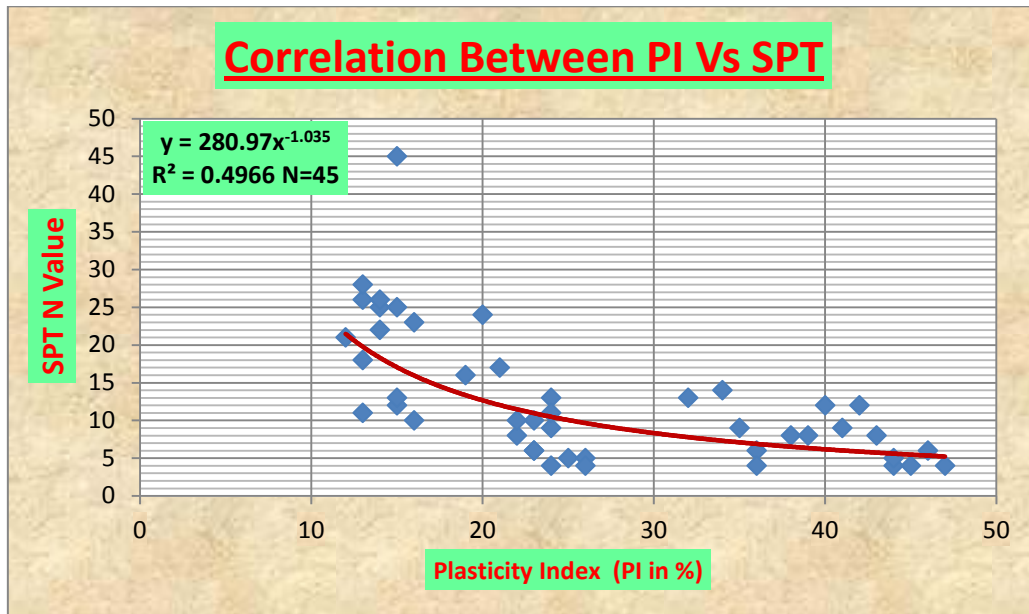
**Figure 9** Scatter plot and best-fit curve of undrained Shear Strength and SPT for Silty clay and Sandy silt together



**Figure 10** Scatter plot and best-fit curve of liquidity index and Undrained shear strength for Silty clay and Sandy silt together



**Figure 11** Scatter plot and best-fit curve of liquidity index and SPT for Silty clay and Sandy silt together



**Figure 12** Scatter plot and best-fit curve of plasticity Index and SPT for Silty clay and Sandy silt together

In Figure 9, 11 & 12, the dependent variable is SPT, and the independent variables are: undrained shear strength, plastic index, and liquidity index. Note that in predicting the undrained shear strength variable in the regression analysis there are two variables may be involved at a time. However, in the scatter plot (Figure 10), show the relationship between the undrained shear strength with liquidity index.

The Undrained shear strength has relatively strong correlation with standard penetration number ( $R^2 = 0.6669$ ) value than liquidity index. On the other hand, as shown in Figure 10 the relationship between undrained shear strength with liquidity index has a large correlation coefficient ( $R^2 = 0.6609$ ).

In general, it can be observed that for preliminary soil investigation the undrained shear strength of fine grained soils (silty clay and sandy silt), can be predicted from SPT with significant errors.

4.2.2. Regression Analysis for fine grained soils separately

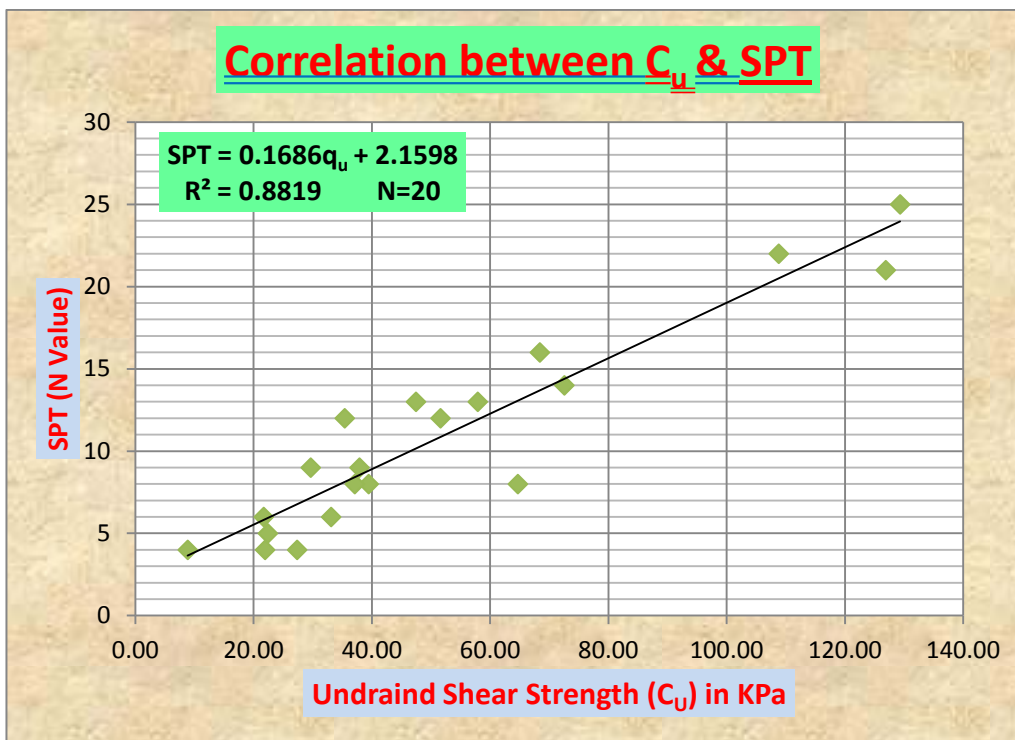
4.2.2.1. Silty Clay Soil

**Model 2: Correlation of Standard penetration numbers (SPT) with UCS ( $C_u$ ),  $I_L$  and PI, for Silty Clay soil (at depth 2.5m-3.0m)**

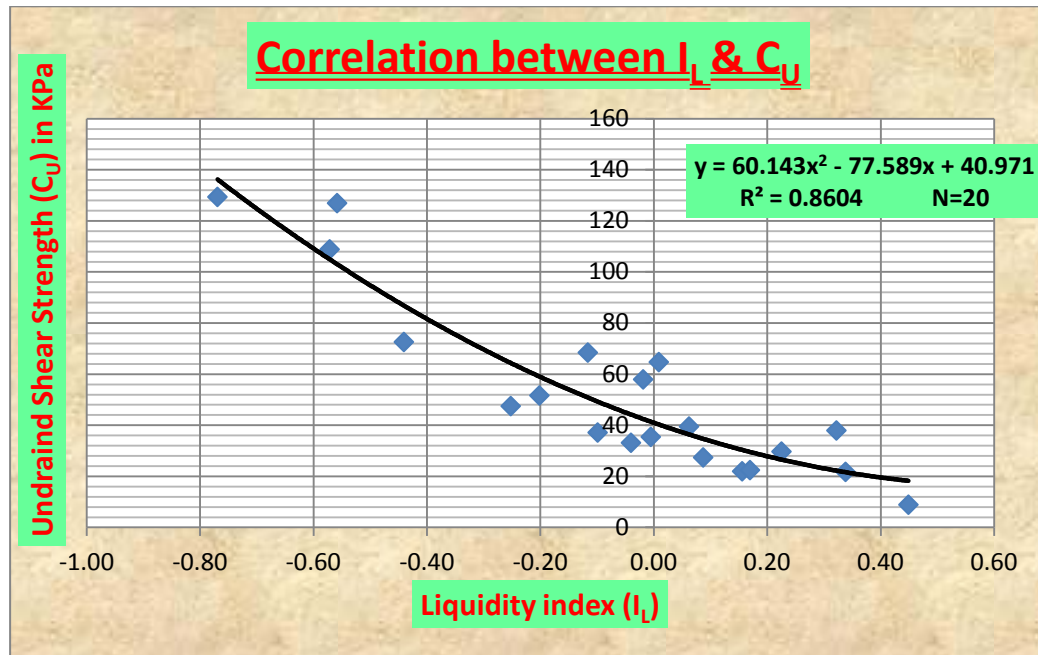
The resulting regression analysis after correlating SPT with UCS,  $I_L$  and PI for 20 available data of silty clay soil is expressed by the respective regression equation with its corresponding correlation coefficients (Table 8):

Variable	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs UCS	20	$N = 0.1686C_u + 2.1598$	$R^2 = 0.8819$
UCS Vs $I_L$	20	$C_u = 60.143 I_L^2 - 77.589 I_L + 40.971$	$R^2 = 0.8604$
SPT Vs $I_L$	20	$N = 11.073 I_L^2 - 13.394 I_L + 8.9528$	$R^2 = 0.8197$
SPT Vs PI	20	$N = 0.003PI^2 - 0.6696PI + 30.088$	$R^2 = 0.8431$

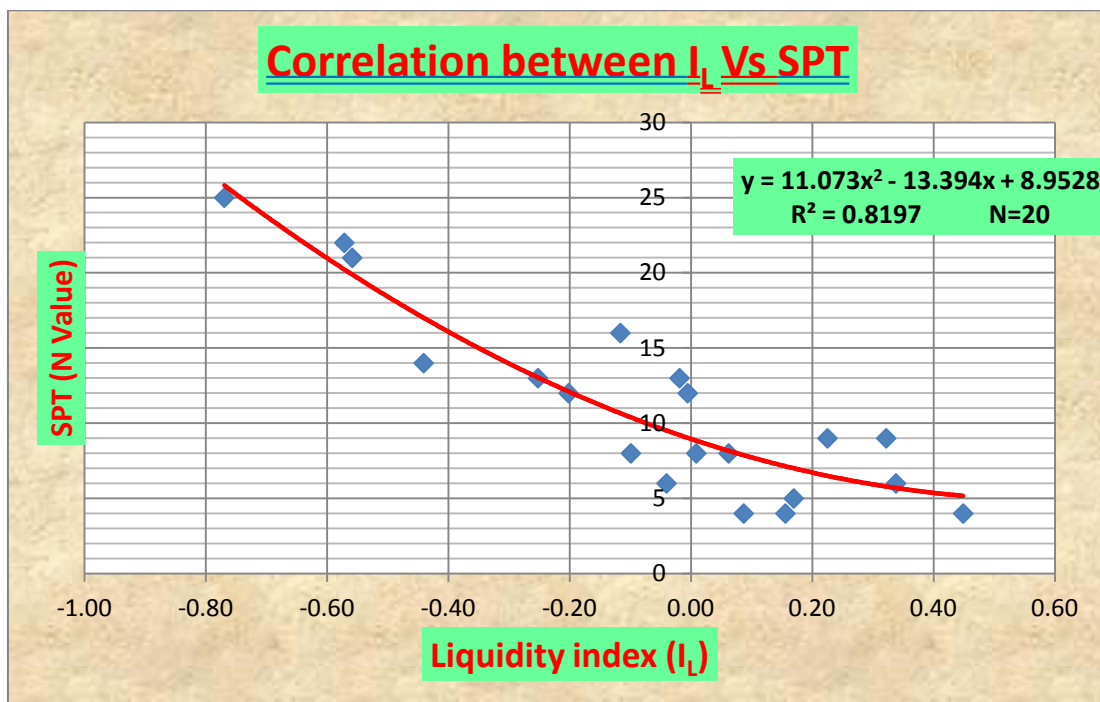
**Table 8** Correlation between Standard penetration numbers (SPT) with UCS ( $C_u$ ),  $I_L$  and PI, for Silty Clay soil (at depth 2.5m-3.0m)



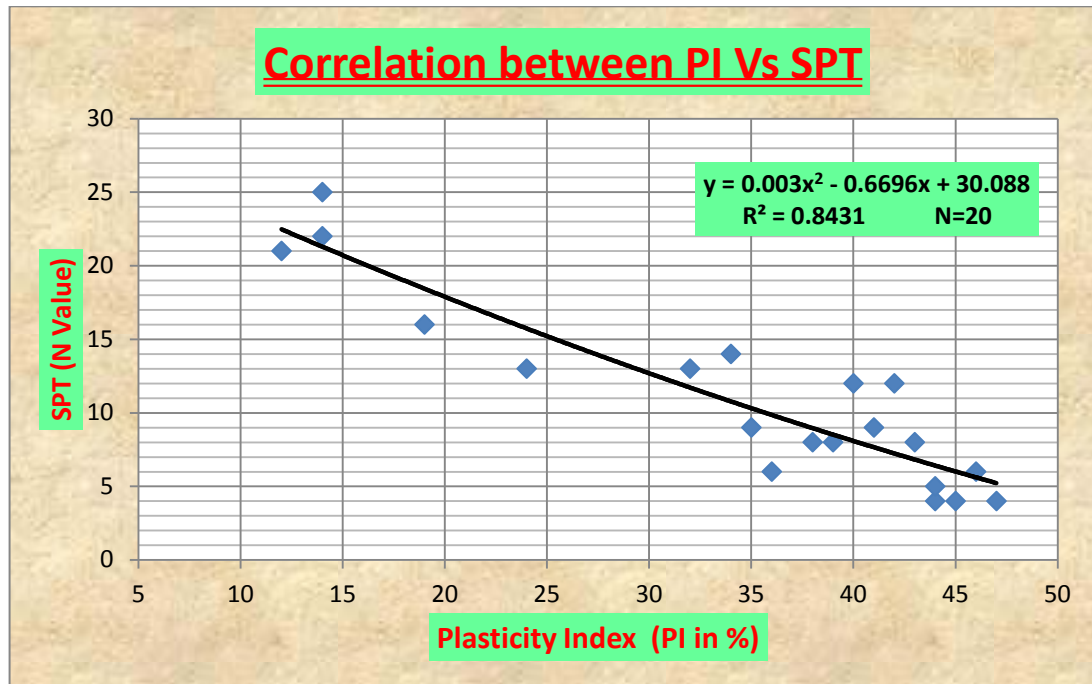
**Figure 13** Scatter plot and best-fit curve of undrained Shear Strength and SPT for Silty Clay soil



**Figure 14** Scatter plot and best-fit curve of Liquidity index and Undrained shear strength for Silty Clay soil



**Figure 15** Scatter plot and best-fit curve of liquidity index and SPT for Silty Clay soil



**Figure 16** Scatter plot and best-fit curve of plasticity index and SPT for Silty Clay soil

In Figure 13, 15 & 16, the dependent variable is SPT, and the independent variables are: undrained shear strength, plastic index, and liquidity index. Note that in predicting the undrained shear strength variable in the regression analysis there are two variables may be involved at a time. However in the scatter plot (Figure 14), show the relationship between the undrained shear strength with liquidity index.

The Undrained shear strength of silty clay soil has strong correlation with standard penetration number ( $R^2= 0.8819$ ) value than the liquidity index. On the other hand, as shown in Figure 14, the relationship between undrained shear strength with liquidity index has a relatively strong correlation coefficient ( $R^2= 0.8604$ ).

In general, it can be observed that for preliminary soil investigation the undrained shear strength of silty clay soils, can be predicted from SPT and liquidity index without significant errors.

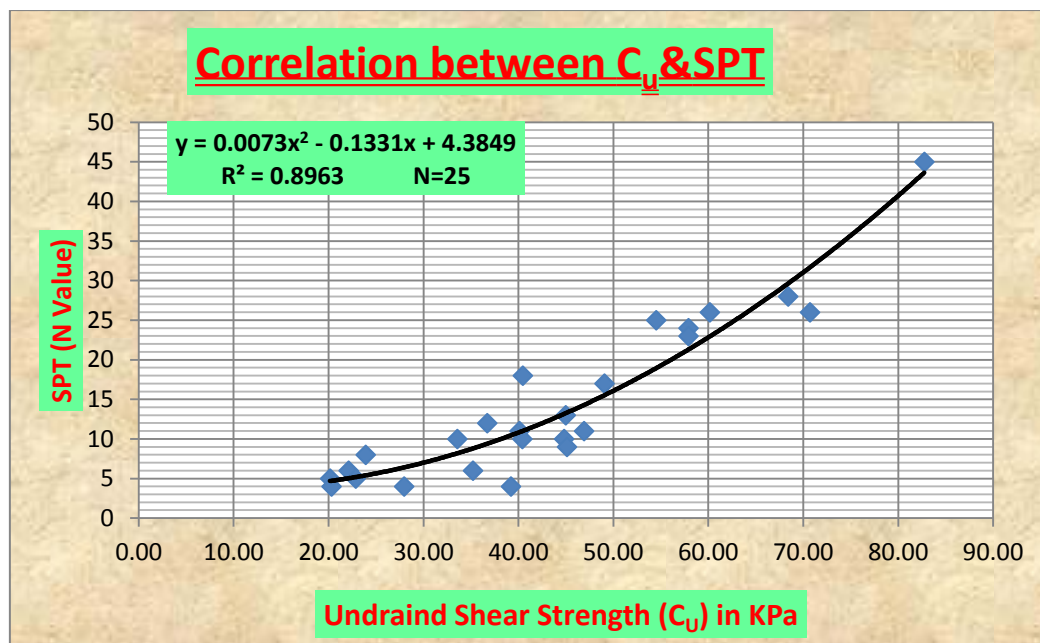
#### 4.2.2.2. Sandy Silt Soil

##### **Model 3: Correlation of Standard penetration numbers (SPT) with UCS ( $C_U$ ), $I_L$ and PI, for Sandy Silt soil (at depth 2.5m-3.0m)**

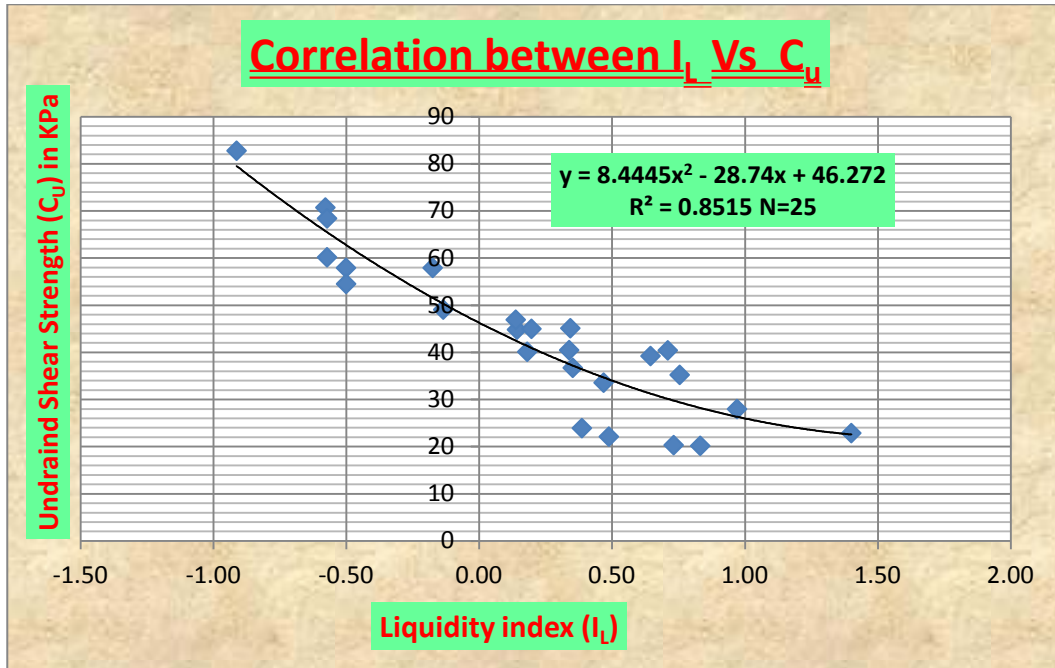
The resulting regression analysis after correlating SPT with UCS,  $I_L$  and PI for 25 available data of sandy silt soil is expressed by the respective regression equation with its corresponding correlation coefficients (Table 9):

Variable	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs UCS	25	$N = 0.0073C_U^2 - 0.1331 C_U + 4.3849$	$R^2 = 0.8963$
UCS Vs $I_L$	25	$C_U = 8.4445 I_L^2 - 28.74 I_L + 46.272$	$R^2 = 0.8515$
SPT Vs $I_L$	25	$N = 8.521 I_L^2 - 18.792 I_L + 15.165$	$R^2 = 0.9201$
SPT Vs PI	25	$N = 41.599 PI^{-0.319}$	$R^2 = 0.6142$

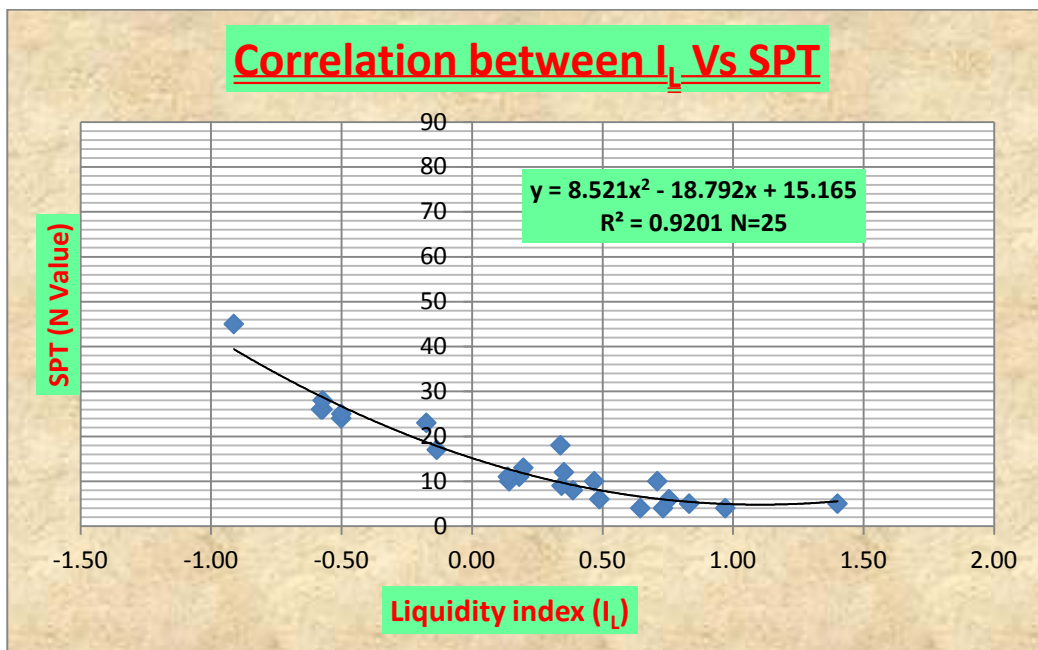
**Table 9** Correlation between Standard penetration numbers (SPT) with UCS ( $C_U$ ),  $I_L$  and PI, for Sandy Silt soil (at depth 2.5m-3.0m)



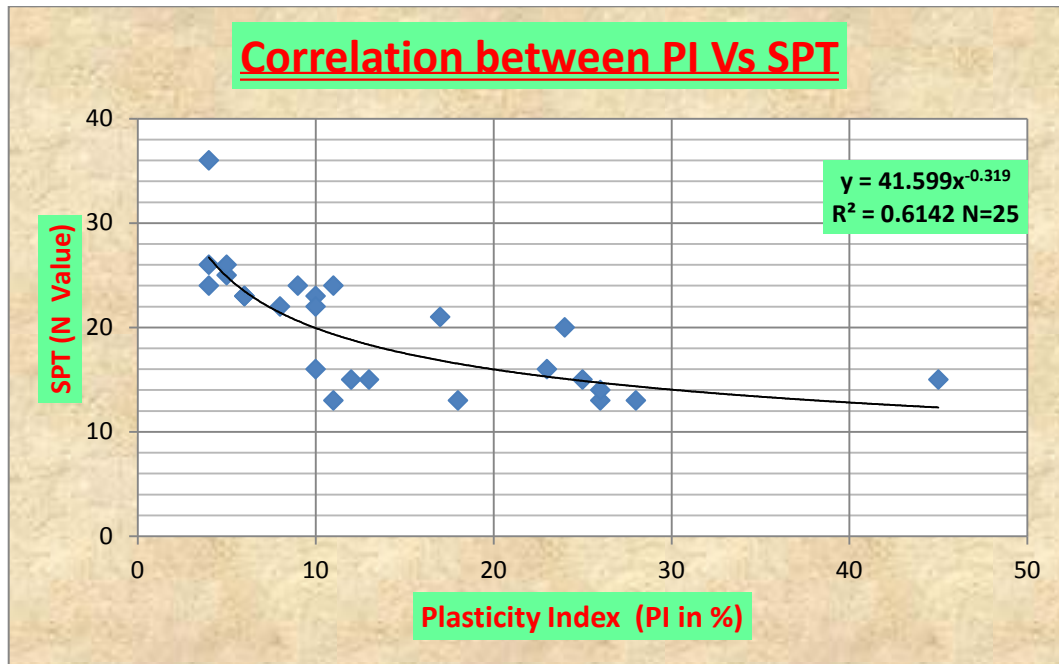
**Figure 17** Scatter plot and best-fit curve of undrained Shear Strength and SPT for Sandy Silt soil



**Figure 18** Scatter plot and best-fit curve of liquidity index and Undrained shear strength for Sandy Silt soil



**Figure 19** Scatter plot and best-fit curve of liquidity index and SPT for Sandy Silt soil



**Figure 20** Scatter plot and best-fit curve of plasticity index and SPT for Sandy Silt soil

In Figure 17, 19 & 20 the dependent variable is SPT, and the independent variables are: undrained shear strength, plastic index, and liquidity index. Note that in predicting the undrained shear strength variable in the regression analysis there are two variables may be involved at a time. However in the scatter plot (Figure 18), show the relationship between the undrained shear strength with liquidity index.

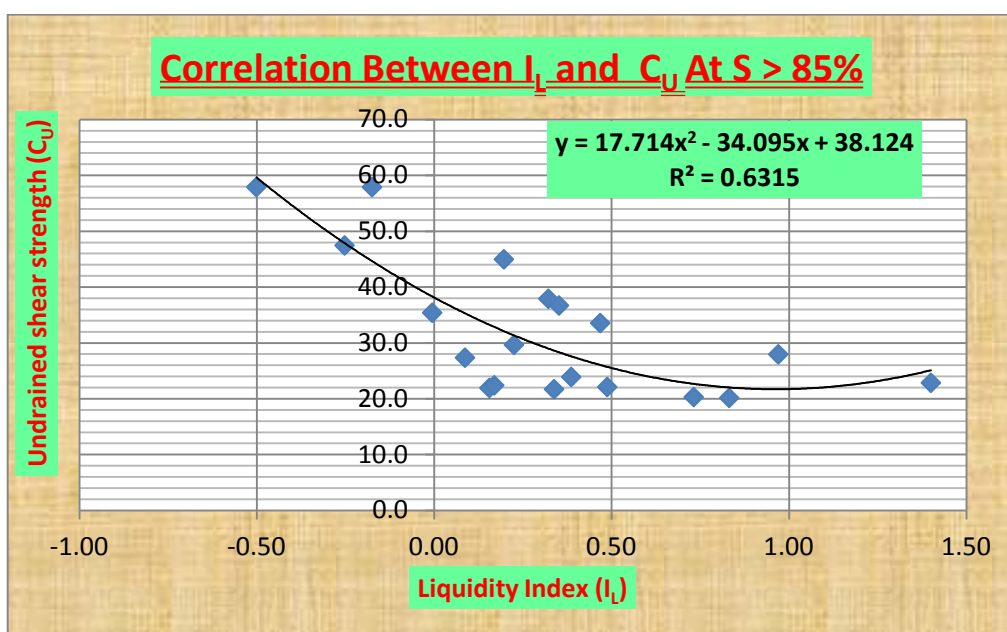
The Undrained shear strength has strong correlation with standard penetration number ( $R^2 = 0.8963$ ) value than the liquidity index. On the other hand, as shown in Figure 18, the relationship between the undrained shear strength with liquidity index of sandy silt soil has a relatively strong correlation coefficient ( $R^2 = 0.8515$ ).

In general, it can be observed that for preliminary soil investigation the undrained shear strength of sandy silt soils, can be predicted from SPT without significant errors.

**4.3. Regression Analysis between undrained Shear strength ( $C_U$ ) with liquidity index ( $I_L$ ) at difference degree of saturation**

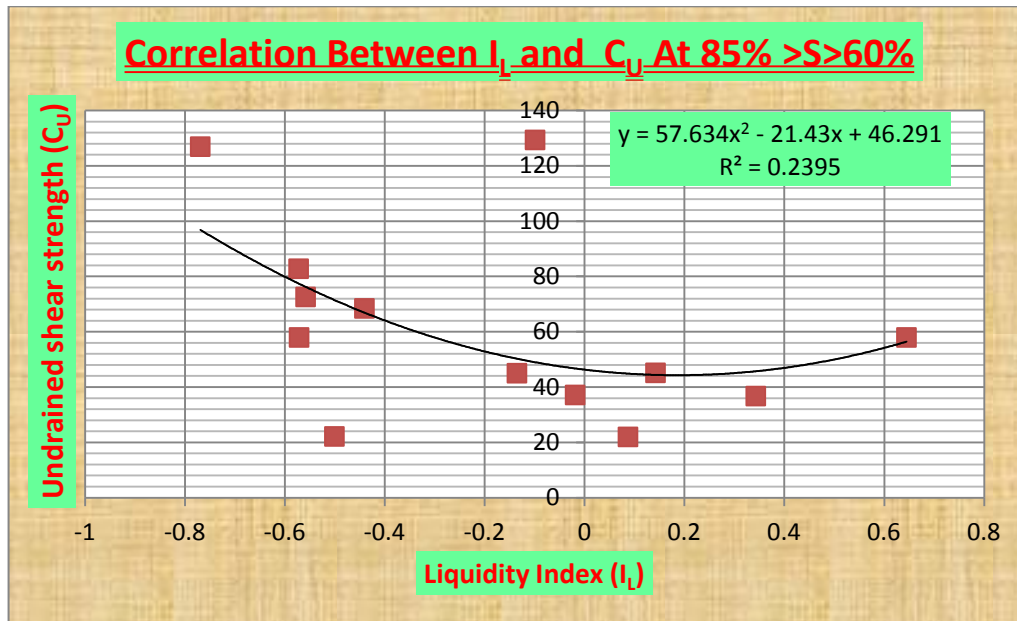
**Model 4: Correlation of undrained Shear strength ( $C_U$ ) with liquidity index ( $I_L$ ) at difference degree of saturation (S) for Silty Clay and Sandy Silt soil.**

The resulting regression analysis after correlating undrained Shear strength ( $C_U$ ) with liquidity index ( $I_L$ ) at degree of saturation above 85% for 20 selected data of Silty clay and Sandy Silt soil is expressed by the following regression equation with its corresponding correlation coefficients shown in figure 21 and figure 22



**Figure 21** Correlation between undrained Shear strength ( $C_U$ ) with liquidity index at degree of saturation above 85% for Silty Clay and Sandy Silt soil

The resulting regression analysis after correlating undrained Shear strength ( $C_U$ ) with liquidity index at degree of saturation below 85% for 25 selected data of Silty clay and Sandy Silt soil is expressed by the following single linear equation with its corresponding correlation coefficients:



**Figure 22** Correlation between undrained Shear strength ( $C_u$ ) with liquidity index at degree of saturation below 85% for Silty Clay and Sandy Silt soil

The Undrained shear strength has strong correlation with liquidity index at the degree of saturation is more than 85% ( $R^2 = 0.6315$ ) and at high degree of saturation the value of undrained shear strength is more reliable than at low degree of saturation (Figure 21 & 22).

#### 4.4. Regression Analysis of SPT with Index Property of fine grained soils

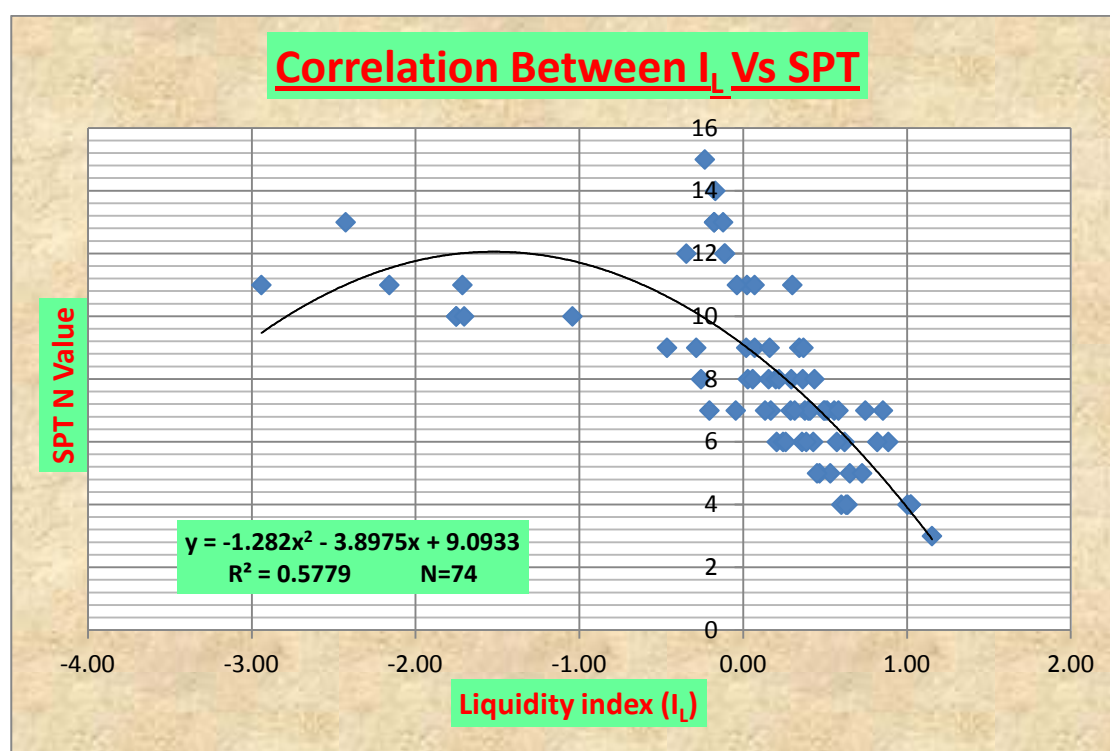
##### 4.4.1. Silty Clay Soil

##### Model 5: Correlation of Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for Silty Clay soil (at depth 1.5m- 5.1m)

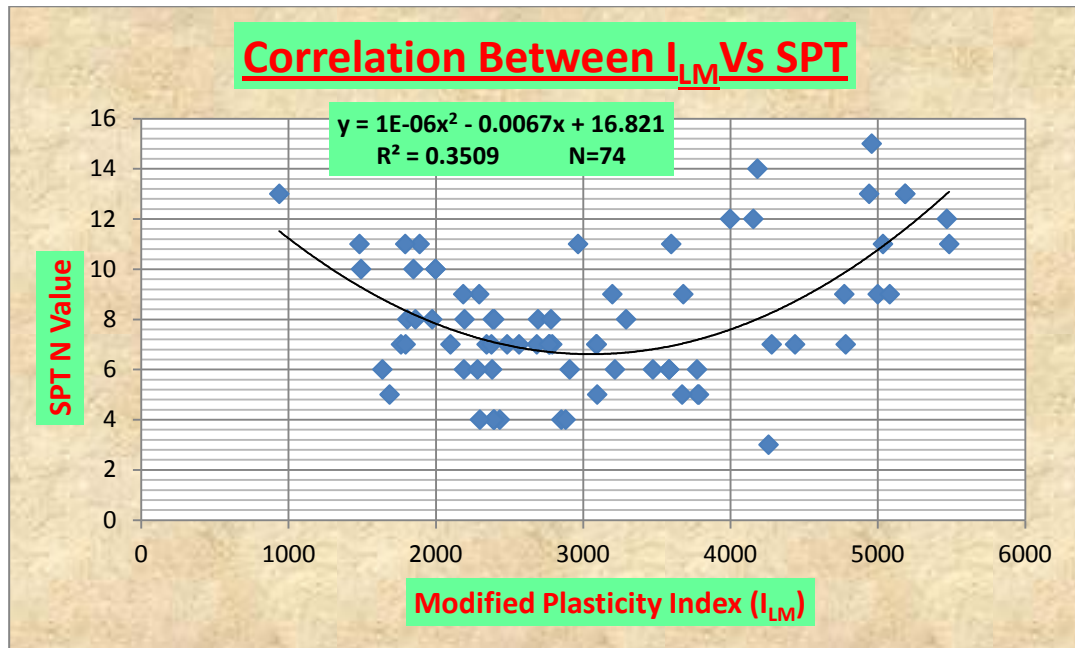
The resulting regression analysis after correlating SPT with  $I_L$ , Modified plasticity index and PI for 74 selected data of silty clay soil is expressed by the following single linear equation with its corresponding correlation coefficients (Table 10):

Variable	Depth (m)	No. of Data	Regression Equation	Coefficient of Regression (R <sup>2</sup> )
SPT Vs I <sub>L</sub>	1.5m-4.5m	74	$N = -1.282 I_L^2 - 3.8975 I_L + 9.0933$	R <sup>2</sup> = 0.5779
SPT Vs I <sub>LM</sub>	1.5m-4.5m	74	$N = 1E-06 I_{LM}^2 - 0.0067 I_{LM} + 16.821$	R <sup>2</sup> = 0.3509
SPT Vs PI	1.5m-4.5m	74	$N = 0.0122 PI^2 - 0.7635 PI + 18.435$	R <sup>2</sup> = 0.3977

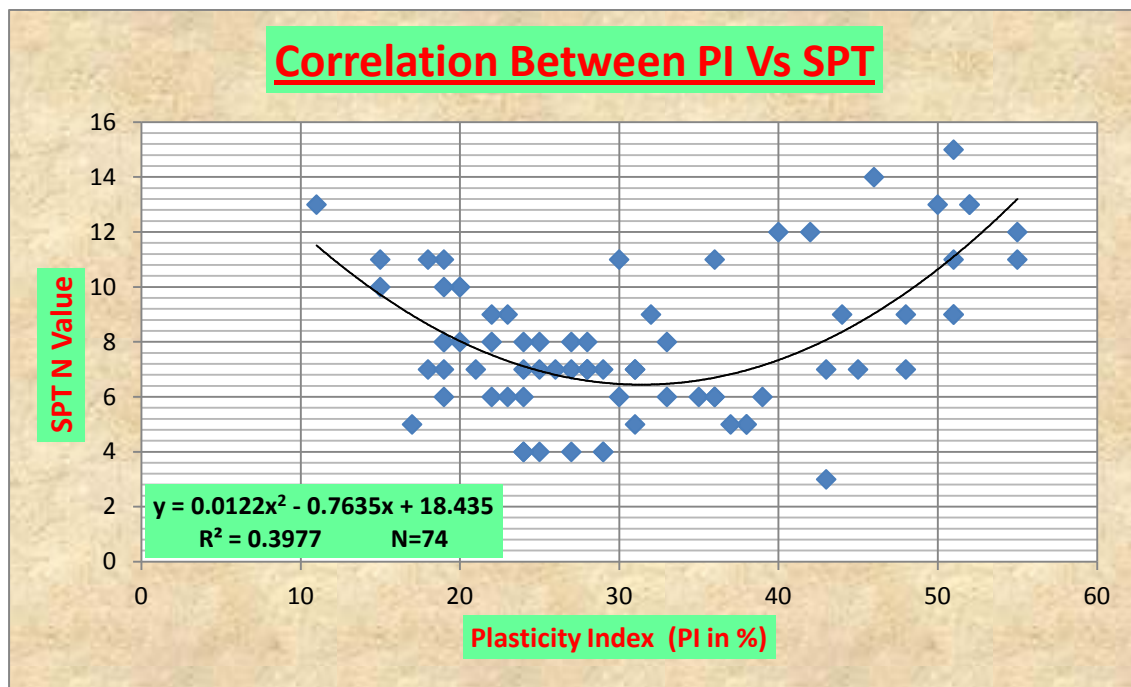
**Table 10** Correlation between S tandard pe netration nu mbers ( SPT) with I<sub>L</sub>, I<sub>LM</sub> and PI for Silty Clay soil (at depth 1.5m- 5.1m)



**Figure 23** Scatter plot and best-fit curve of Liquidity Index and SPT for Silty Clay soil (at 1.5m-5.1m)



**Figure 24** Scatter plot and best-fit curve of Modified Plasticity index and SPT for Silty Clay soil (at 1.5m-5.1m)



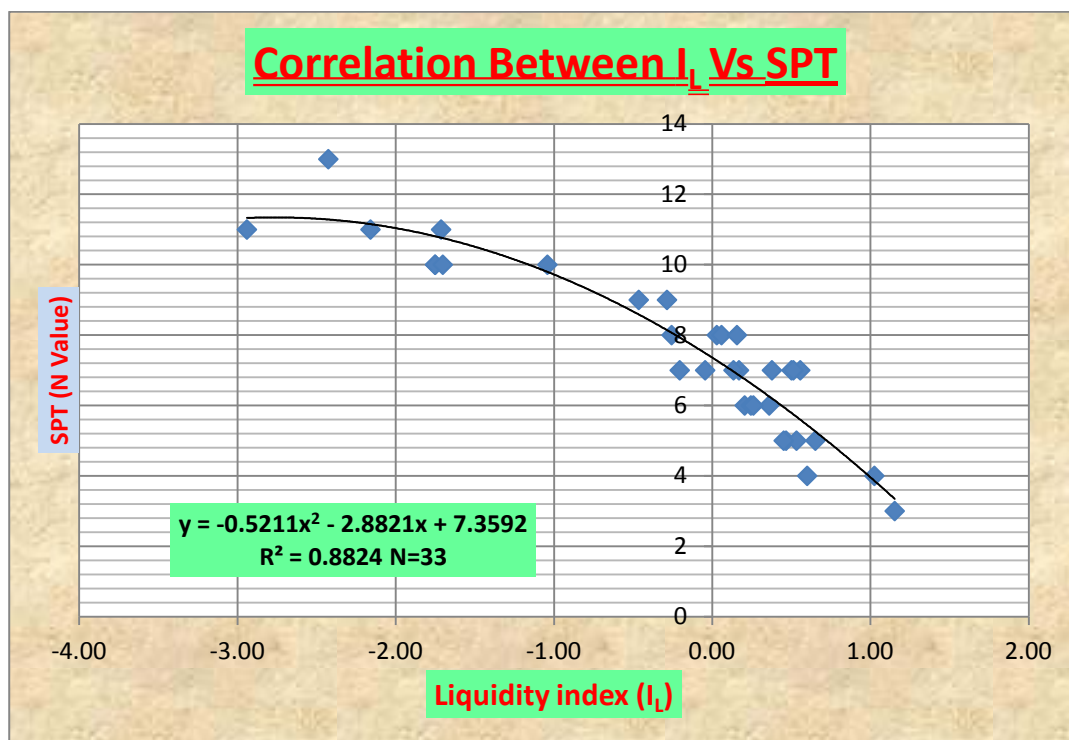
**Figure 25** Scatter plot and best-fit curve of plasticity Index and SPT for Silty Clay soil (at 1.5m-5.1m)

**Model 6: Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for Silty Clay soil (at depth 1.5m- 2.1m)**

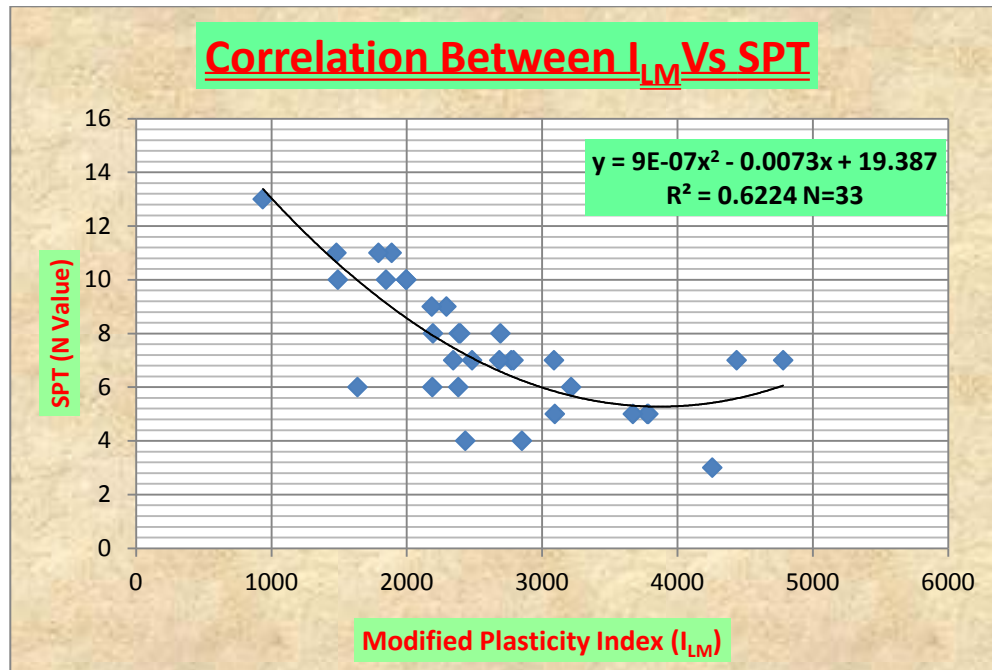
The resulting regression analysis after correlating SPT with  $I_L$ , Modified plasticity index and PI for 33 selected data of silty clay soil is expressed by the following regression equation with its corresponding correlation coefficients (Table 11):

Variable	Depth (m)	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs $I_L$	1.5m-2.1m	33	$N = -0.5211 I_L^2 - 2.8821 I_L + 7.3592$	$R^2 = 0.8824$
SPT Vs $I_{LM}$	1.5m-2.1m	33	$N = 9E-07 I_{LM}^2 - 0.0073 I_{LM} + 19.387$	$R^2 = 0.6224$
SPT Vs PI	1.5m-2.1m	33	$N = 0.0108 PI^2 - 0.8254 PI + 21.029$	$R^2 = 0.6709$

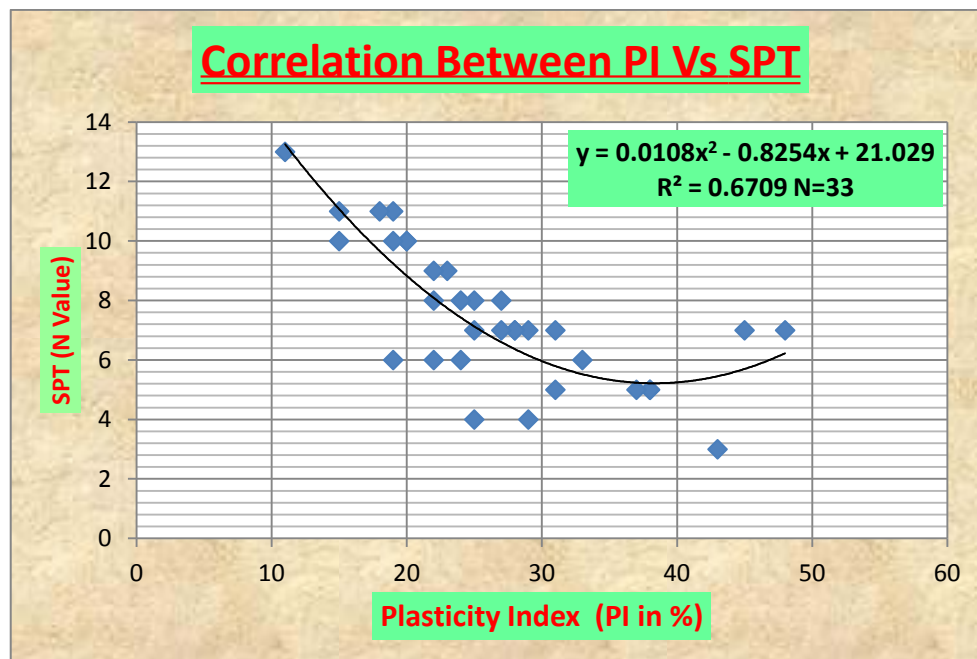
**Table 11** Correlation between Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for Silty Clay soil (at depth 1.5m- 2.1m)



**Figure 26** Scatter plot and best-fit curve of liquidity Index and SPT for Silty Clay soil (at 1.5m-2.1m)



**Figure 27** Scatter plot and best-fit curve of Modified Plasticity index and SPT for Silty Clay soil (at 1.5m-2.1m)



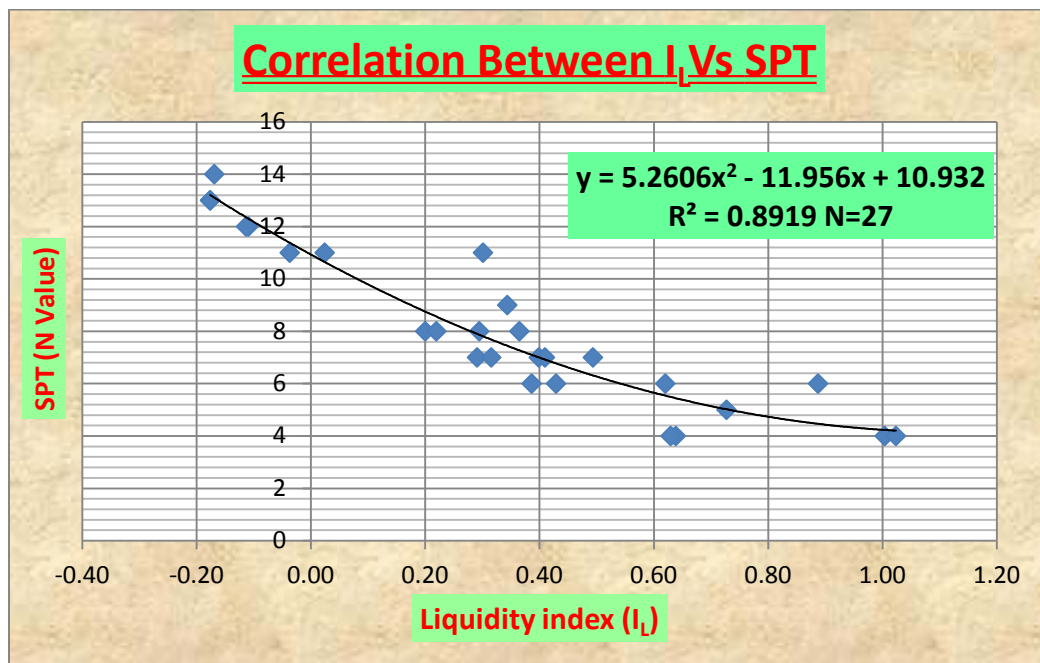
**Figure 28** Scatter plot and best-fit curve of plasticity Index and SPT for Silty Clay soil (at 1.5m-2.1m)

**Model 7: Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for Silty Clay soil (at depth 3.1m- 3.7m)**

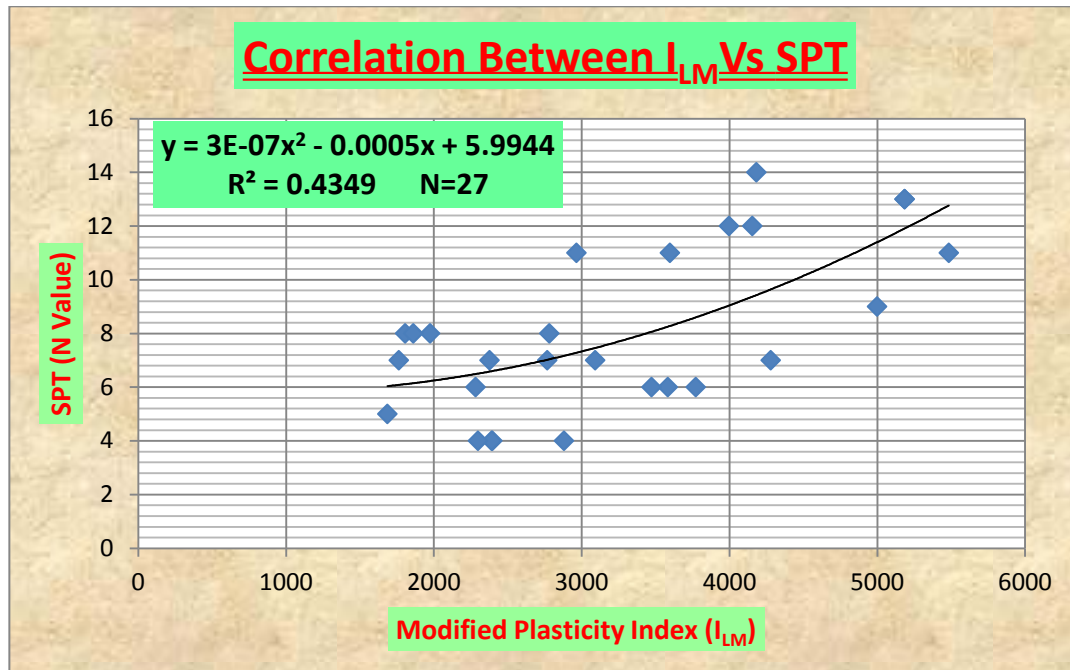
The resulting regression analysis after correlating SPT with  $I_L$ , Modified plasticity index and PI for 27 selected data of silty clay soil is expressed by the following regression equation with its corresponding correlation coefficients (Table 12):

Variable	Depth (m)	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs $I_L$	3.1m-3.7m	27	$N = 5.2606 I_L^2 - 11.956 I_L + 10.932$	$R^2 = 0.8919$
SPT Vs $I_{LM}$	3.1m-3.7m	27	$N = 3E-07 I_{LM}^2 - 0.0005 I_{LM} + 5.9944$	$R^2 = 0.4349$
SPT Vs PI	3.1m-3.7m	27	$N = 0.0042PI^2 - 0.1269PI + 7.1479$	$R^2 = 0.4516$

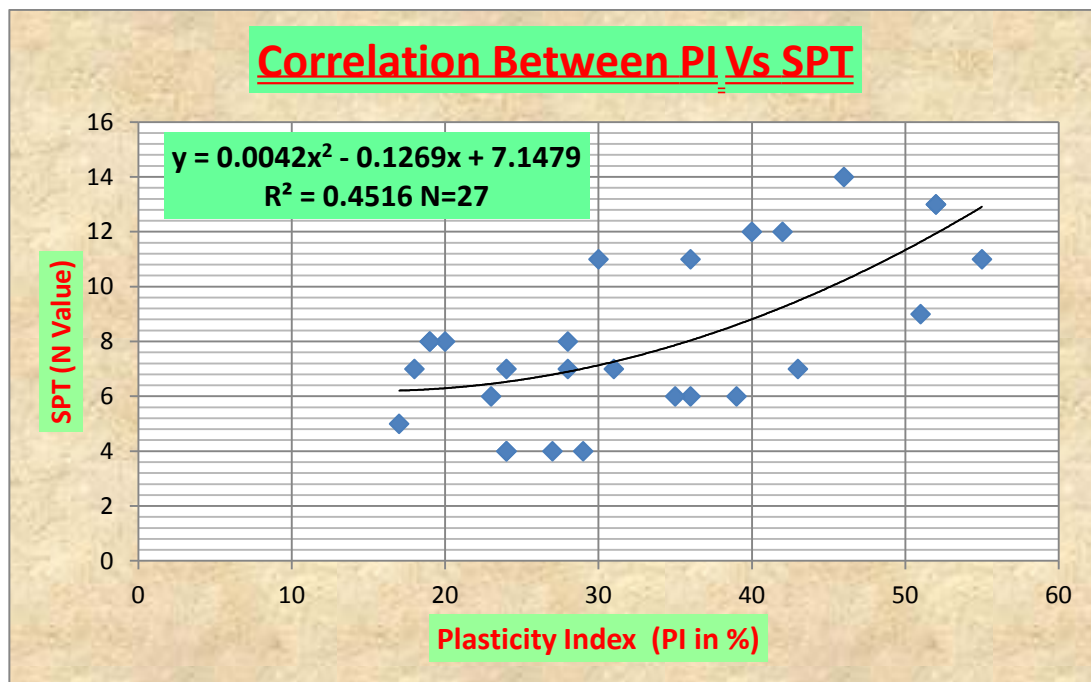
**Table 12** Correlation between Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for Silty Clay soil (at depth 3.1m- 3.7m)



**Figure 29** Scatter plot and best-fit curve of liquidity Index and SPT for Silty Clay soil (at 2.m-3.7m)



**Figure 30** Scatter plot and best-fit curve of Modified Plasticity index and SPT for Silty Clay soil (at 2.m-3.7m)



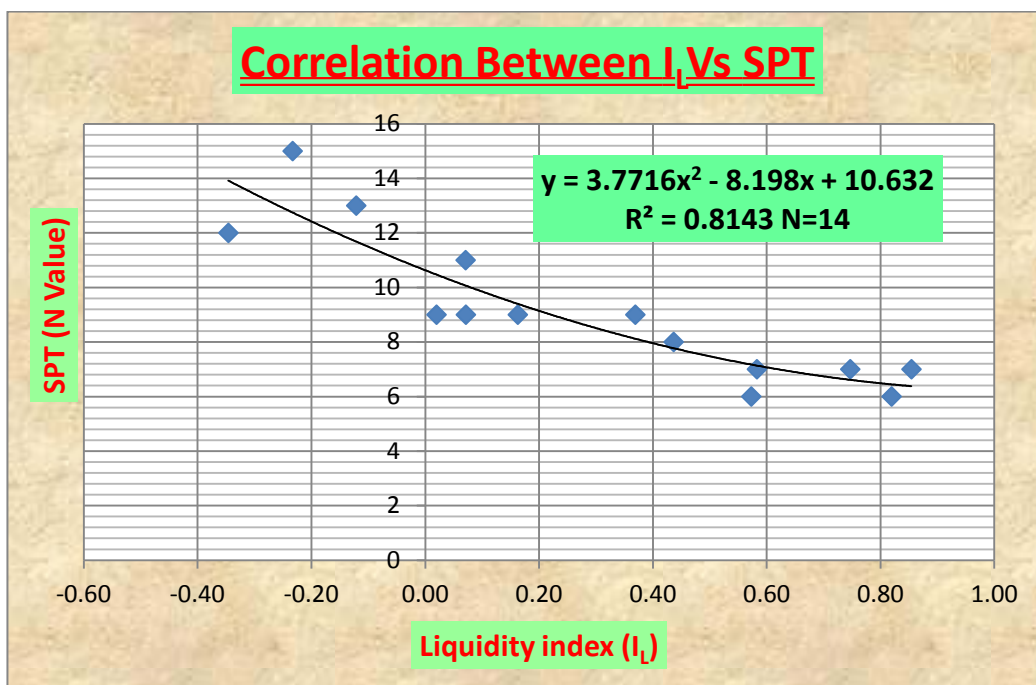
**Figure 31** Scatter plot and best-fit curve of plasticity Index and SPT for Silty Clay soil (at 2.m-3.7m)

### Model 8: Correlation of Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for Silty Clay soil (at depth 4.5m- 5.1m)

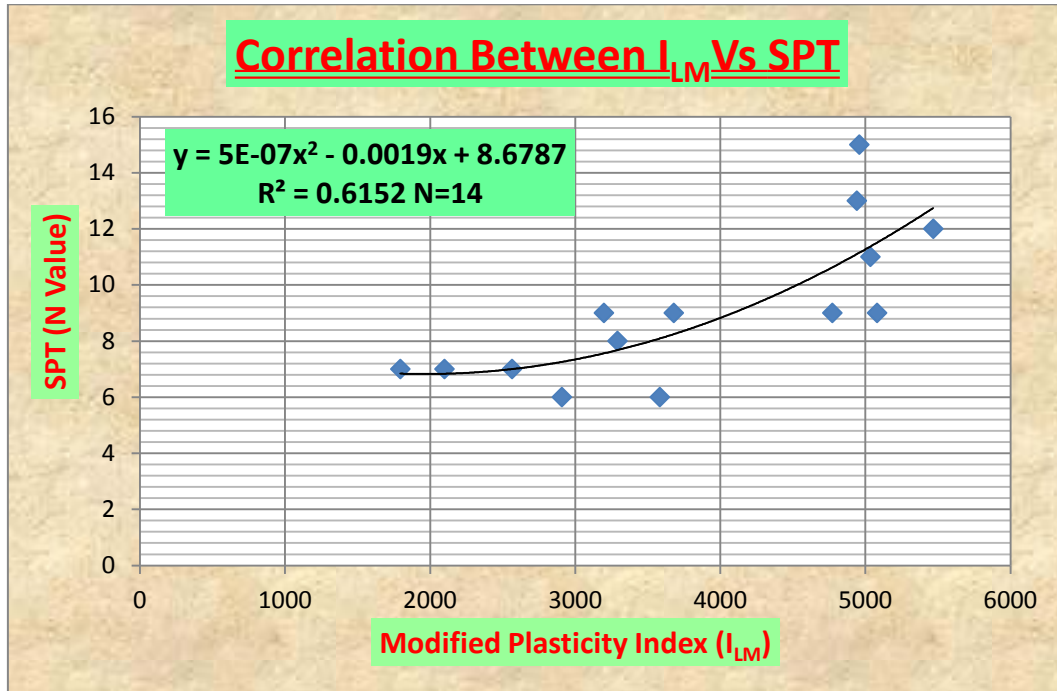
The resulting regression analysis after correlating SPT with  $I_L$ , Modified plasticity index and PI for 14 selected data of silty clay soil is expressed by the following regression equation with its corresponding correlation coefficients (Table 13):

Variable	Depth (m)	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs $I_L$	4.5m-5.1m	14	$N = 3.7716 I_L^2 - 8.198 I_L + 10.632$	$R^2 = 0.8143$
SPT Vs $I_{LM}$	4.5m-5.1m	14	$N = 5E-07 I_{LM}^2 - 0.0019 I_{LM} + 8.6787$	$R^2 = 0.6152$
SPT Vs PI	4.5m-5.1m	14	$N = 0.0067 PI^2 - 0.3362 PI + 11.072$	$R^2 = 0.653$

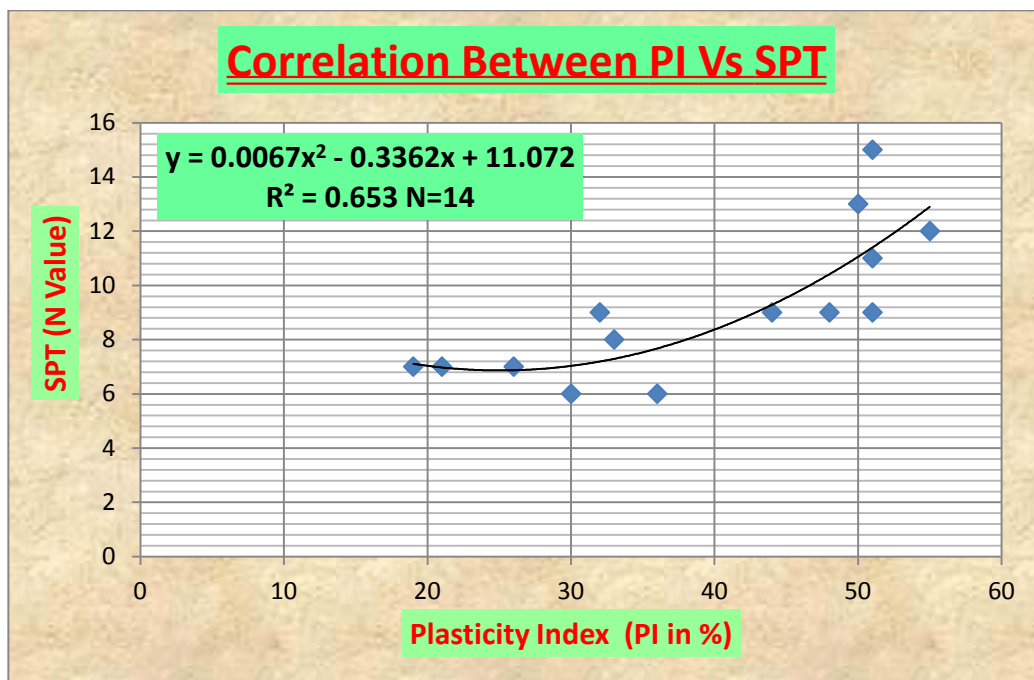
**Table 13** Correlation between Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for Silty Clay soil (at depth 4.5m- 5.1m)



**Figure 32** Scatter plot and best-fit curve of liquidity Index and SPT for Silty Clay soil (at 4.5m-5.1m)



**Figure 33** Scatter plot and best-fit curve of Modified Plasticity index and SPT for Silty Clay soil (at 4.5m-5.1m)



**Figure 34** Scatter plot and best-fit curve of plasticity Index and SPT for Silty Clay soil (at 4.5m-5.1m)

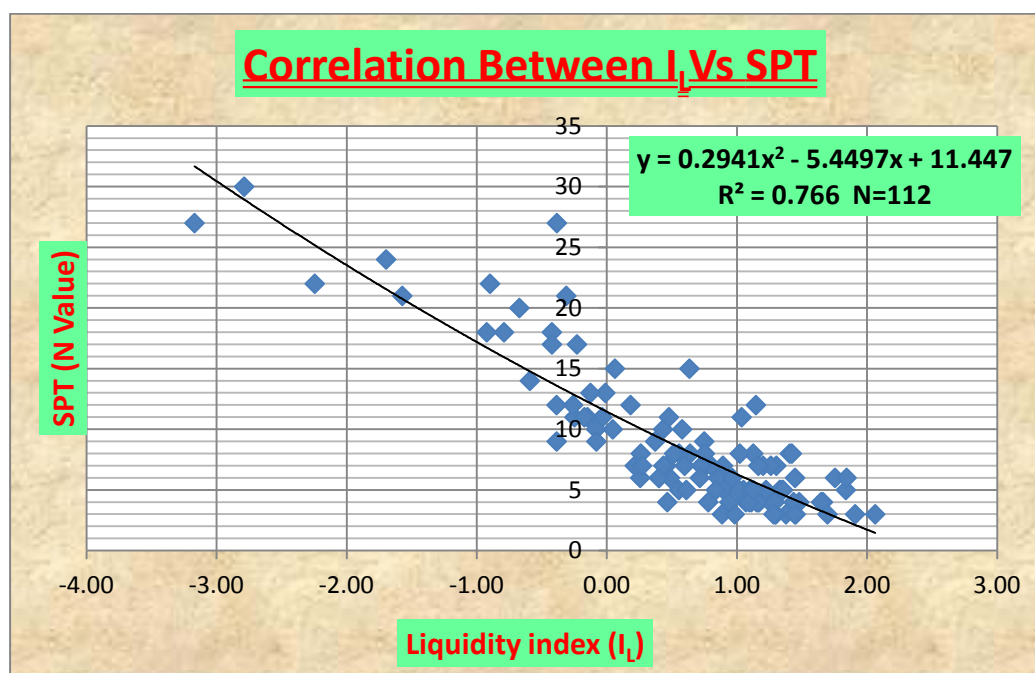
#### 4.4.2. Sandy Silt soil

##### **Model 9: Correlation of Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for Sandy Silt soil (at depth 1.5m-5.1m)**

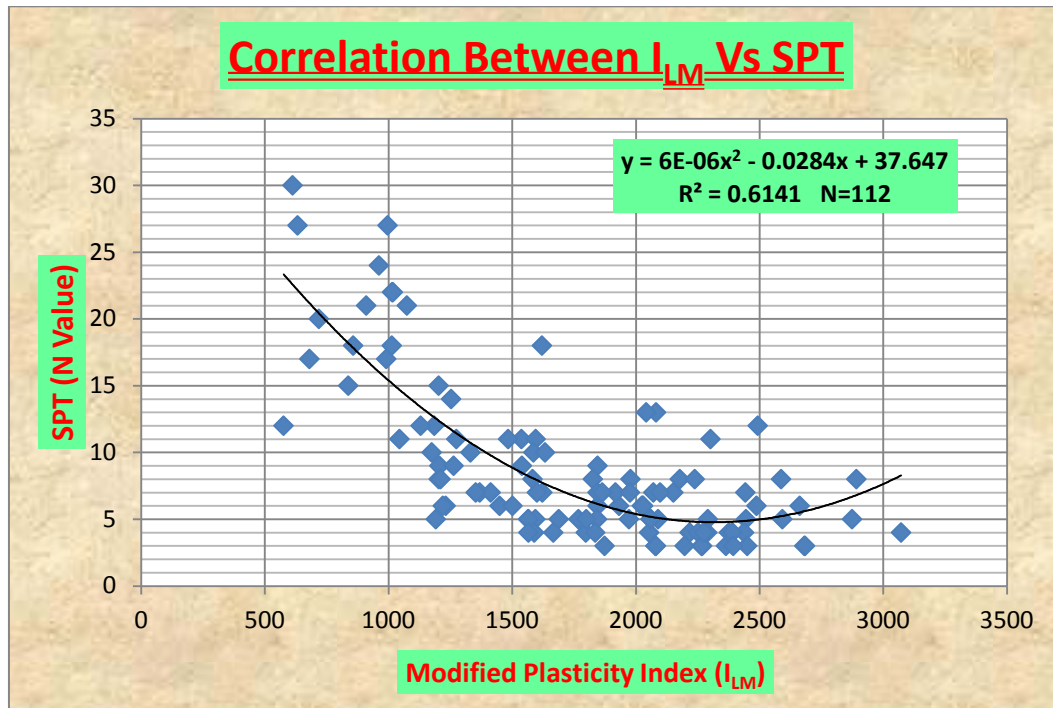
The resulting regression analysis after correlating SPT with  $I_L$ , Modified plasticity index and PI for 112 selected data of Sandy Silt soil is expressed by the following regression equation with its corresponding correlation coefficients (Table 14):

Variable	Depth (m)	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs $I_L$	1.5m-5.1m	112	$N = 0.2941 I_L^2 - 5.4497 I_L + 11.447$	$R^2 = 0.766$
SPT Vs $I_{LM}$	1.5m-5.1m	112	$N = 6E-06 I_{LM}^2 - 0.0284 I_{LM} + 37.647$	$R^2 = 0.6141$
SPT Vs PI	1.5m-5.1m	112	$N = 0.0845 PI^2 - 3.9789 PI + 51.502$	$R^2 = 0.6519$

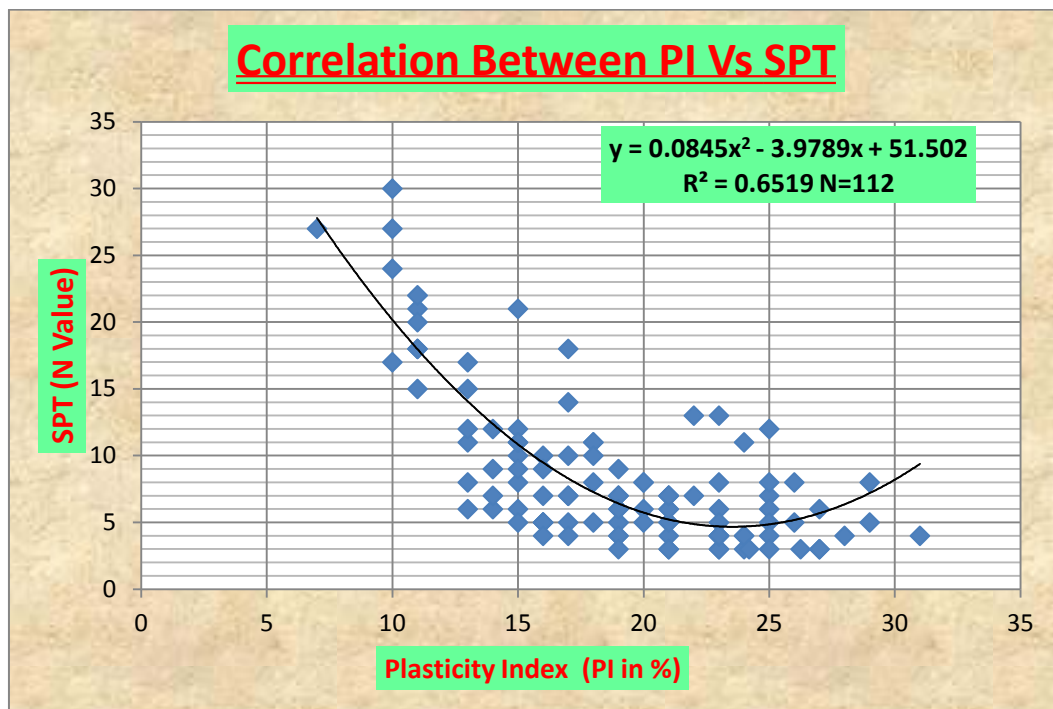
**Table 14** Correlation between Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for Sandy Silt soil (at depth 1.5m-5.1m)



**Figure 35** Scatter plot and best-fit curve of liquidity Index and SPT for Sandy Silt soil (at 1.5m-5.1m)



**Figure 36** Scatter plot and best-fit curve of Modified Plasticity index and SPT for Sandy Silt soil (at 1.5m-5.1m)



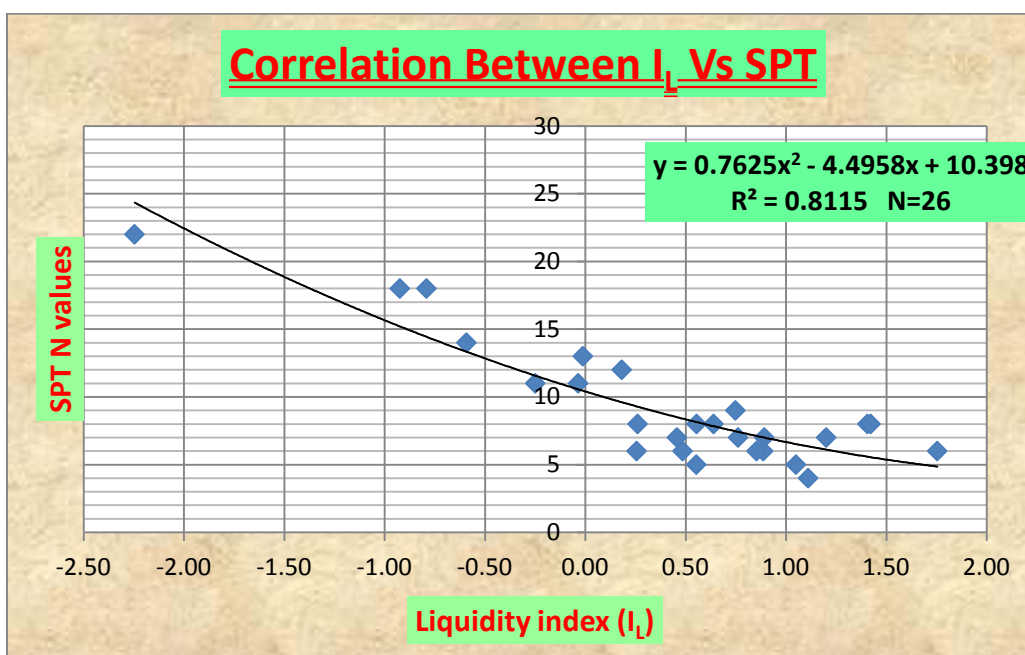
**Figure 37** Scatter plot and best-fit curve of plasticity Index and SPT for Sandy Silt soil (at 1.5m-5.1m)

**Model 10: Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for sandy silt soil (at depth 1.5m- 2.1m)**

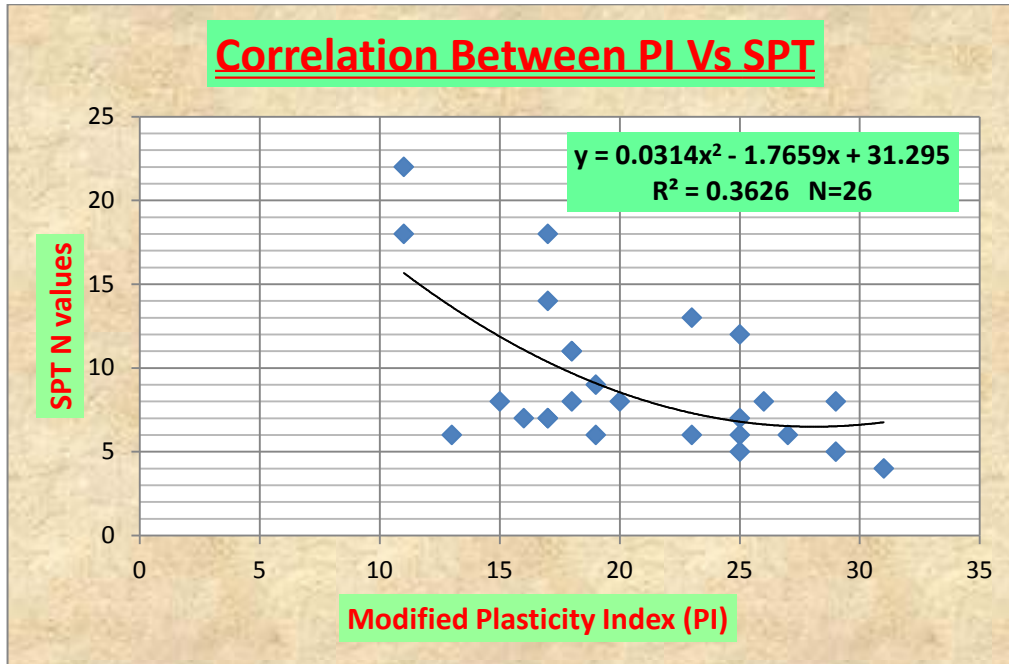
The resulting regression analysis after correlating SPT with  $I_L$ , Modified plasticity index and PI for 26 selected data of sandy silt soil is expressed by the following regression equation with its corresponding correlation coefficients (Table 15):

Variable	Depth (m)	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs $I_L$	1.5m-2.1m	26	$N = 0.7625 I_L^2 - 4.4958I_L + 10.398$	$R^2 = 0.8115$
SPT Vs $I_{LM}$	1.5m-2.1m	26	$N = 0.0314I_{LM}^2 - 1.7659I_{LM} + 31.295$	$R^2 = 0.3626$
SPT Vs PI	1.5m-2.1m	26	$N = 2359.8PI^{-0.751}$	$R^2 = 0.336$

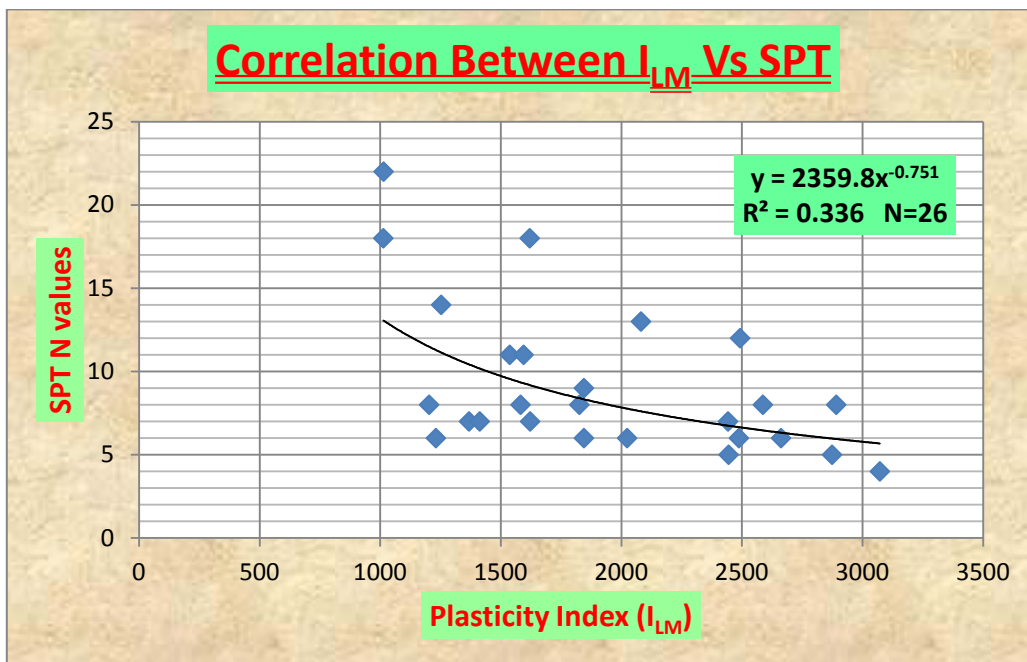
**Table 15** Correlation between Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for sandy silt soil (at depth 1.5m- 2.1m)



**Figure 38** Scatter plot and best-fit curve of liquidity Index and SPT for Sandy Silt soil (at 1.5m-2.1m)



**Figure 39** Scatter plot and best-fit curve of Modified plasticity Index and SPT for Sandy Silt soil (at 1.5m-2.1m)



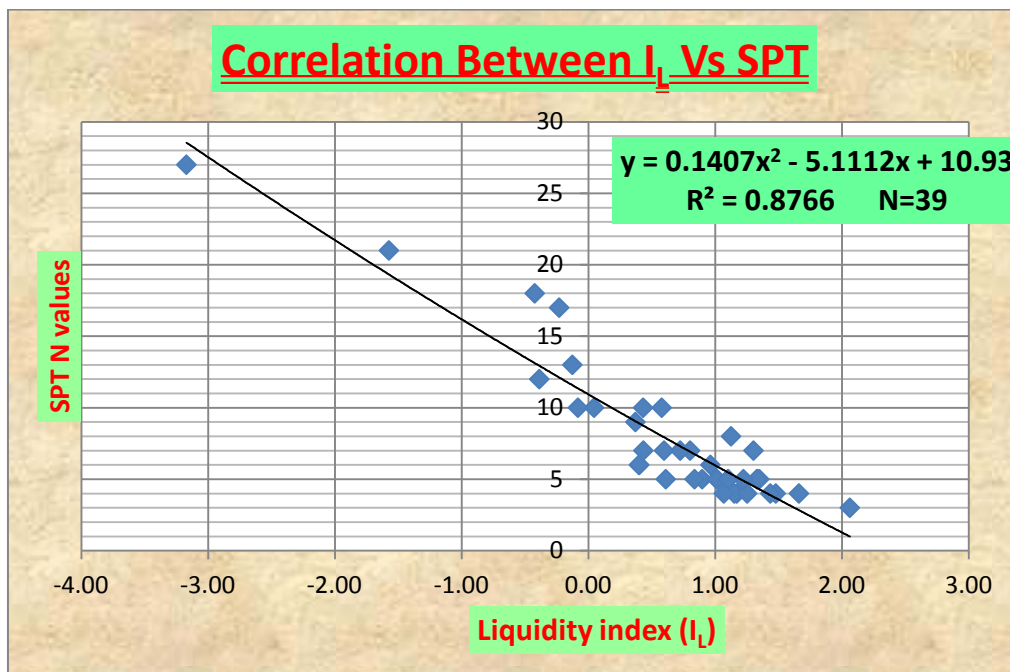
**Figure 40** Scatter plot and best-fit curve of plasticity Index and SPT for Sandy Silt soil (at 1.5m-2.1m)

**Model 11: Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for sandy silt soil (at depth 3.1m- 3.7m)**

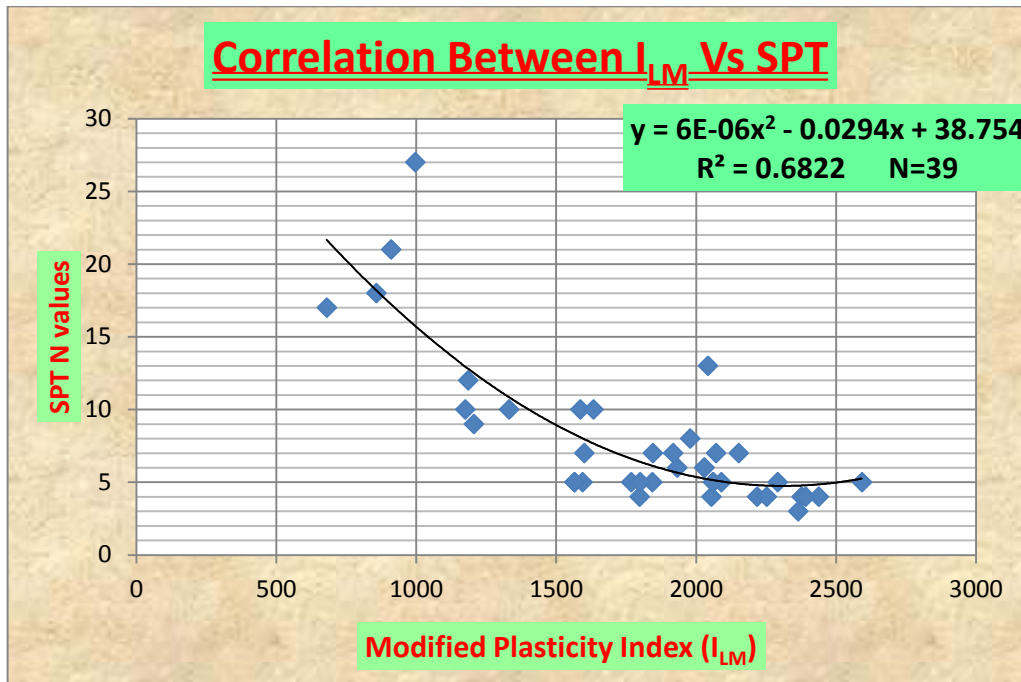
The resulting regression analysis after correlating SPT with  $I_L$ , Modified plasticity index and PI for 39 selected data of sandy silt soil is expressed by the following regression equation with its corresponding correlation coefficients (Table 16):

Variable	Depth (m)	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs $I_L$	3.1m- 3.7m	39	$N = 0.1407I_L^2 - 5.1112I_L + 10.93$	$R^2 = 0.8766$
SPT Vs $I_{LM}$	3.1m- 3.7m	39	$N = 6E-06I_{LM}^2 - 0.0294I_{LM} + 38.754$	$R^2 = 0.6822$
SPT Vs PI	3.1m- 3.7m	39	$N = 0.1051PI^2 - 4.7008PI + 57.427$	$R^2 = 0.7548$

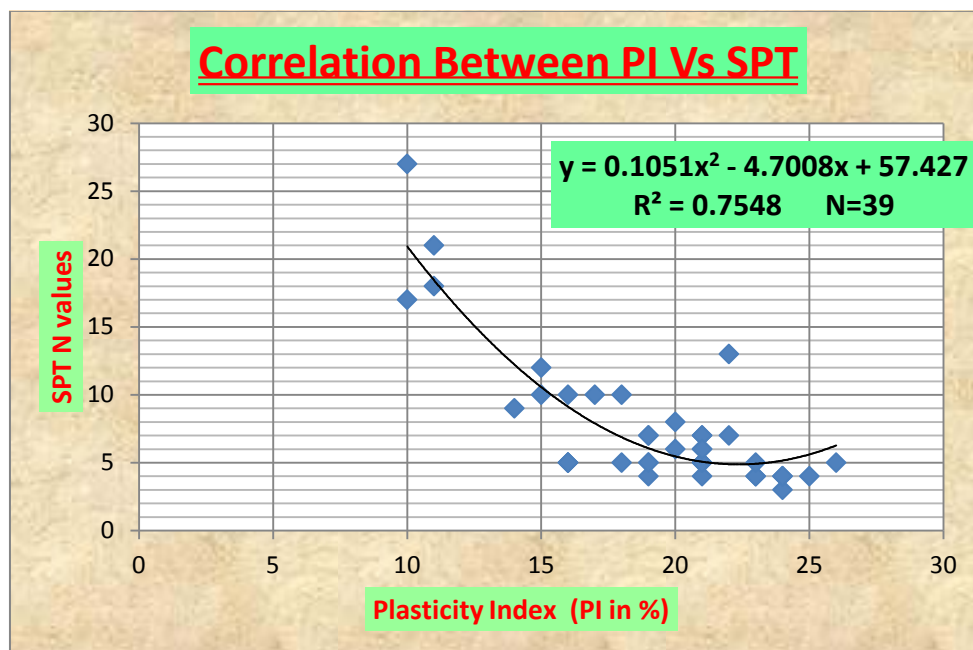
**Table 16** Correlation between Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for sandy silt soil (at depth 3.1m- 3.7m)



**Figure 41** Scatter plot and best-fit curve of liquidity Index and SPT for Sandy Silt soil (at 3.1m- 3.7m)



**Figure 42** Scatter plot and best-fit curve of Modified Plasticity index and SPT for Sandy Silt soil (at 3.1m- 3.7m)



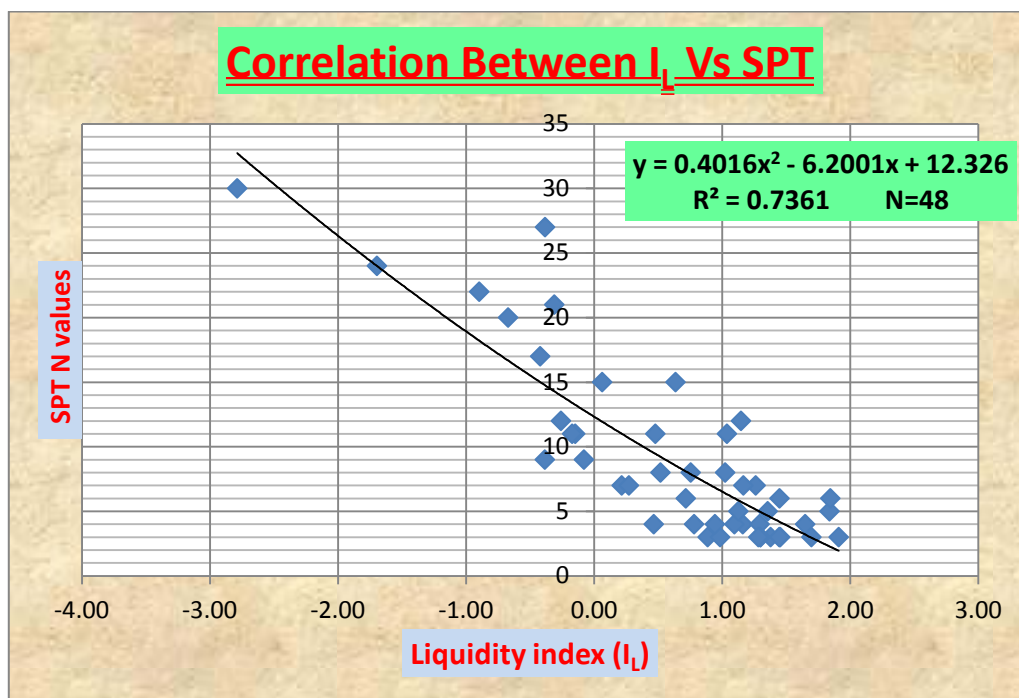
**Figure 43** Scatter plot and best-fit curve of Plasticity index and SPT for Sandy Silt soil (at 3.1m- 3.7m)

### Model 12: Correlation of Standard penetration numbers (SPT) with $I_L$ , $I_{LM}$ and PI for sandy silt soil (at depth 4.5m-5.1m)

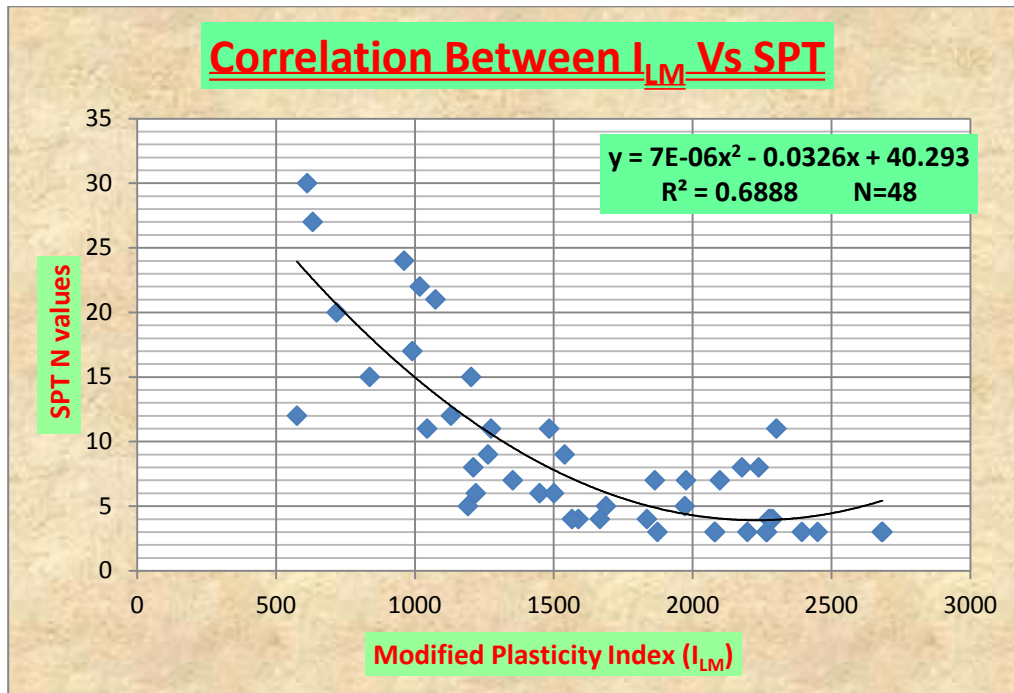
The resulting regression analysis after correlating SPT with  $I_L$ , Modified plasticity index and PI for 48 selected data of sandy silt soil is expressed by the following regression equation with its corresponding correlation coefficients (Table 17):

Variable	Depth (m)	No. of Data	Regression Equation	Coefficient of Regression ( $R^2$ )
SPT Vs $I_L$	3.1m- 3.7m	48	$N = 0.4016x^2 - 6.2001x + 12.326$	$R^2 = 0.7361$
SPT Vs $I_{LM}$	3.1m- 3.7m	48	$N = 7E-06x^2 - 0.0326x + 40.293$	$R^2 = 0.6888$
SPT Vs PI	3.1m- 3.7m	48	$N = 0.1065x^2 - 4.8465x + 58.673$	$R^2 = 0.7378$

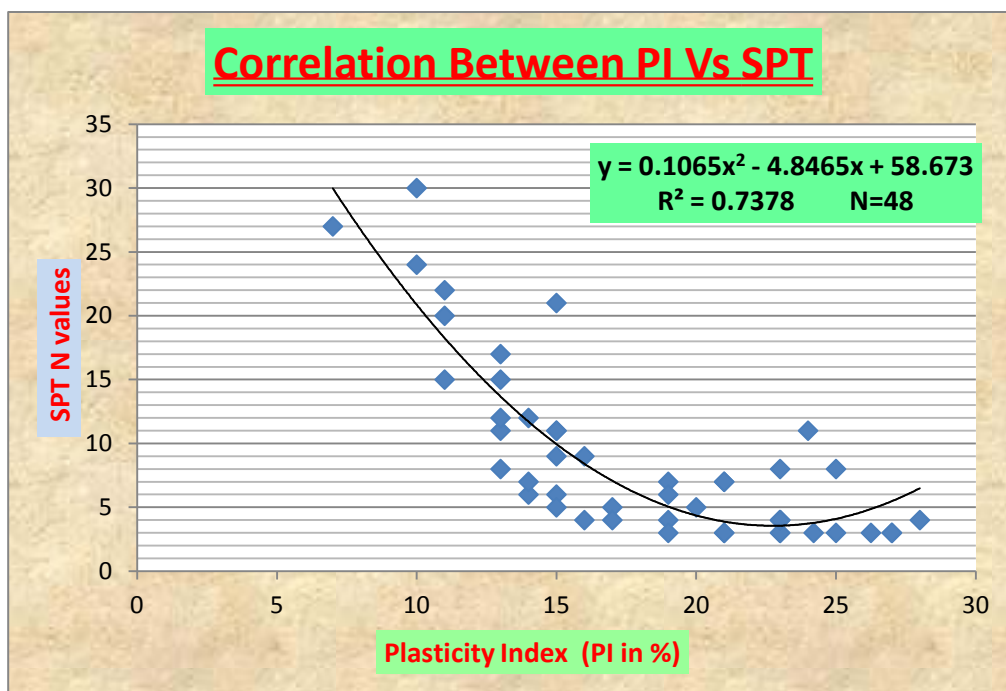
**Table 17** Correlation between Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI for sandy silt soil (at depth 4.5m-5.1m)



**Figure 44** Scatter plot and best-fit curve of liquidity index and SPT for Sandy Silt soil (at 4.5m- 5.1m)



**Figure 45** Scatter plot and best-fit curve of Modified Plasticity index and SPT for Sandy Silt soil (at 4.5m- 5.1m)



**Figure 46** Scatter plot and best-fit curve of plasticity Index and SPT for Sandy Silt soil (at 4.5m- 5.1m)

## 5. Summary of the Regression analysis and Comparison with Existing correlation

### 5.1. Correlation of Standard penetration numbers (SPT) with UCS ( $C_U$ ), $I_L$

#### 5.1.1. Silty Clay soil

Prediction of  $C_U$  from SPT,  $I_L$

Variable	No. of Data	Proposed Equation	Coefficient of Regression ( $R^2$ )
SPT Vs UCS	20	$C_U = 5.931N - 12.81$	$R^2 = 0.8819$
UCS Vs $I_L$	20	$C_U = 60.143I_L^2 - 77.589I_L + 40.971$	$R^2 = 0.8604$
SPT Vs PI	20	$N = 0.003PI^2 - 0.6696PI + 30.088$	$R^2 = 0.8431$

#### 5.1.2. Sandy Silt soil

Prediction of  $C_U$  from SPT,  $I_L$

Variable	No. of Data	Proposed Equation	Coefficient of Regression ( $R^2$ )
SPT Vs UCS	25	$N = 0.0073C_U^2 - 0.1331C_U + 4.3849$	$R^2 = 0.8963$
UCS Vs $I_L$	25	$C_U = 8.4445I_L^2 - 28.74I_L + 46.272$	$R^2 = 0.8515$
SPT Vs PI	20	$N = 0.003PI^2 - 0.6696PI + 30.088$	$R^2 = 0.8431$

### 5.2. Correlation of Standard penetration numbers (SPT) with the Index properties

#### 5.2.1. Silty Clay soil

The best relationship between SPT with  $I_L, I_{LM}$  and PI

Variable	Depth (m)	No. of Data	Proposed Equation	Coefficient of Regression (R <sup>2</sup> )
SPT Vs I <sub>L</sub>	2.5m- 3.0m	25	$N = 8.521 I_L^2 - 18.792 I_L + 15.165$	R <sup>2</sup> = 0.9201
SPT Vs I <sub>L</sub>	3.1m- 3.7m	39	$N = 0.1407 I_L^2 - 5.1112 I_L + 10.93$	R <sup>2</sup> = 0.8766
SPT Vs I <sub>LM</sub>	4.5m- 5.1m	48	$N = 7E-06 I_{LM}^2 - 0.0326 I_{LM} + 40.293$	R <sup>2</sup> = 0.6888
SPT Vs PI	3.1m- 3.7m	39	$N = 0.1051 PI^2 - 4.7008 PI + 57.427$	R <sup>2</sup> = 0.7548

### 5.2.2. Sandy Silt soil

The best relationship between SPT with I<sub>L</sub>, I<sub>LM</sub> and PI

Variable	Depth (m)	No. of Data	Single Linear Equation	Coefficient of Regression (R <sup>2</sup> )
SPT Vs I <sub>L</sub>	3.1m- 3.7m	39	$N = 0.1407 I_L^2 - 5.1112 I_L + 10.93$	R <sup>2</sup> = 0.8766
SPT Vs I <sub>LM</sub>	4.5m- 5.1m	48	$N = 7E-06 I_{LM}^2 - 0.0326 I_{LM} + 40.293$	R <sup>2</sup> = 0.6888
SPT Vs PI	3.1m- 3.7m	39	$N = 0.1051 PI^2 - 4.7008 PI + 57.427$	R <sup>2</sup> = 0.7548

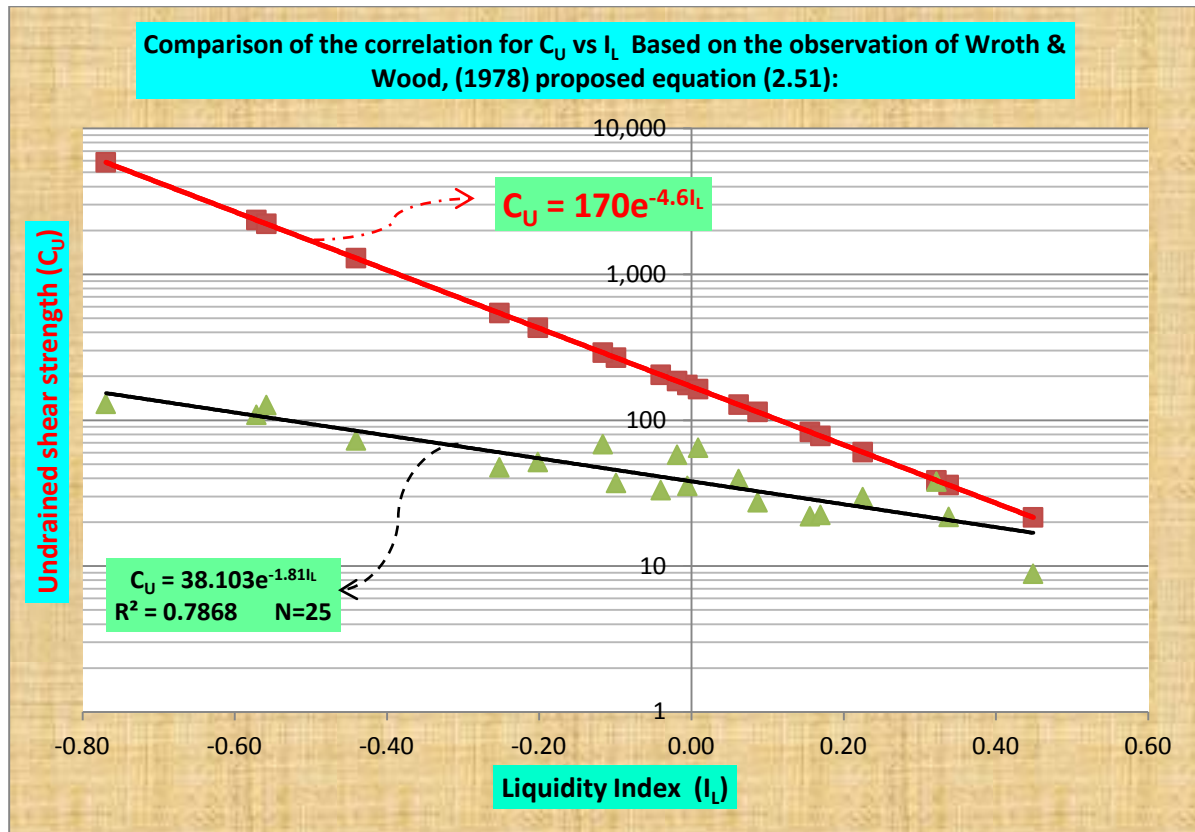
### 5.3. Comparison the resulting with existing correlation

#### 5.3.1. Comparison for correlation of SPT (N'<sub>70</sub>) Vs. q<sub>u</sub> in the general form

Previous correlation		The best scenario Correlation find (C <sub>u</sub> =5.931N-12.81)	The list Correlation find (C <sub>u</sub> =3.96N <sup>0.9985</sup> )
N' <sub>70</sub>	q <sub>u</sub> (Kpa)	q <sub>u</sub> (Kpa)	q <sub>u</sub> (Kpa)
0 - 2	<25	<10	<16
3 - 5	25-50	10-34	16-24
6 - 9	50-100	46-81	47-71
10 - 16	100-200	91-164	79-126
17 - 30	200-400	176-330	134-236
>30	>400	>330	>236

#### 5.3.2. Comparison for correlation of C<sub>u</sub> Vs. I<sub>L</sub> based on the observation of Wroth & Wood, (1978) eq (2.51) [22]:

$$C_u = 170e^{-4.6I_L} = 1.7 \times 10^2(1-I_L) \quad \text{kPa}$$



**Figure 47** Comparison of the correlation for  $C_U$  vs  $I_L$  based on the observation of Wroth & Wood, (1978) proposed equation.

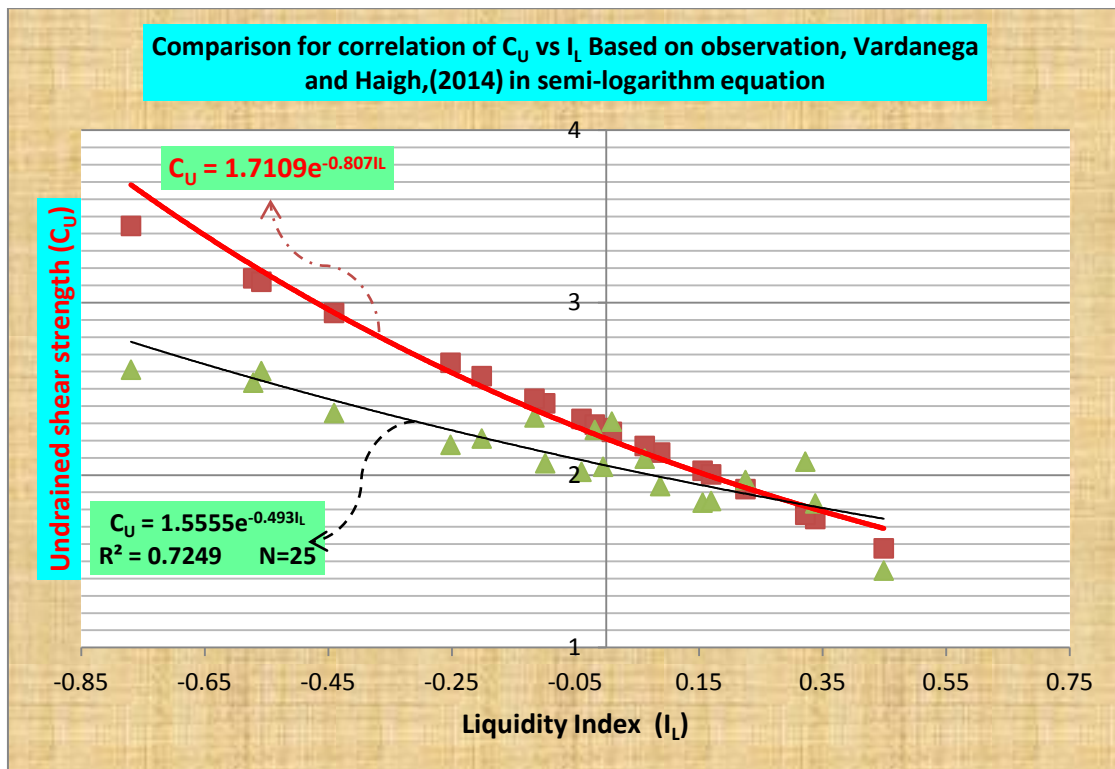
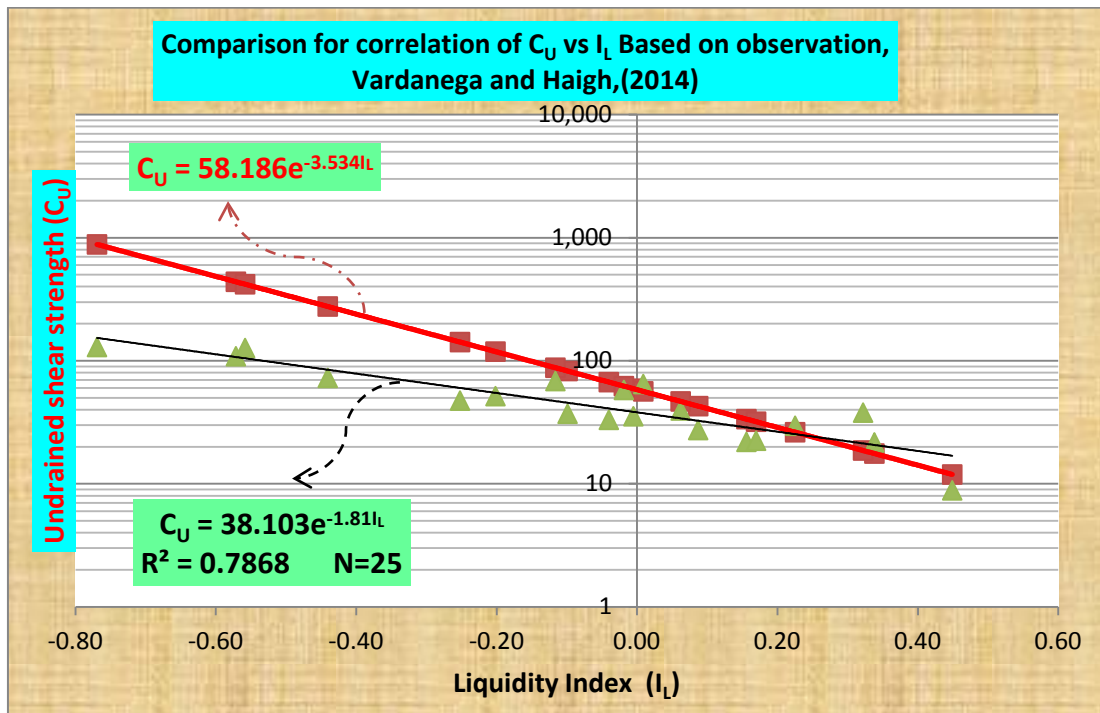
The Undrained shear strength has strong correlation with liquidity index and the best fitting equation by comparing with the observation of **Wroth and Wood** (1978) can be

$$C_U = 170e^{-4.6I_L} \quad R^2 = 1 \quad \text{by Wroth and Wood (1978)}$$

$$C_U = 40e^{-3.8I_L} \quad R^2 = 1 \quad \text{by this study}$$

**Comparison for the correlation for  $C_U$  vs.  $I_L$  with Semi-logarithmic relationship as it was proposed by Vardanega and Haigh, (2014) [8]**

$$I_L = 1.150 - 0.283 \ln(C_U) \quad \Longleftrightarrow \quad C_U = e^{3.5336(1.15 - I_L)}$$



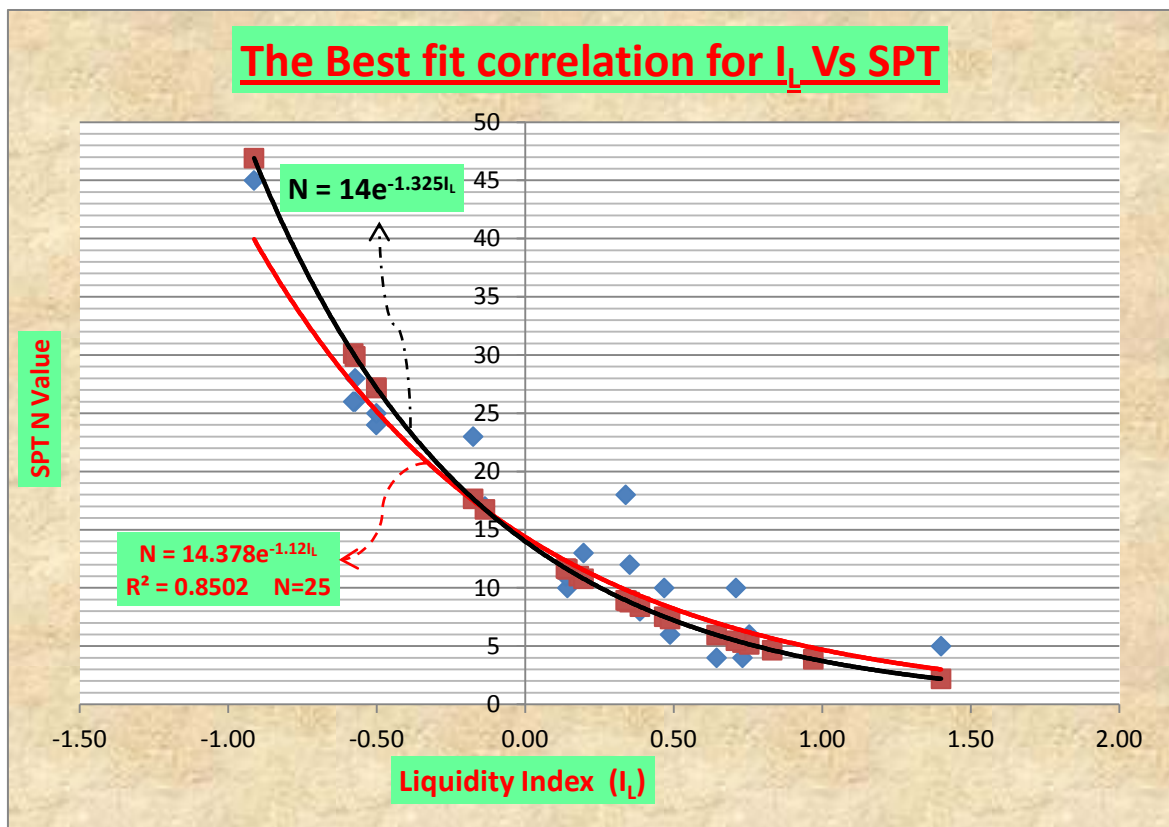
**Figure 48** Comparison of the correlation of  $C_U$  vs.  $I_L$  with normal coordinate and semi-logarithmic

The Undrained shear strength has strong correlation with liquidity index and the best fitting equation by comparing with the observation of **Vardanega and Haigh, (2014)** can be

$$C_u = 58.186e^{-3.534I_L} \quad R^2 = 1 \quad \text{by Vardanega and Haigh, (2014)}$$

$$C_u = 35e^{-3.25I_L} \quad R^2 = 1 \quad \text{by this study}$$

### 5.3.3. The best fit equation for the correlation of $I_L$ vs. SPT



**Figure 49** The best fit equation for the correlation of  $I_L$  vs. SPT

The Standard penetration number (N) has strong correlation with liquidity index and the best fit equation for this study can be

$$SPT = 14e^{-1.325I_L}$$

$$R^2 = 1$$

## 6. Conclusion and Recommendation

### 6.1. Conclusion

The independent project was conducted to find a suitable correlation between undrained compressive strength (UCS) and Standard penetration number, and index properties, liquidity index and modified plasticity index was carried out using the selected 112 borehole data's.

The following results are concluded based on the results and on the discussion and analysis presented in this independent project:

1. Among the single linear regression analysis the correlation between  $C_U$  and SPT,  $I_L$  of Silty Clay soil has resulted the following relationship

$$C_U = 5.931 \cdot N - 12.81 \quad R^2 = 0.8819 \quad n=20$$

$$C_U = 60.143 \cdot I_L^2 - 77.589 \cdot I_L + 40.971 \quad R^2 = 0.8604 \quad n=20$$

$$N = 0.003 \cdot PI^2 - 0.6696 \cdot PI + 30.088 \quad R^2 = 0.8431 \quad n=20$$

2. Among the single linear regression analysis the correlation between  $C_U$  and SPT,  $I_L$  of Sandy Silt soil has resulted the following relationship

$$N = 0.0073 \cdot C_U^2 - 0.1331 \cdot C_U + 4.3849 \quad R^2 = 0.8963 \quad n=25$$

$$C_U = 8.4445 \cdot I_L^2 - 28.74 \cdot I_L + 46.272 \quad R^2 = 0.8515 \quad n=25$$

$$N = 0.003 \cdot PI^2 - 0.6696 \cdot PI + 30.088 \quad R^2 = 0.8431 \quad n=25$$

3. Among the single linear regression analysis the correlation between SPT and,  $I_L$ ,  $I_{LM}$ , PI of Silty Clay soil has resulted the following relationship

$$N = 0.1407 \cdot I_L^2 - 5.1112 \cdot I_L + 10.93 \quad R^2 = 0.8766 \quad n=25$$

$$N = 7E-06 \cdot I_{LM}^2 - 0.0326 \cdot I_{LM} + 40.293 \quad R^2 = 0.6888 \quad n=48$$

$$N = 0.105 \cdot PI^2 - 4.7008 \cdot PI + 57.427 \quad R^2 = 0.7548 \quad n=39$$

4. Among the single linear regression analysis the correlation between SPT and,  $I_L$ ,  $I_{LM}$ , PI of Sandy Silt soil has resulted the following relationship

$$N = 8.521 \cdot I_L^2 - 18.792 \cdot I_L + 15.165 \quad R^2 = 0.9201 \quad n=25$$

$$N = 7E-06 \cdot I_{LM}^2 - 0.0326 \cdot I_{LM} + 40.293 \quad R^2 = 0.6888 \quad n=48$$

$$N = 0.105 \cdot PI^2 - 4.7008 \cdot PI + 57.427 \quad R^2 = 0.7548 \quad n=39$$

5. The standard penetration test (SPT) is strongly reliable in predicting of shear strength parameter of fine grained soils.

6. The Undrained shear strength of fine grained soil has strong correlation with liquidity index and more reliable at higher degree of saturation than at lower degree of saturation.
7. The standard penetration test (SPT) has more relation with the liquidity index of fine grained soils.

## **6.2. Recommendation**

In trying to conduct the independent project has uncovered areas where further efforts may be proved in the future. Following are some of the recommendations in relation to the subject study:

1. It is recommended to carry out farther correlation study in the area where mass condominium construction site, since they conducted a large number of soil investigation within a limited area.
2. It is also recommended to carry out such a study in other parts of Ethiopia especially in regions where mass condominium buildings to be constructed.
3. Further, it is advisable to study the correlation between index properties and swelling potential of the highly plastic silty clay soil.
4. It would be more interest to investigate the correlation study using other software.

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**Appendix A-1: Single Linear Regression Analysis Data**

**Silty clay and Sandy silt****Model 1: Data for Correlation of Standard penetration numbers (SPT) with UCS (C<sub>u</sub>), I<sub>L</sub> and PI, (at depth 2.5m-3.0m)**

Sample No.	BH-ID	D Depth below (G.S) (m)	SPT N	Corrected SPT N70	LL (%)	PL (%)	PI (%)	q ,Kpa	C ,Kpa	USCS	NMC%	G <sub>s</sub>	Liquidity Index (IL)	S (Degree of Saturation)
1	BH-1	2.50-3.00	13	13	83	51	32	94.90	47.45	CH	42.93	2.62	-0.25	91.9
2	BH-2	2.50-3.00	12	12	86	46	40	70.80	35.40	CH	45.79	2.346	-0.01	95.3
3	BH-3	2.50-3.00	6	6	94	48	46	66.20	33.10	CH	46.15	2.62	-0.04	95.0
4	BH-5	2.50-3.00	12	12	82	40	42	103.20	51.60	CH	31.53	2.62	-0.20	60.3
5	BH - 25	2.50-3.00	4	4	82	38	44	54.70	27.35	CH	41.83	2.59	0.09	83.1
6	BH - 26	2.50-3.00	4	4	91	46	45	43.86	21.93	CH	53.01	2.62	0.16	93.6
7	BH - 34	2.50-3.10	6	6	74	38	36	43.40	21.70	CH	50.17	2.61	0.34	86.8
8	BH - 45	2.50-3.00	4	4	85	38	47	17.70	8.85	CH	59.10	2.62	0.45	99.7
9	BH - 46	2.50-3.00	8	8	80	37	43	129.36	64.68	CH	37.38	2.64	0.01	85.9
10	BH-83	2.50-3.10	9	9	80	39	41	75.80	37.90	CH	52.20	2.63	0.32	94.7
11	BH -87	2.50-3.10	8	8	72	34	38	78.90	39.45	CH	36.36	2.64	0.06	60.5
12	BH - 99	2.50-3.10	5	5	79	35	44	44.80	22.40	CH	42.46	2.64	0.17	90.8
13	BH - 101	2.50-3.00	23	22	45	31	14	217.60	108.80	CH	23.00	2.64	-0.57	70.3
14	BH - 195	2.50-3.00	14	13	50	26	24	115.80	57.90	CL	25.55	2.63	-0.02	55.4
15	BH - 196	2.50-3.00	28	8	68	29	39	74.20	37.10	CH	25.14	2.65	-0.10	67.3
16	BH - 212	2.50-3.00	27	25	42	28	14	258.66	129.33	CH	17.23	2.64	-0.77	50.9
17	BH - 223	2.50-3.00	26	21	38	26	12	253.80	126.90	CL	19.30	2.63	-0.56	64.2
18	BH - 230	2.50-3.10	11	14	74	40	34	145.10	72.55	CH	25.02	2.63	-0.44	67.5
19	BH - 231	2.50-3.10	16	16	46	27	19	136.80	68.40	CL	24.79	2.63	-0.12	58.8
20	BH - 235	2.50-3.00	9	9	72	37	35	59.30	29.65	CH	44.88	2.63	0.23	95.4
21	BH-4	2.50-3.00	8	8	67	45	22	47.80	23.90	MH	53.50	2.65	0.39	98.2
22	BH-6	2.50-3.00	11	11	54	41	13	80.20	40.10	ML	43.35	2.64	0.18	93.9
23	BH-7	2.50-3.10	27	26	44	31	13	120.30	60.15	MH	23.56	2.62	-0.57	50.9
24	BH-8	2.50-3.10	10	10	48	32	16	67.10	33.55	ML	39.49	2.61	0.47	90.5
25	BH-16	2.60-3.20	5	5	58	33	25	40.30	20.15	ML	53.79	2.59	0.83	96.7
26	BH - 27	2.50-3.00	4	4	75	39	36	40.60	20.30	MH	65.34	2.63	0.73	93.8
27	BH - 33	2.50-3.10	10	10	64	41	23	89.60	44.80	MH	44.27	2.64	0.14	76.7
28	BH - 48	2.50-3.00	9	9	62	38	24	90.20	45.10	MH	46.23	2.61	0.34	79.6
29	BH - 57	2.50-3.00	12	12	52	37	15	73.40	36.70	MH	42.28	2.59	0.35	86.3
30	BH - 77	2.50-3.10	20	18	37	24	13	80.90	40.45	ML	28.40	2.62	0.34	66.3
31	BH - 80	2.50-3.10	27	26	49	35	14	141.40	70.70	MH	26.90	2.63	-0.58	54.5
32	BH - 81	2.50-3.10	6	6	59	36	23	70.40	35.20	MH	53.35	2.64	0.75	96.7
33	BH - 92	2.50-3.00	25	24	55	40	20	115.80	57.90	MH	29.98	2.64	-0.50	87.9
34	BH - 93	2.50-3.00	26	25	49	34	15	109.00	54.50	MH	26.49	2.63	-0.50	55.4
35	BH - 94	2.50-3.00	6	6	65	42	23	44.20	22.10	MH	53.22	2.64	0.49	94.1
36	BH - 96	2.50-3.00	29	28	46	33	13	136.80	68.40	MH	25.56	2.62	-0.57	60.5
37	BH - 162	2.50-3.10	57	45	53	38	15	165.50	82.75	MH	24.31	2.63	-0.91	50.7
38	BH - 168	4.00-4.50	5	5	58	32	26	45.70	22.85	ML	68.40	2.63	1.40	99.0
39	BH - 169	2.50-3.00	4	4	56	30	26	55.90	27.95	ML	55.22	2.60	0.97	90.3
40	BH - 173	4.00-4.50	11	11	72	48	24	93.80	46.90	MH	51.30	2.62	0.14	86.0
41	BH - 175	2.50-3.00	4	4	55	31	24	78.40	39.20	MH	46.47	2.64	0.64	77.8
42	BH - 181	2.50-3.00	23	23	51	35	16	115.80	57.90	MH	32.20	2.62	-0.18	88.0
43	BH - 189	2.50-3.00	10	10	51	29	22	80.80	40.40	ML	44.61	2.63	0.71	85.4
44	BH - 194	2.50-3.10	19	17	60	39	21	98.10	49.05	MH	36.16	2.63	-0.14	62.6
45	BH - 209	2.50-3.00	13	13	52	37	15	89.93	44.97	MH	39.95	2.63	0.20	94.8

**Silty Clay soil**

**Model 2: Data for Correlation of Standard penetration numbers (SPT) with UCS (C<sub>u</sub>), I<sub>L</sub> and PI, (at depth 2.5m-3.0m)**

BH-ID	D Depth below (G.S) (m)	SPT N	Correcte d SPT N70	LL (%)	PL (%)	PI (%)	q ,Kpa	C ,Kpa	USCS	NMC%	Liquidity Index (I <sub>L</sub> )
BH-1	2.50-3.00	13	13	83	51	32	94.90	47.45	CH	42.93	-0.25
BH-2	2.50-3.00	12	12	86	46	40	70.80	35.40	CH	45.79	-0.01
BH-3	2.50-3.00	6	6	94	48	46	66.20	33.10	CH	46.15	-0.04
BH-5	2.50-3.00	12	12	82	40	42	103.20	51.60	CH	31.53	-0.20
BH - 25	2.50-3.00	4	4	82	38	44	54.70	27.35	CH	41.83	0.09
BH - 26	2.50-3.00	4	4	91	46	45	43.86	21.93	CH	53.01	0.16
BH - 34	2.50-3.10	6	6	74	38	36	43.40	21.70	CH	50.17	0.34
BH - 45	2.50-3.00	4	4	85	38	47	17.70	8.85	CH	59.10	0.45
BH - 46	2.50-3.00	8	8	80	37	43	129.36	64.68	CH	37.38	0.01
BH-83	2.50-3.10	9	9	80	39	41	75.80	37.90	CH	52.20	0.32
BH -87	2.50-3.10	8	8	72	34	38	78.90	39.45	CH	36.36	0.06
BH - 99	2.50-3.10	5	5	79	35	44	44.80	22.40	CH	42.46	0.17
BH - 101	2.50-3.00	23	22	45	31	14	217.60	108.80	CH	23.00	-0.57
BH - 195	2.50-3.00	14	13	50	26	24	115.80	57.90	CL	25.55	-0.02
BH - 196	2.50-3.00	28	8	68	29	39	74.20	37.10	CH	25.14	-0.10
BH - 212	2.50-3.00	27	25	42	28	14	258.66	129.33	CH	17.23	-0.77
BH - 223	2.50-3.00	26	21	38	26	12	253.80	126.90	CL	19.30	-0.56
BH - 230	2.50-3.10	11	14	74	40	34	145.10	72.55	CH	25.02	-0.44
BH - 231	2.50-3.10	16	16	46	27	19	136.80	68.40	CL	24.79	-0.12
BH - 235	2.50-3.00	9	9	72	37	35	59.30	29.65	CH	44.88	0.23

**Sandy Silt soil**

**Model 3: Data for Correlation of Standard penetration numbers (SPT) with UCS (C<sub>u</sub>), I<sub>L</sub> and PI, (at depth 2.5m-3.0m)**

Sample No.	BH-ID	D Depth below (G.S) (m)	SPT N	Corrected SPT N70	LL (%)	PL (%)	PI (%)	q ,Kpa	C ,Kpa	USCS	NMC%	Gs	Liquidity Index (IL)
1	BH-4	2.50-3.00	8	8	67	45	22	47.80	23.90	MH	53.50	2.65	0.39
2	BH-6	2.50-3.00	11	11	54	41	13	80.20	40.10	ML	43.35	2.64	0.18
3	BH-7	2.50-3.10	27	26	44	31	13	120.30	60.15	MH	23.56	2.62	-0.57
4	BH-8	2.50-3.10	10	10	48	32	16	67.10	33.55	ML	39.49	2.61	0.47
5	BH-16	2.60-3.20	5	5	58	33	25	40.30	20.15	ML	53.79	2.59	0.83
6	BH - 27	2.50-3.00	4	4	75	39	36	40.60	20.30	MH	65.34	2.63	0.73
7	BH - 33	2.50-3.10	10	10	64	41	23	89.60	44.80	MH	44.27	2.64	0.14
8	BH - 48	2.50-3.00	9	9	62	38	24	90.20	45.10	MH	46.23	2.61	0.34
9	BH - 57	2.50-3.00	12	12	52	37	15	73.40	36.70	MH	42.28	2.59	0.35
10	BH - 77	2.50-3.10	20	18	37	24	13	80.90	40.45	ML	28.40	2.62	0.34
11	BH - 80	2.50-3.10	27	26	49	35	14	141.40	70.70	MH	26.90	2.63	-0.58
12	BH - 81	2.50-3.10	6	6	59	36	23	70.40	35.20	MH	53.35	2.64	0.75
13	BH - 92	2.50-3.00	25	24	60	40	20	115.80	57.90	MH	29.98	2.64	-0.50
14	BH - 93	2.50-3.00	26	25	49	34	15	109.00	54.50	MH	26.49	2.63	-0.50
15	BH - 94	2.50-3.00	6	6	65	42	23	44.20	22.10	MH	53.22	2.64	0.49
16	BH - 96	2.50-3.00	29	28	46	33	13	136.80	68.40	MH	25.56	2.62	-0.57
17	BH - 162	2.50-3.10	57	45	53	38	15	165.50	82.75	MH	24.31	2.63	-0.91
18	BH - 168	4.00-4.50	5	5	58	32	26	45.70	22.85	ML	68.40	2.63	1.40
19	BH - 169	2.50-3.00	4	4	56	30	26	55.90	27.95	ML	55.22	2.61	0.97
20	BH - 173	4.00-4.50	11	11	72	48	24	93.80	46.90	MH	51.30	2.62	0.14
21	BH - 175	2.50-3.00	4	4	55	31	24	78.40	39.20	MH	46.47	2.62	0.64
22	BH - 181	2.50-3.00	23	23	51	35	16	115.80	57.90	MH	32.20	2.62	-0.18
23	BH - 189	2.50-3.00	10	10	51	29	22	80.80	40.40	ML	44.61	2.64	0.71
24	BH - 194	2.50-3.10	19	17	60	39	21	98.10	49.05	MH	36.16	2.63	-0.14
25	BH - 209	2.50-3.00	13	13	52	37	15	89.93	44.97	MH	39.95	2.63	0.20

**Silty Clay soil (at depth 1.5m- 5.1m)**

**Model 5: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI**

Sr No	BH-ID	Depth (m)	NMC	Gs	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	SPT N-values/300mm	Adjusted SPT N values	Liquidity Index ( $I_L$ )	Modified Plasticity Index ( $I_{LM}$ )
					2.0mm	0.425mm	0.075mm	LL	PL	PI					
1	BH-18	1.50-2.10	60.92	2.62	99.9	99.3	96.5	72	47	25	CH	7	7	0.56	2482.50
2	BH-01	1.50-2.10	76.60	2.63	99.3	99	98.3	70	27	43	CH	3	3	1.15	4257.00
3	BH-02	1.50-2.10	37.98	2.64	100	99.4	97.4	98	79	19	CH	11	11	-2.16	1888.60
4	BH-03	1.50-2.10	25.99	2.66	100	99.8	98.4	81	61	20	CH	10	10	-1.75	1996.00
5	BH-06	1.50-2.10	45.33	2.63	100	99.7	97.6	79	56	23	CH	9	9	-0.46	2293.10
6	BH-07	1.50-2.10	43.72	2.63	99.8	99.3	95.3	72	50	22	CH	9	9	-0.29	2184.60
7	BH-08	1.50-2.10	25.99	2.66	100	99.8	98.4	81	61	20	CH	10	10	-1.75	1996.00
8	BH-16	1.70-2.30	55.14	2.63	99.9	99.6	98.2	95	47	48	CH	7	7	0.17	4780.80
9	BH-43	1.50-2.10	43.71	-	100	99.6	95.3	63	32	31	CH	7	7	0.38	3087.60
10	BH-26	1.50-2.10	66.75	-	100	99.6	98	87	49	38	CH	5	5	0.47	3784.80
11	BH-27	1.50-2.10	56.07	-	98.9	98.6	97.3	95	50	45	CH	7	7	0.13	4437.00
12	BH-30	1.50-2.10	29.22	-	99.6	97.2	93.8	68	49	19	CH	10	10	-1.04	1846.80
13	BH-31	1.50-2.10	47.76	-	99.7	99	98.1	77	49	28	CH	7	7	-0.04	2772.00
14	BH-32	1.50-2.10	46.73	2.62	98.8	95.4	86.3	71	46	25	CH	8	8	0.03	2385.00
15	BH-33	1.50-2.10	27.17	-	99.8	99.5	99	76	58	18	CH	11	11	-1.71	1791.00
16	BH-34	1.70-2.30	42.85	2.64	99.9	99.8	99.3	73	49	24	CH	8	8	-0.26	2395.20
17	BH-68	1.50-2.10	51.73	-	99.7	98.3	95.4	51	22	29	CH	4	4	1.03	2850.70
18	BH-45	1.50-2.10	26.32	-	97.1	85.1	72.7	64	53	11	CH	13	13	-2.43	936.10
19	BH-46	1.50-2.10	36.47	-	99.7	99.4	98.3	77	62	15	CH	10	10	-1.70	1491.00
20	BH-50	1.50-2.10	31.52	-	99.8	99.5	98.5	49	27	22	CL	6	6	0.21	2189.00
21	BH-58	1.70-2.30	55.01	-	99.9	97.3	89.1	65	40	25	CH	4	4	0.60	2432.50
22	BH-59	1.50-2.10	49.9	-	99.5	97.4	94.7	71	38	33	CH	6	6	0.36	3214.20
23	BH-69	1.70-2.30	31.9	-	99.6	98.7	97.4	91	76	15	CH	11	11	-2.94	1480.50
24	BH-70	1.50-2.10	46.65	2.62	96.5	86.1	71.2	61	42	19	CH	6	6	0.24	1635.90
25	BH-83	1.50-2.10	49.53	2.64	95.3	80.8	61.5	64	35	29	CH	7	7	0.50	2343.20
26	BH-84	1.50-2.10	52.26	2.63	99.9	99.6	99	86	58	28	CH	7	7	-0.21	2788.80
27	BH-85	1.50-2.10	53.3	2.63	99.9	99.7	99.1	74	52	22	CH	8	8	0.06	2193.40
28	BH-86	1.50-2.10	49.86	-	99.7	99.4	99	63	36	27	CH	7	7	0.51	2683.80
29	BH-90	1.50-2.10	42.23	2.63	100	99.7	99.1	65	38	27	CH	8	8	0.16	2691.90
30	BH-91	1.50-2.10	45.52	2.63	100	99.8	99.4	60	29	31	CH	5	5	0.53	3093.80
31	BH-92	1.50-2.10	46.25	-	99.7	99.2	98.2	64	40	24	CH	6	6	0.26	2380.80
32	BH-94	1.50-2.10	51.18	-	99.9	99.4	98.7	72	34	38	CH	5	5	0.45	3777.20
33	BH-95	1.50-2.10	50.13	2.63	99.8	99.2	98.2	63	26	37	CH	5	5	0.65	3670.40
34	BH-17	3.10-3.70	61.14	2.63	99.7	99.5	98.3	87	44	43	CH	7	7	0.40	4278.50

**Silty Clay soil (at depth 1.5m- 5.1m)**

**Model 5: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI**

Sr No	BH-ID	Depth (m)	NMC	Gs	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	SPT N-values/300mm	Adjusted SPT N values	Liquidit y Index ( $I_L$ )	Modified Plasticity Index ( $I_{LM}$ )
					2.m m	0.425mm	0.075mm	LL	PL	PI					
35	BH-19	3.10-3.70	72.11	2.62	99.9	99.3	97.6	82	43	29	CH	4	4	1.00	2879.70
36	BH-01	3.00-3.60	41.84	2.62	99.9	99.7	98.6	103	51	52	CH	13	13	-0.18	5184.40
37	BH-01	3.00-3.60	41.84	2.62	99.9	99.7	98.6	103	51	52	CH	13	13	-0.18	5184.40
38	BH-02	3.00-3.60	41.63	2.64	100	99.9	98.8	86	46	40	CH	12	12	-0.11	3996.00
39	BH-03	3.00-3.60	40.23	2.62	97.2	90.9	77.2	94	48	46	CH	14	14	-0.17	4181.40
40	BH-05	3.00-3.60	35.24	2.62	99.2	98.9	96.9	82	40	42	CH	12	12	-0.11	4153.80
41	BH-06	3.00-3.60	41.87	2.64	100	99.9	98.7	77	41	36	CH	11	11	0.02	3596.40
42	BH-16	3.20-3.80	45.36	2.59	99.9	99.1	94	50	33	17	CL	5	5	0.73	1684.70
43	BH-25	3.00-3.60	62.56	2.59	100	99.8	98.8	62	38	24	CH	4	4	1.02	2395.20
44	BH-26	3.00-3.60	61.32	-	100	99.6	98.7	70	46	24	CH	4	4	0.64	2390.40
45	BH-34	3.10-3.70	53.44	2.61	99.9	99.5	97.6	74	38	36	CH	6	6	0.43	3582.00
46	BH-45	3.00-3.60	54.99	2.62	97.1	85.1	72.7	65	38	27	CH	4	4	0.63	2297.70
47	BH-46	3.00-3.60	51.06	2.64	99.6	96.7	89.6	75	36	39	CH	6	6	0.39	3771.30
48	BH-47	3.00-3.60	41.89	2.63	99.6	98.7	97.9	56	36	20	CH	8	8	0.29	1974.00
49	BH-83	3.10-3.70	56.52	2.63	99.5	98	94.7	90	39	51	CH	9	9	0.34	4998.00
50	BH-85	3.00-3.60	50.56	2.61	100	99.7	99.1	89	34	55	CH	11	11	0.30	5483.50
51	BH-86	3.10-3.70	67.05	2.63	99.8	99.2	98.5	71	36	35	CH	6	6	0.89	3472.00
52	BH-87	3.10-3.70	44.21	2.64	99.5	99.3	98.7	62	34	28	CH	8	8	0.36	2780.40
53	BH-88	3.00-3.60	29.89	2.63	99.8	98.8	97.8	61	31	30	CH	11	11	-0.04	2964.00
54	BH-91	3.00-3.60	41.84	2.62	99.7	99	98.1	54	30	24	CH	7	7	0.49	2376.00
55	BH-92	3.00-3.60	43.8	2.64	98.9	95	90	59	40	19	CL	8	8	0.20	1805.00
56	BH-93	3.00-3.60	38.17	2.63	99.7	97.9	94.8	53	34	19	CH	8	8	0.22	1860.10
57	BH-94	3.00-3.60	56.26	2.64	99.7	99.2	98.6	65	42	23	CH	6	6	0.62	2281.60
58	BH-95	3.00-3.60	47.14	2.64	99.3	98.8	97.4	67	39	28	CH	7	7	0.29	2766.40
59	BH-96	3.00-3.60	40.37	2.62	99.5	97.9	96	51	33	18	CL	7	7	0.41	1762.20
60	BH-137	3.00-3.60	46.78	2.63	99.9	99.7	98.1	68	37	31	CH	7	7	0.32	3090.70
61	BH-01	4.50-5.10	31.97	2.59	100	99.4	97.4	106	51	55	CH	15	12	-0.35	5467.00
62	BH-03	4.50-5.10	41.63	2.58	100	99.9	98.4	73	41	32	CH	11	9	0.02	3196.80
63	BH-16	4.50-5.10	52.21	2.62	99.6	98.6	96.9	56	30	26	CL	9	7	0.85	2563.60
64	BH-34	4.50-5.10	65.62	-	99.8	99.5	98.1	81	45	36	CH	7	6	0.57	3582.00
65	BH-46	4.50-5.10	59.58	-	99.7	96.9	89.5	65	35	30	CH	7	6	0.82	2907.00
66	BH-47	4.50-5.10	28.11	-	99.3	97.2	93.7	91	40	51	CH	20	15	-0.23	4957.20
67	BH-83	4.50-5.10	43.42	-	99.5	99.4	98.7	88	40	48	CH	11	9	0.07	4771.20
68	BH-84	4.50-5.10	46.82	-	99.9	99.6	99.1	79	28	51	CH	11	9	0.37	5079.60
69	BH-85	4.50-5.10	34.61	-	99.7	98.7	97.6	82	31	51	CH	13	11	0.07	5033.70
70	BH-86	4.50-5.10	45.4	-	99.9	99.7	99.2	64	31	33	CH	9	8	0.44	3290.10
71	BH-88	4.50-5.10	36.93	-	99.8	98.8	98	93	43	50	CH	15	13	-0.12	4940.00
72	BH-91	4.50-5.10	46.68	-	100	99.9	99.4	52	31	21	CH	8	7	0.75	2097.90
73	BH-92	4.50-5.10	41.15	-	94.1	83.6	75.6	78	34	44	CH	10	9	0.16	3678.40
74	BH-95	4.50-5.10	38.07	-	99.1	94.4	81	46	27	19	CL	8	7	0.58	1793.60

Silty Clay soil (at depth 1.5m- 2.1m)

Model 6: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI

Sr No	BH-ID	Depth (m)	NMC	Gs	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/ 300mm	Adjusted SPT N values	Liquidity Index ( $I_L$ )	Modified Plasticity Index ( $I_{LM}$ )
					2.0 m m	0.425mm	0.075mm	LL	PL	PI						
1	BH-18	1.50-2.10	60.92	2.62	99.9	99.3	96.5	72	47	25	CH	90	7	7	0.56	2482.50
2	BH-01	1.50-2.10	76.60	2.63	99.3	99	98.3	70	27	43	CH	50	3	3	1.15	4257.00
3	BH-02	1.50-2.10	37.98	2.64	100	99.4	97.4	98	79	19	CH	140	11	11	-2.16	1888.60
4	BH-03	1.50-2.10	25.99	2.66	100	99.8	98.4	81	61	20	CH	140	10	10	-1.75	1996.00
5	BH-06	1.50-2.10	45.33	2.63	100	99.7	97.6	79	56	23	CH	95	9	9	-0.46	2293.10
6	BH-07	1.50-2.10	43.72	2.63	99.8	99.3	95.3	72	50	22	CH	70	9	9	-0.29	2184.60
7	BH-08	1.50-2.10	25.99	2.66	100	99.8	98.4	81	61	20	CH	140	10	10	-1.75	1996.00
8	BH-16	1.70-2.30	55.14	2.63	99.9	99.6	98.2	95	47	48	CH	140	7	7	0.17	4780.80
9	BH-43	1.50-2.10	43.71	-	100	99.6	95.3	63	32	31	CH	130	7	7	0.38	3087.60
10	BH-26	1.50-2.10	66.75	-	100	99.6	98	87	49	38	CH	125	5	5	0.47	3784.80
11	BH-27	1.50-2.10	56.07	-	98.9	98.6	97.3	95	50	45	CH	140	7	7	0.13	4437.00
12	BH-30	1.50-2.10	29.22	-	99.6	97.2	93.8	68	49	19	CH	80	10	10	-1.04	1846.80
13	BH-31	1.50-2.10	47.76	-	99.7	99	98.1	77	49	28	CH	100	7	7	-0.04	2772.00
14	BH-32	1.50-2.10	46.73	2.62	98.8	95.4	86.3	71	46	25	CH	100	8	8	0.03	2385.00
15	BH-33	1.50-2.10	27.17	-	99.8	99.5	99	76	58	18	CH	120	11	11	-1.71	1791.00
16	BH-34	1.70-2.30	42.85	2.64	99.9	99.8	99.3	73	49	24	CH	130	8	8	-0.26	2395.20
17	BH-68	1.50-2.10	51.73	-	99.7	98.3	95.4	51	22	29	CH	50	4	4	1.03	2850.70
18	BH-45	1.50-2.10	26.32	-	97.1	85.1	72.7	64	53	11	CH	110	13	13	-2.43	936.10
19	BH-46	1.50-2.10	36.47	-	99.7	99.4	98.3	77	62	15	CH	120	10	10	-1.70	1491.00
20	BH-50	1.50-2.10	31.52	-	99.8	99.5	98.5	49	27	22	CL	40	6	6	0.21	2189.00
21	BH-58	1.70-2.30	55.01	-	99.9	97.3	89.1	65	40	25	CH	85	4	4	0.60	2432.50
22	BH-59	1.50-2.10	49.9	-	99.5	97.4	94.7	71	38	33	CH	100	6	6	0.36	3214.20
23	BH-69	1.70-2.30	31.9	-	99.6	98.7	97.4	91	76	15	CH	-	11	11	-2.94	1480.50
24	BH-70	1.50-2.10	46.65	2.62	96.5	86.1	71.2	61	42	19	MH	-	6	6	0.24	1635.90
25	BH-83	1.50-2.10	49.53	2.64	95.3	80.8	61.5	64	35	29	CH	80	7	7	0.50	2343.20
26	BH-84	1.50-2.10	52.26	2.63	99.9	99.6	99	86	58	28	CH	100	7	7	-0.21	2788.80
27	BH-85	1.50-2.10	53.3	2.63	99.9	99.7	99.1	74	52	22	CH	90	8	8	0.06	2193.40
28	BH-86	1.50-2.10	49.86	-	99.7	99.4	99	63	36	27	CH	-	7	7	0.51	2683.80
29	BH-90	1.50-2.10	42.23	2.63	100	99.7	99.1	65	38	27	CH	100	8	8	0.16	2691.90
30	BH-91	1.50-2.10	45.52	2.63	100	99.8	99.4	60	29	31	CH	120	5	5	0.53	3093.80
31	BH-92	1.50-2.10	46.25	-	99.7	99.2	98.2	64	40	24	CH	130	6	6	0.26	2380.80
32	BH-94	1.50-2.10	51.18	-	99.9	99.4	98.7	72	34	38	CH	-	5	5	0.45	3777.20
33	BH-95	1.50-2.10	50.13	2.63	99.8	99.2	98.2	63	26	37	CH	110	5	5	0.65	3670.40

**Silty Clay soil (at depth 3.1m- 3.7m)**

**Model 7: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI**

Sr No	BH-ID	Depth (m)	NMC	Gs	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/300mm	Adjusted SPT N values	Liquidity Index ( $I_L$ )	Modified Plasticity Index ( $I_{LM}$ )
					2.0 mm	0.425mm	0.075mm	LL	PL	PI						
1	BH-17	3.10-3.70	61.14	2.63	99.7	99.5	98.3	87	44	43	CH	130	7	7	0.40	4278.50
2	BH-19	3.10-3.70	72.11	2.62	99.9	99.3	97.6	82	43	29	CH	85	4	4	1.00	2879.70
3	BH-01	3.00-3.60	41.84	2.62	99.9	99.7	98.6	103	51	52	CH	155	13	13	-0.18	5184.40
4	BH-01	3.00-3.60	41.84	2.62	99.9	99.7	98.6	103	51	52	CH	155	13	13	-0.18	5184.40
5	BH-02	3.00-3.60	41.63	2.64	100	99.9	98.8	86	46	40	CH	110	12	12	-0.11	3996.00
6	BH-03	3.00-3.60	40.23	2.62	97.2	90.9	77.2	94	48	46	CH	160	14	14	-0.17	4181.40
7	BH-05	3.00-3.60	35.24	2.62	99.2	98.9	96.9	82	40	42	CH	110	12	12	-0.11	4153.80
8	BH-06	3.00-3.60	41.87	2.64	100	99.9	98.7	77	41	36	CH	70	11	11	0.02	3596.40
9	BH-16	3.20-3.80	45.36	2.59	99.9	99.1	94	50	33	17	CL	30	5	5	0.73	1684.70
10	BH-25	3.00-3.60	62.56	2.59	100	99.8	98.8	62	38	24	CH	80	4	4	1.02	2395.20
11	BH-26	3.00-3.60	61.32	-	100	99.6	98.7	70	46	24	CH	110	4	4	0.64	2390.40
12	BH-34	3.10-3.70	53.44	2.61	99.9	99.5	97.6	74	38	36	CH	125	6	6	0.43	3582.00
13	BH-45	3.00-3.60	54.99	2.62	97.1	85.1	72.7	65	38	27	CH	140	4	4	0.63	2297.70
14	BH-46	3.00-3.60	51.06	2.64	99.6	96.7	89.6	75	36	39	CH	110	6	6	0.39	3771.30
15	BH-47	3.00-3.60	41.89	2.63	99.6	98.7	97.9	56	36	20	CH	65	8	8	0.29	1974.00
16	BH-83	3.10-3.70	56.52	2.63	99.5	98	94.7	90	39	51	CH	110	9	9	0.34	4998.00
17	BH-85	3.00-3.60	50.56	2.61	100	99.7	99.1	89	34	55	CH	120	11	11	0.30	5483.50
18	BH-86	3.10-3.70	67.05	2.63	99.8	99.2	98.5	71	36	35	CH	90	6	6	0.89	3472.00
19	BH-87	3.10-3.70	44.21	2.64	99.5	99.3	98.7	62	34	28	CH	60	8	8	0.36	2780.40
20	BH-88	3.00-3.60	29.89	2.63	99.8	98.8	97.8	61	31	30	CH	80	11	11	-0.04	2964.00
21	BH-91	3.00-3.60	41.84	2.62	99.7	99	98.1	54	30	24	CH	70	7	7	0.49	2376.00
22	BH-92	3.00-3.60	43.8	2.64	98.9	95	90	59	40	19	CL	60	8	8	0.20	1805.00
23	BH-93	3.00-3.60	38.17	2.63	99.7	97.9	94.8	53	34	19	CH	50	8	8	0.22	1860.10
24	BH-94	3.00-3.60	56.26	2.64	99.7	99.2	98.6	65	42	23	CH	120	6	6	0.62	2281.60
25	BH-95	3.00-3.60	47.14	2.64	99.3	98.8	97.4	67	39	28	CH	90	7	7	0.29	2766.40
26	BH-96	3.00-3.60	40.37	2.62	99.5	97.9	96	51	33	18	CL	50	7	7	0.41	1762.20
27	BH-137	3.00-3.60	46.78	2.63	99.9	99.7	98.1	68	37	31	CH	55	7	7	0.32	3090.70

**Silty Clay soil (at depth 4.5m- 5.1m)**

**Model 8: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI**

Sr No	BH-ID	Depth (m)	NMC	Gs	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/300mm	Adjusted SPT N values	Liquidity Index ( $I_L$ )	Modified Plasticity Index ( $I_{LM}$ )
					2.0 mm	0.425mm	0.075mm	LL	PL	PI						
1	BH-01	4.50-5.10	31.97	2.59	100	99.4	97.4	106	51	55	CH	120	15	12	-0.35	5467.00
2	BH-03	4.50-5.10	41.63	2.58	100	99.9	98.4	73	41	32	CH	100	11	9	0.02	3196.80
3	BH-16	4.50-5.10	52.21	2.62	99.6	98.6	96.9	56	30	26	CL	40	9	7	0.85	2563.60
4	BH-34	4.50-5.10	65.62	-	99.8	99.5	98.1	81	45	36	CH	140	7	6	0.57	3582.00
5	BH-46	4.50-5.10	59.58	-	99.7	96.9	89.5	65	35	30	CH	-	7	6	0.82	2907.00
6	BH-47	4.50-5.10	28.11	-	99.3	97.2	93.7	91	40	51	CH	105	20	15	-0.23	4957.20
7	BH-83	4.50-5.10	43.42	-	99.5	99.4	98.7	88	40	48	CH	-	11	9	0.07	4771.20
8	BH-84	4.50-5.10	46.82	-	99.9	99.6	99.1	79	28	51	CH	-	11	9	0.37	5079.60
9	BH-85	4.50-5.10	34.61	-	99.7	98.7	97.6	82	31	51	CH	-	13	11	0.07	5033.70
10	BH-86	4.50-5.10	45.4	-	99.9	99.7	99.2	64	31	33	CH	-	9	8	0.44	3290.10
11	BH-88	4.50-5.10	36.93	-	99.8	98.8	98	93	43	50	CH	-	15	13	-0.12	4940.00
12	BH-91	4.50-5.10	46.68	-	100	99.9	99.4	52	31	21	CH	100	8	7	0.75	2097.90
13	BH-92	4.50-5.10	41.15	-	94.1	83.6	75.6	78	34	44	CH	-	10	9	0.16	3678.40
14	BH-95	4.50-5.10	38.07	-	99.1	94.4	81	46	27	19	CL	-	8	7	0.58	1793.60

**Sandy Silt soil (at depth 1.5m-5.1m)**

**Model 9: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI**

Sr No	BH-ID	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/300mm	Adjusted SPT N values	Liquidity Index (IL)	Modified Plasticity Index ( $I_{LM}$ )
		2.0 mm	0.425mm	0.075mm	LL	PL	PI						
1	BH-10	97.8	95.4	92.6	51	34	17	MH	15	7	7	0.89	16.22
2	BH-11	99.80	99.10	97.70	71	42	29	ML	125.00	5	5	0.55	28.74
3	BH-12	99.50	97.10	91.80	51	32	19	MH	10.00	9	9	0.75	18.45
4	BH-13	99.60	98.60	97.80	63	36	27	ML	65.00	6	6	0.49	26.62
5	BH-14	99.80	97.70	91.20	61	36	25	MH	20.00	7	7	0.76	24.43
6	BH-15	100.00	99.70	97.40	71	42	29	ML	80.00	8	8	0.26	28.91
7	BH-40	94.20	88.00	83.30	63	40	23	MH	40.00	6	6	0.26	20.24
8	BH-42	99.60	99.10	98.60	67	36	31	MH	110.00	4	4	1.11	30.72
9	BH-28	98.90	92.20	87.50	61	50	11	ML	40.00	22	22	-2.25	10.14
10	BH-29	99.00	94.70	92.50	43	30	13	ML	40.00	6	6	1.75	12.31
11	BH-35	99.50	97.10	93.20	51	32	19	MH	40.00	6	6	0.89	18.45
12	BH-36	99.90	99.50	95.40	58	33	25	MH	70.00	6	6	0.85	24.88
13	BH-61	96.8	90.5	85.3	64	41	23	MH	60	13	13	-0.01	20.82
14	BH-62	97.8	92.1	84.7	45	34	11	ML	30	18	18	-0.79	10.13
15	BH-63	99.3	85.4	75	55	37	18	MH	40	11	11	-0.04	15.37
16	BH-64	88.5	80.5	76.3	52	35	17	MH	60	7	7	0.46	13.69
17	BH-67	97.3	91.3	82.8	48	28	20	ML	10	8	8	1.41	18.26
18	BH-57	99.2	95.3	88.7	58	41	17	MH	50	18	18	-0.92	16.20
19	BH-60	96.4	87.9	73.9	61	43	18	MH	30	8	8	0.64	15.82
20	BH-77	99.9	97.8	93	67	42	25	MH	60	5	5	1.05	24.45
21	BH-76	96.8	88.6	78.2	55	37	18	MH	50	11	11	-0.25	15.95
22	BH-220	92	73.7	60.3	53	36	17	MH	-	14	14	-0.59	12.53
23	BH-89	99.9	99.5	98.8	58	32	26	CH	-	8	8	0.56	25.87
24	BH-131	97.9	88.3	72.8	51	35	16	MH	60	7	7	1.20	14.13
25	BH-135	95.6	80.2	54	37	22	15	ML	-	8	8	1.42	12.03
26	BH-136	99.9	99.7	99	61	36	25	CH	-	12	12	0.18	24.93
27	BH-18	99.8	99.5	97.5	48	27	21	ML	25	5	5	1.33	20.90
28	BH-21	99.6	97	86.4	48	29	19	ML	30	5	5	0.90	18.43
29	BH-22	99.1	96.4	94.3	44	21	23	ML	10	4	4	1.17	22.17
30	BH-23	99.7	97.9	92.8	50	27	23	ML	10	4	4	1.15	22.52
31	BH-24	99.8	98.1	96.2	56	35	21	MH	30	5	5	1.01	20.60
32	BH-04	97.9	92.8	86.6	67	45	22	MH	10	16	13	-0.13	20.42
33	BH-08	99.8	99.1	91.7	48	32	16	ML	30	10	10	0.58	15.86
34	BH-09	99.9	98.5	92.5	41	17	24	ML	10	3	3	2.06	23.64
35	BH-10	100	99.6	98.3	55	32	23	MH	30	5	5	1.35	22.91
36	BH-11	99.8	99	98.1	55	31	24	MH	70	4	4	1.48	23.76

**Sandy Silt soil (at depth 1.5m-5.1m)**

**Model 9: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI**

Sr No	BH-ID	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/ 300mm	Adjusted SPT N values	Liquidity Index (IL)	Modified Plasticity Index ( $I_{LM}$ )
		2.0 mm	0.425mm	0.075mm	LL	PL	PI						
37	BH-12	100	99.7	97.2	69	43	26	MH	100	5	5	0.61	25.92
38	BH-13	98.9	97.1	94.6	49	30	19	ML	40	7	7	0.80	18.45
39	BH-14	99.7	98.6	93.4	49	28	21	ML	30	7	7	0.72	20.71
40	BH-15	99.5	97.8	94.5	43	27	16	ML	10	5	5	1.10	15.65
41	BH-40	99.9	99.6	98.4	68	58	10	MH	60	28	27	-3.17	9.96
42	BH-41	99.6	96.6	93.3	49	28	21	ML	60	6	6	0.40	20.29
43	BH-42	99.8	97.8	96.1	61	39	22	MH	60	7	7	1.30	21.52
44	BH-43	98.4	94.6	92.5	48	29	19	ML	20	4	4	1.66	17.97
45	BH-44	99.8	98.2	96.9	49	31	18	ML	40	5	5	1.33	17.68
46	BH-27	99.8	97.8	94.8	60	39	21	MH	80	4	4	1.07	20.54
47	BH-28	94.3	86.1	78.9	54	40	14	MH	30	11	9	0.37	12.05
48	BH-29	99.6	97.5	95.5	53	28	25	MH	50	4	4	1.44	24.38
49	BH-30	98	96.6	94.3	62	42	20	MH	60	6	6	0.96	19.32
50	BH-31	100	99.6	98	63	39	24	MH	70	4	4	1.25	23.90
51	BH-32	86.9	78.3	71.7	67	50	17	MH	75	10	10	0.05	13.31
52	BH-33	96.5	90.7	73.3	64	46	18	MH	75	10	10	0.43	16.33
53	BH-35	99.8	98.9	98	52	32	20	MH	50	8	8	1.13	19.78
54	BH-36	99.9	99.6	98.2	51	35	16	MH	30	5	5	1.22	15.94
55	BH-61	97.4	82.7	67.3	54	43	11	MH	20	23	21	-1.57	9.10
56	BH-67	91.9	68	48.1	39	29	10	SM	0	19	17	-0.23	6.80
57	BH-57	91	79	65.4	52	37	15	MH	40	12	12	-0.39	11.85
58	BH-77	94.5	77.9	58.4	40	29	11	ML	30	20	18	-0.42	8.57
59	BH-78	99.5	94.7	79.7	58	39	19	MH	-	5	5	0.84	17.99
60	BH-80	96.3	84.2	66.9	51	32	19	MH	30	7	7	0.60	16.00
61	BH-81	97.4	91.3	82.9	57	36	21	MH	40	7	7	0.43	19.17
62	BH-24	99.8	98.1	96.2	56	35	21	MH	30	5	5	1.01	20.60
63	BH-15	99.5	97.8	94.5	43	27	16	ML	10	5	5	1.10	15.65
64	BH-41	99.6	96.6	93.3	49	28	21	ML	60	6	6	0.40	20.29
65	BH-32	86.9	78.3	71.7	67	52	15	MH	75	10	10	-0.08	11.75
66	BH-17	99.7	98	91.5	49	24	25	ML	30	4	3	1.38	24.50
67	BH-18	98.3	96.6	89.8	50	35	15	ML	10	8	6	0.71	14.49
68	BH-19	98.2	92.5	78.7	48	35	13	ML	20	19	15	0.63	12.03
69	BH-21	98.9	98.6	98.3	51	28	23	MH	20	4	3	1.70	22.68
70	BH-22	99.7	98.5	97.6	54	31	23	MH	30	4	3	1.30	22.66
71	BH-24	77.9	71.6	58	46	31	15	ML	35	26	21	-0.31	10.74
72	BH-02	98.6	98.1	95.7	52	33	19	MH	40	9	7	0.21	18.64
73	BH-04	96.7	90.3	72.7	34	27	7	ML	30	39	27	-0.38	6.32

Sandy Silt soil (at depth 1.5m-5.1m)

Model 9: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI

Sr No	BH-ID	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/300mm	Adjusted SPT N values	Liquidity Index (IL)	Modified Plasticity Index ( $I_{LM}$ )
		2.0 mm	0.425mm	0.075mm	LL	PL	PI						
74	BH-05	100	99.5	97.3	56	33	23	MH	30	5	4	1.16	22.89
75	BH-06	95.1	87.1	72.7	44	30	14	ML	10	7	6	1.45	12.19
76	BH-07	100	98	80.8	43	30	13	ML	15	13	11	0.48	12.74
77	BH-08	99.9	99.2	97.5	55	32	23	MH	20	5	4	0.78	22.82
78	BH-09	99.8	98.9	97.4	46	21.8	24.2	ML	30	4	3	1.91	23.93
79	BH-11	86.9	83.7	80.5	71	44.75	26.25	MH	85	4	3	0.89	21.97
80	BH-12	70.9	61.2	51.8	63	53	10	MH	10	37	30	-2.79	6.12
81	BH-13	75.9	65.3	61.5	58	47	11	MH	30	25	20	-0.67	7.18
82	BH-14	99.9	99.3	96.1	52	36	16	MH	10	5	4	1.29	15.89
83	BH-15	53	41.1	29.5	45	31	14	SM	10	15	12	1.15	5.75
84	BH-39	94.6	87.1	82.3	57	32	25	MH	60	9	8	1.02	21.78
85	BH-41	99.8	99.3	98.7	47	30	17	ML	40	5	5	1.35	16.88
86	BH-42	99.7	98.6	96.7	51	31	20	MH	55	5	5	1.84	19.72
87	BH-43	100	99.3	98	69	42	27	MH	70	4	3	0.98	26.81
88	BH-44	99.4	96.6	93.3	53	34	19	MH	50	5	4	1.65	18.35
89	BH-25	94.9	92.1	87.8	48	31	17	ML	50	4	4	0.94	15.66
90	BH-26	86	79	70.3	42	23	19	ML	40	8	6	1.84	15.01
91	BH-27	99.4	98.6	96.5	56	37	19	MH	50	4	3	1.30	18.73
92	BH-28	98.4	96.1	91.3	54	44	10	MH	60	30	24	-1.70	9.61
93	BH-29	96.2	94.1	92.5	60	39	21	MH	-	9	7	1.26	19.76
94	BH-30	99.8	98.9	98.2	62	39	23	MH	70	5	4	1.09	22.75
95	BH-31	99.9	99.4	98.7	62	35	27	MH	-	4	3	1.28	26.84
96	BH-35	99.8	99	98.2	54	33	21	MH	40	4	3	1.45	20.79
97	BH-36	99.8	99.1	96.6	46	25	21	ML	30	4	3	1.44	20.81
98	BH-45	96.8	86.9	71.8	50	37	13	ML	50	15	12	-0.26	11.30
99	BH-54	87.5	69.6	59.9	56	41	15	MH	-	14	11	-0.15	10.44
100	BH-78	92.8	76.2	55.1	45	32	13	ML	30	23	17	-0.42	9.91
101	BH-82	98.8	84.2	69.6	50	35	15	ML	30	11	9	-0.39	12.63
102	BH-219	76.7	59.5	52	79	51	28	MH	40	6	4	0.46	16.66
103	BH-220	90.3	79.4	75.9	54	39	15	MH	-	7	5	1.13	11.91
104	BH-87	99.1	95.9	94	63	39	24	MH	-	13	11	1.04	23.02
105	BH-90	97.6	92.5	75.1	47	36	11	ML	-	25	22	-0.90	10.18
106	BH-91	100	99.9	99.4	52	31	21	MH	100	8	7	0.27	20.98
107	BH-93	97.5	93.1	89.1	43	30	13	ML	-	9	8	0.52	12.10
108	BH-94	99.1	96.2	90.7	54	38	16	MH	20	10	9	-0.08	15.39
109	BH-96	99.7	96.6	81	39	25	14	ML	-	8	7	1.16	13.52
110	BH-132	93.8	76.1	56.3	53	42	11	MH	-	20	15	0.06	8.37
111	BH-136	99.6	97.3	92	54	31	23	MH	-	9	8	0.75	22.38
112	BH-138	99.7	98.9	97.6	71	56	15	MH	-	13	11	-0.17	14.84

Sandy silt soil (at depth 1.5m- 2.1m)

Model 10: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI

Sr No	BH-ID	Depth (m)	NMC	Gs	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/300mm	Adjusted SPT N values	Liquid Limit Index (IL)	Modified Plasticity Index ( $I_{LM}$ )
					2.0 m	0.425m	0.075m	LL	PL	PI						
1	BH-10	1.70-2.30	49.17	-	97.8	95.4	92.6	51	34	17	MH	15	7	7	0.89	1621.80
2	BH-11	1.70-2.30	58.05	2.64	99.80	99.10	97.70	71	42	29	ML	125.00	5	5	0.55	2873.90
3	BH-12	1.50-2.10	46.22	2.64	99.50	97.10	91.80	51	32	19	MH	10.00	9	9	0.75	1844.90
4	BH-13	1.50-2.10	49.10	2.63	99.60	98.60	97.80	63	36	27	ML	65.00	6	6	0.49	2662.20
5	BH-14	1.70-2.30	55.04	2.63	99.80	97.70	91.20	61	36	25	MH	20.00	7	7	0.76	2442.50
6	BH-15	1.70-2.30	49.57	2.64	100.00	99.70	97.40	71	42	29	ML	80.00	8	8	0.26	2891.30
7	BH-40	1.50-2.10	45.89	-	94.20	88.00	83.30	63	40	23	MH	40.00	6	6	0.26	2024.00
8	BH-42	1.70-2.30	70.43	-	99.60	99.10	98.60	67	36	31	MH	110.00	4	4	1.11	3072.10
9	BH-28	1.50-2.10	25.3	-	98.90	92.20	87.50	61	50	11	ML	40.00	22	22	-2.25	1014.20
10	BH-29	1.50-2.10	52.80	2.64	99.00	94.70	92.50	43	30	13	ML	40.00	6	6	1.75	1231.10
11	BH-35	1.70-2.30	48.85	-	99.50	97.10	93.20	51	32	19	MH	40.00	6	6	0.89	1844.90
12	BH-36	1.70-2.30	54.34	-	99.90	99.50	95.40	58	33	25	MH	70.00	6	6	0.85	2487.50
13	BH-61	1.50-2.10	40.73	-	96.8	90.5	85.3	64	41	23	MH	60	13	13	-0.01	2081.50
14	BH-62	1.50-2.10	25.3	-	97.8	92.1	84.7	45	34	11	ML	30	18	18	-0.79	1013.10
15	BH-63	1.50-2.10	36.37	-	99.3	85.4	75	55	37	18	MH	40	11	11	-0.04	1537.20
16	BH-64	1.50-2.10	42.77	-	88.5	80.5	76.3	52	35	17	MH	60	7	7	0.46	1368.50
17	BH-67	1.50-2.10	56.12	-	97.3	91.3	82.8	48	28	20	ML	10	8	8	1.41	1826.00
18	BH-57	1.70-2.30	25.3	-	99.2	95.3	88.7	58	41	17	MH	50	18	18	-0.92	1620.10
19	BH-60	1.50-2.10	54.51	-	96.4	87.9	73.9	61	43	18	MH	30	8	8	0.64	1582.20
20	BH-77	1.50-2.10	48.56	2.64	99.9	97.8	93	67	42	25	MH	60	5	5	1.05	2445.00
21	BH-76	1.50-2.10	32.52	-	96.8	88.6	78.2	55	37	18	MH	50	11	11	-0.25	1594.80
22	BH-220	1.50-2.10	25.94	-	92	73.7	60.3	53	36	17	MH	-	14	14	-0.59	1252.90
23	BH-89	1.50-2.10	46.43	-	99.9	99.5	98.8	58	32	26	CH	-	8	8	0.56	2587.00
24	BH-131	1.50-2.10	54.21	2.62	97.9	88.3	72.8	51	35	16	MH	60	7	7	1.20	1412.80
25	BH-135	1.50-2.10	43.33	2.62	95.6	80.2	54	37	22	15	ML	-	8	8	1.42	1203.00
26	BH-136	1.50-2.10	40.55	-	99.9	99.7	99	61	36	25	CH	-	12	12	0.18	2492.50

Sandy silt soil (at depth 3.1m- 3.7m)

Model 11: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI

Sr No	BH-ID	Depth (m)	NMC	Gs	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/300mm	Adjusted SPT N values	Liquidity Index (IL)	Plasticity Index (PI)
					2.0 m m	0.425mm	0.075mm	LL	PL	PI						
1	BH-18	3.10-3.70	55	2.63	99.8	99.5	97.5	48	27	21	ML	25	5	5	1.33	2089.50
2	BH-21	3.10-3.70	46.06	2.65	99.6	97	86.4	48	29	19	ML	30	5	5	0.90	1843.00
3	BH-22	3.10-3.70	47.93	2.59	99.1	96.4	94.3	44	21	23	ML	10	4	4	1.17	2217.20
4	BH-23	3.10-3.70	53.48	2.63	99.7	97.9	92.8	50	27	23	ML	10	4	4	1.15	2251.70
5	BH-24	3.10-3.70	56.3	2.62	99.8	98.1	96.2	56	35	21	MH	30	5	5	1.01	2060.10
6	BH-04	3.00-3.60	42.23	2.65	97.9	92.8	86.6	67	45	22	MH	10	16	13	-0.13	2041.60
7	BH-08	3.10-3.70	41.26	2.61	99.8	99.1	91.7	48	32	16	ML	30	10	10	0.58	1585.60
8	BH-09	3.30-3.90	66.5	2.64	99.9	98.5	92.5	41	17	24	ML	10	3	3	2.06	2364.00
9	BH-10	3.40-4.00	63.02	2.62	100	99.6	98.3	55	32	23	MH	30	5	5	1.35	2290.80
10	BH-11	3.20-3.80	66.48	2.61	99.8	99	98.1	55	31	24	MH	70	4	4	1.48	2376.00
11	BH-12	3.20-3.80	58.88	2.61	100	99.7	97.2	69	43	26	MH	100	5	5	0.61	2592.20
12	BH-13	3.20-3.80	45.25	2.61	98.9	97.1	94.6	49	30	19	ML	40	7	7	0.80	1844.90
13	BH-14	3.20-3.80	43.22	-	99.7	98.6	93.4	49	28	21	ML	30	7	7	0.72	2070.60
14	BH-15	3.20-3.80	44.64	2.61	99.5	97.8	94.5	43	27	16	ML	10	5	5	1.10	1564.80
15	BH-40	3.10-3.70	26.3	2.6	99.9	99.6	98.4	68	58	10	MH	60	28	27	-3.17	996.00
16	BH-41	3.30-3.90	36.41	2.61	99.6	96.6	93.3	49	28	21	ML	60	6	6	0.40	2028.60
17	BH-42	3.10-3.70	67.66	2.64	99.8	97.8	96.1	61	39	22	MH	60	7	7	1.30	2151.60
18	BH-43	3.00-3.60	60.56	2.61	98.4	94.6	92.5	48	29	19	ML	20	4	4	1.66	1797.40
19	BH-44	3.10-3.70	54.93	2.62	99.8	98.2	96.9	49	31	18	ML	40	5	5	1.33	1767.60
20	BH-27	3.00-3.60	61.44	2.63	99.8	97.8	94.8	60	39	21	MH	80	4	4	1.07	2053.80
21	BH-28	3.00-3.60	45.2	2.62	94.3	86.1	78.9	54	40	14	MH	30	11	9	0.37	1205.40
22	BH-29	3.00-3.60	63.88	2.59	99.6	97.5	95.5	53	28	25	MH	50	4	4	1.44	2437.50
23	BH-30	3.00-3.60	61.26	2.62	98	96.6	94.3	62	42	20	MH	60	6	6	0.96	1932.00
24	BH-31	3.00-3.60	69.07	2.66	100	99.6	98	63	39	24	MH	70	4	4	1.25	2390.40
25	BH-32	3.00-3.60	50.77	2.6	86.9	78.3	71.7	67	50	17	MH	75	10	10	0.05	1331.10
26	BH-33	3.10-3.70	53.78	2.64	96.5	90.7	73.3	64	46	18	MH	75	10	10	0.43	1632.60
27	BH-35	3.30-3.90	54.51	2.63	99.8	98.9	98	52	32	20	MH	50	8	8	1.13	1978.00
28	BH-36	3.30-3.90	54.57	2.61	99.9	99.6	98.2	51	35	16	MH	30	5	5	1.22	1593.60
29	BH-61	3.00-3.60	25.7	2.63	97.4	82.7	67.3	54	43	11	MH	20	23	21	-1.57	909.70
30	BH-67	3.10-3.70	26.7	2.63	91.9	68	48.1	39	29	10	SM	0	19	17	-0.23	680.00
31	BH-57	3.00-3.60	31.2	2.59	91	79	65.4	52	37	15	MH	40	12	12	-0.39	1185.00
32	BH-77	3.10-3.70	24.35	2.62	94.5	77.9	58.4	40	29	11	ML	30	20	18	-0.42	856.90
33	BH-78	3.10-3.70	54.92	-	99.5	94.7	79.7	58	39	19	MH	-	5	5	0.84	1799.30
34	BH-80	3.10-3.70	43.35	2.63	96.3	84.2	66.9	51	32	19	MH	30	7	7	0.60	1599.80
35	BH-81	3.10-3.70	45.12	2.64	97.4	91.3	82.9	57	36	21	MH	40	7	7	0.43	1917.30
36	BH-24	3.10-3.70	56.3	2.62	99.8	98.1	96.2	56	35	21	MH	30	5	5	1.01	2060.10
37	BH-15	3.20-3.80	44.64	2.61	99.5	97.8	94.5	43	27	16	ML	10	5	5	1.10	1564.80
38	BH-41	3.30-3.90	36.41	2.61	99.6	96.6	93.3	49	28	21	ML	60	6	6	0.40	2028.60
39	BH-32	3.00-3.60	50.77	2.6	86.9	78.3	71.7	67	52	15	MH	75	10	10	-0.08	1174.50

## Sandy silt soil (at depth 4.5m-5.1m)

Model 12: Data for Correlation of Standard penetration numbers (SPT) with  $I_L$ ,  $I_{LM}$  and PI

Sr No	BH-ID	Depth (m)	NMC	Gs	Wet Sieve Analysis (AASHTO T27)			Atterberg Limit (AASHTO T89&90)			USCS	Free Swell (%)	SPT N-values/300mm	Adjusted SPT N values	Liquidity Index (IL)	Modified Plasticity Index ( $I_{LM}$ )
					2.0 mm	0.425mm	0.075mm	LL	PL	PI						
1	BH-17	4.50-5.10	58.42	2.6	99.7	98	91.5	49	24	25	ML	30	4	3	1.38	2450.00
2	BH-18	4.50-5.10	45.72	2.61	98.3	96.6	89.8	50	35	15	ML	10	8	6	0.71	1449.00
3	BH-19	4.50-5.10	43.25	2.59	98.2	92.5	78.7	48	35	13	ML	20	19	15	0.63	1202.50
4	BH-21	4.50-5.10	67	2.62	98.9	98.6	98.3	51	28	23	MH	20	4	3	1.70	2267.80
5	BH-22	4.50-5.10	60.87	2.62	99.7	98.5	97.6	54	31	23	MH	30	4	3	1.30	2265.50
6	BH-24	4.50-5.10	26.32	-	77.9	71.6	58	46	31	15	ML	35	26	21	-0.31	1074.00
7	BH-02	4.50-5.10	37.07	2.62	98.6	98.1	95.7	52	33	19	MH	40	9	7	0.21	1863.90
8	BH-04	4.50-5.10	24.31	2.63	96.7	90.3	72.7	34	27	7	ML	30	39	27	-0.38	632.10
9	BH-05	4.50-5.10	59.67	2.64	100	99.5	97.3	56	33	23	MH	30	5	4	1.16	2288.50
10	BH-06	4.50-5.10	50.25	2.61	95.1	87.1	72.7	44	30	14	ML	10	7	6	1.45	1219.40
11	BH-07	4.50-5.10	36.2	2.62	100	98	80.8	43	30	13	ML	15	13	11	0.48	1274.00
12	BH-08	4.50-5.10	49.93	-	99.9	99.2	97.5	55	32	23	MH	20	5	4	0.78	2281.60
13	BH-09	4.50-5.10	67.99	-	99.8	98.9	97.4	46	21.8	24.2	ML	30	4	3	1.91	2393.38
14	BH-11	4.50-5.10	67.99	-	86.9	83.7	80.5	71	44.75	26.25	MH	85	4	3	0.89	2197.13
15	BH-12	4.50-5.10	25.12	2.58	70.9	61.2	51.8	63	53	10	MH	10	37	30	-2.79	612.00
16	BH-13	4.50-5.10	39.6	2.59	75.9	65.3	61.5	58	47	11	MH	30	25	20	-0.67	718.30
17	BH-14	4.50-5.10	56.66	2.61	99.9	99.3	96.1	52	36	16	MH	10	5	4	1.29	1588.80
18	BH-15	4.50-5.10	47.04	2.59	53	41.1	29.5	45	31	14	SM	10	15	12	1.15	575.40
19	BH-39	4.50-5.10	57.55	-	94.6	87.1	82.3	57	32	25	MH	60	9	8	1.02	2177.50
20	BH-41	4.70-5.30	53.02	-	99.8	99.3	98.7	47	30	17	ML	40	5	5	1.35	1688.10
21	BH-42	4.50-5.10	67.74	-	99.7	98.6	96.7	51	31	20	MH	55	5	5	1.84	1972.00
22	BH-43	4.50-5.10	68.53	-	100	99.3	98	69	42	27	MH	70	4	3	0.98	2681.10
23	BH-44	4.50-5.10	65.29	-	99.4	96.6	93.3	53	34	19	MH	50	5	4	1.65	1835.40
24	BH-25	4.50-5.10	47.02	2.58	94.9	92.1	87.8	48	31	17	ML	50	4	4	0.94	1565.70
25	BH-26	4.50-5.10	58.02	2.62	86	79	70.3	42	23	19	ML	40	8	6	1.84	1501.00
26	BH-27	4.50-5.10	61.61	-	99.4	98.6	96.5	56	37	19	MH	50	4	3	1.30	1873.40
27	BH-28	4.50-5.10	27.03	-	98.4	96.1	91.3	54	44	10	MH	60	30	24	-1.70	961.00
28	BH-29	4.50-5.10	65.47	-	96.2	94.1	92.5	60	39	21	MH	-	9	7	1.26	1976.10
29	BH-30	4.50-5.10	64.17	-	99.8	98.9	98.2	62	39	23	MH	70	5	4	1.09	2274.70
30	BH-31	4.50-5.10	69.59	-	99.9	99.4	98.7	62	35	27	MH	-	4	3	1.28	2683.80
31	BH-35	4.50-5.10	63.49	-	99.8	99	98.2	54	33	21	MH	40	4	3	1.45	2079.00
32	BH-36	4.50-5.10	55.34	-	99.8	99.1	96.6	46	25	21	ML	30	4	3	1.44	2081.10
33	BH-45	4.50-5.10	33.62	-	96.8	86.9	71.8	50	37	13	ML	50	15	12	-0.26	1129.70
34	BH-54	4.50-5.10	38.77	2.58	87.5	69.6	59.9	56	41	15	MH	-	14	11	-0.15	1044.00
35	BH-78	4.50-5.10	26.51	2.63	92.8	76.2	55.1	45	32	13	ML	30	23	17	-0.42	990.60
36	BH-82	4.50-5.10	29.21	2.61	98.8	84.2	69.6	50	35	15	ML	30	11	9	-0.39	1263.00
37	BH-219	5.00-5.60	64.01	-	76.7	59.5	52	79	51	28	MH	40	6	4	0.46	1666.00
38	BH-220	4.50-5.10	55.88	2.6	90.3	79.4	75.9	54	39	15	MH	-	7	5	1.13	1191.00
39	BH-87	4.50-5.10	63.86	-	99.1	95.9	94	63	39	24	MH	-	13	11	1.04	2301.60
40	BH-90	4.50-5.10	26.12	2.62	97.6	92.5	75.1	47	36	11	ML	-	25	22	-0.90	1017.50
41	BH-91	4.50-5.10	36.68	-	100	99.9	99.4	52	31	21	MH	100	8	7	0.27	2097.90
42	BH-93	4.50-5.10	36.72	-	97.5	93.1	89.1	43	30	13	ML	-	9	8	0.52	1210.30
43	BH-94	4.50-5.10	36.71	-	99.1	96.2	90.7	54	38	16	MH	20	10	9	-0.08	1539.20
44	BH-96	4.50-5.10	41.3	-	99.7	96.6	81	39	25	14	ML	-	8	7	1.16	1352.40
45	BH-132	4.50-5.10	42.68	-	93.8	76.1	56.3	53	42	11	MH	-	20	15	0.06	837.10
46	BH-136	4.50-5.10	48.32	-	99.6	97.3	92	54	31	23	MH	-	9	8	0.75	2237.90
48	BH-138	4.50-5.10	53.41	-	99.7	98.9	97.6	71	56	15	MH	-	13	11	-0.17	1483.50

## **Appendix A-2: Soil Stratification Profile**

**Note:-**

- Layer 1:** Soft, dark grey, highly plastic CLAY
- Layer 2:** Medium stiff to stiff, yellowish brown Sandy SILT
- Layer 3:** Medium dense to dense, yellowish to brownish grey Silty SAND with gravel (Highly weathered to completely decomposed Tuff).
- Layer 4:** Stiff to very stiff, yellowish to brownish grey Sandy SILT with few gravel
- Layer5:** Very Stiff to hard, grayish to light reddish brown Silty CLAY
- Layer6:** Dense, light brownish grey, Clayey Silty SAND (Highly weathered to completely decomposed BASALT).
- Layer7:** BASALT

