# CO-RELATION OF SPT AND PLT FOR ESTIMATION OF SETTLEMENT FOR KHYBER PAKHTUNKHWA SOILS

**FINAL YEAR PROJECT UG 2024**

**BY**


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YEAR 2024

This is to certify that the

Final Year Project Titled

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Has been accepted towards the

requirements for the undergraduate degree program

**in**

**BACHELORS IN CIVIL ENGINEERING**

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# PROJECT ACCEPTANCE CERTIFICATE

Certified that the final copy of BE Civil Engineering Final year project written by Mr. Aftab Sultan, Mr. Hamza Zulfiqar, Mr. Hamza Sakeen, Mr. Usama Hikmat of MCE, Risalpur has been vetted by the undersigned, found complete in all respects as per NUST Statutes/ Regulations Policy, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for the award of BCE degree.

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This is to certify that the research work presented in this BE Civil Engineering Final year project entitled "Co-Relation of SPT and PLT for estimation of settlement for Khyber Pakhtunkhwa soil" was conducted by Mr. Aftab Sultan, Mr. Hamza Zulfiqar, Mr. Hamza Sakeen, Mr. Usama Hikmat under the supervision of Maj. Dr Ramez.

No part of this thesis has been submitted anywhere else for any other degree. This project is submitted to the Department of Geotechnical Engineering in partial fulfillment of the requirements for the degree of BE Civil Engineering in the Field of Department of Geotechnical Engineering, MCE National University of Sciences and Technology, Islamabad.

Supervisor Name: Maj. Dr Rameez Signature: ________________

## AUTHOR'S DECLARATION

We hereby state that our BE Civil Engineering project titled "Co-relation of SPT and PLT for estimation of settlement for Khyber Pakhtunkhwa soil" is our work and has not been submitted previously by us for taking any degree from the National University of Sciences and Technology, Islamabad, or anywhere else in the country/ world.

At any time if my statement is found to be incorrect even after I graduate, the university has the right to withdraw my BS degree.

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We solemnly declare that the research work presented in the project titled "Co-Relation of SPT and PLT for estimation of settlement for Khyber Pakhtunkhwa soil" is solely our research work with no significant contribution from any other person. Small contributions/ help wherever taken has been duly acknowledged and that complete project have been written by us.

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# DECLARATION

We hereby declare that the thesis entitled "Co-relation of SPT and PLT for estimation of settlement for Khyber Pakhtunkhwa soils" submitted by us, is based on the study and work done solely by us. All references to work done by any other person, institution, or source have been duly cited. We further clarify that this thesis has not been published or submitted for publication anywhere else.

# ACKNOWLEDGEMENT

We express our sincerest gratitude to the Almighty for guiding us through the completion of our research endeavor. We are deeply thankful to all those who played a crucial role in its realization. A special acknowledgment is reserved for our esteemed professors, with heartfelt gratitude extended to our advisor, Maj Dr. Rameez Raja, whose unwavering support and encouragement fueled our journey. We also extend our heartfelt appreciation to our parents for their constant support and prayers. To everyone who contributed in any way to this research, your generosity has left an indelible mark.

# ABSTRACT

To create secure and effective foundation systems for civil engineering projects, the assessment of soil settlement characteristics is essential. The purpose of this study is to establish a correlation between the Unconfined Compressive Strength (UCS), Standard Penetration Test (SPT), and Plate Load Test (PLT) to evaluate the settling behavior of soils in the Khyber Pakhtunkhwa area.

As part of the research approach, undisturbed soil samples were gathered from different parts of Khyber Pakhtunkhwa. Laboratory experiments were used to establish the physical and geotechnical parameters of the soils. PLT and SPT tests were conducted at representative locations by field investigations, and soil samples were extracted for laboratory testing using geotechnical borehole drilling.

To determine links between PLT and SPT, data from field and laboratory research were subjected to statistical analysis and correlation tests. Based on the PLT and SPT data, multiple regression analyses were carried out to create predictive models for assessing the settlement behavior of Khyber Pakhtunkhwa soils.

The findings showed that the PLT and SPT parameters showed strong relationships, demonstrating their dependency for assessing the soils of Khyber Pakhtunkhwa's settlement characteristics. With readily observable parameters, the correlation models that have been created offer a useful tool for assessing the settling behavior of these soils.

The results of this study will be useful to designers, construction managers, and geotechnical engineers in Khyber Pakhtunkhwa who plan and implement foundation systems. The correlations that have been created will augment comprehension of soil behavior, elevate the precision of geotechnical assessments, and aid in the creation of effective and economical foundation designs.

Keywords: Shallow foundation, Settlement testing, SPT and PLT correlation

# TABLE OF CONTENTS

# LIST OF FIGURES

# Chapter 1

## 1. INTRODUCTION

### 1.1 General

The plate load test is increasingly favored for its cost-effectiveness and efficiency compared to other field tests, serving as a crucial method for gauging soil settling. In situ investigations are preferred over laboratory testing for their ability to assess soil behavior in its natural environment, saving time and resources. This test involves loading a rigid plate at the foundation level and recording settlement corresponding to each load increment until the point where the plate starts to sink rapidly, indicating the final settlement. Two primary techniques, the reaction truss method and the gravity loading platform method, are employed to conduct the test, utilizing hydraulic jacks to apply loads while ensuring precise measurement and analysis of soil behavior. This method provides valuable insights into soil load-bearing capacity, aiding decision-making in construction projects.

### 1.2 Problem Statement

In field testing, two primary methods are utilized: in situ field tests and laboratory soil tests. However, certain challenges persist, which plate load testing aims to address. One such challenge lies in obtaining undisturbed samples of sandy soils for Standard Penetration Test (SPT) testing, a difficulty that plate load tests can help overcome by providing estimations based on gathered data. Moreover, plate load testing offers significant advantages in terms of cost and time effectiveness compared to traditional SPT methods. Despite its global rise in popularity, plate load testing still receives limited attention within Pakistan's geotechnical community, despite its potential to fill critical voids in the country's geotechnical domain, particularly in design reliability.

Furthermore, the current lack of direct relationships between Plate Load Test results and those of Standard Penetration Test or Unconfined Compressive Strength Test in Pakistani soils underscores the need for further research in this area. The scant literature available demonstrates a gap in understanding these relationships, emphasizing the necessity for more extensive investigations. Establishing a coefficient of correlation could showcase the Plate Load Test's reliability as a cost-effective and superior alternative to conventional geotechnical tests, potentially encouraging greater adoption and utilization within the geotechnical engineering community.

## 1.3 Objective

To enhance understanding and prediction of soil settlement in Khyber Pakhtunkhwa, we leverage data from the Plate Load Test (PLT) to anticipate settlement and juxtapose these findings with settlement predictions derived from Standard Penetration Test (SPT) analyses. This comparative analysis offers valuable insights into the behavior of the soil under different testing methodologies, enabling engineers and researchers to make informed decisions regarding construction and foundation design. By correlating settlement data obtained from these two geotechnical tests, we gain a deeper understanding of how variations in testing approaches influence the observed settlement characteristics, thereby contributing to more accurate soil characterization and design parameters for engineering projects in the region.

# Chapter 2

## 2 LITERATURE REVIEW

### 2.1 What is Geotechnical Engineering?

Geotechnical engineering delves into the intricate interactions between soils, water, and external forces, providing vital insights crucial for various infrastructural elements such as geosynthetic waste containment systems, retaining walls, foundations, and clay liners. Ground structures supporting our built environment heavily rely on geotechnical engineering principles, as they lay the groundwork for the entire construction process. Conducted by specialized departments, a multitude of experiments and tests ensure the structural integrity of buildings, mitigating risks associated with structural failure. Geotechnical foundations play a pivotal role in supporting diverse structures including transportation infrastructure, underground facilities, dams, landfills, offshore installations, and deep excavations. In essence, geotechnical testing serves as the foundational step in evaluating a site's suitability and stability for its intended purpose, ensuring safety and longevity in infrastructure development.

### 2.2 What is the Purpose of Geotechnical Engineering?

The successful planning and construction of buildings and structural systems necessitate a comprehensive grasp of subsurface conditions. Geotechnical testing is undertaken to meticulously examine these conditions, discern the physical and chemical properties of the earth's layers, gauge the stability of slopes and soil deposits, evaluate risks linked to site conditions, design appropriate foundations, and scrutinize specific ground conditions and foundation construction processes.

### 2.3 How is Geotechnical Testing Carried Out?

Geotechnical testing encompasses both on-site and laboratory methodologies, each serving distinct purposes in evaluating soil properties and site conditions. On-site testing involves direct assessments conducted in the field and includes essential tests such as Dry Density/Moisture Relationship, California Bearing Ratio (CBR) Test, Plate Load Test (PLT), Vane Shear Test, as well as the widely used Cone Penetration Test (CPT) and Standard Penetration Test (SPT). In contrast, laboratory experimentation involves controlled analyses to delve deeper into soil characteristics, encompassing tests like sieve analysis for particle size distribution, liquid and plastic limit tests (LL and PL), tri-axial compression tests, moisture content analyses, and pH value assessments.

General experiments within geotechnical studies are typically categorized into four main groups: test pits for surface assessments, trenches and excavation for deeper insights, boring and drilling for subsurface exploration, and in-situ testing for direct evaluations of ground conditions. These experiments are essential for gathering comprehensive data on ground composition, land stability, site history, and ground movement, providing critical insights for informed decision-making in engineering and construction projects.

## 2.4 Plate Load Test

The plate bearing test, a common field assessment, aims to determine the soil's tendency to settle under designated loads. It involves applying loads at the foundation level onto a rigid slab and recording the settlement at various load levels. The critical load capacity, indicating the point at which rapid sinking of the slab occurs, is a key parameter derived from this test.

### 2.4.1. Limitations of Plate Load Test

- **Size:** Refers to dimensions of test setup, including slab diameter and thickness.
- **Scale:** Describes proportionality between test setup and actual field conditions.
- **Time Factor:** Influences soil settlement rates and consolidation under applied loads.
- **Interpretation of Failure Load:** Determines critical load capacity or failure point for assessing soil bearing capacity.
- **Reaction Load:** Provides support to test slab, maintaining equilibrium during testing.
- **Water-table:** Presence affects soil settlement behavior, particularly in saturated conditions.

### 2.4.2. Advantages of Plate Load Test

- Understanding the mechanics of a weighted foundation helps anticipate settlement.
- Estimating soil settlement at specific depths and predicting settling under designated loads are key aspects.
- Utilizing the plate load test enables derivation of allowable bearing capacity for calculating settlement in shallow foundations.
- Achieving cost and time efficiency while simplifying the settlement assessment process is paramount.

### 2.4.3. Methods of Plate Load Test

The Plate Load Test (PLT) encompasses various methods to assess the bearing capacity of soil beneath a foundation. One common technique involves the reaction truss method, where a rigid plate is placed atop the soil, and loads are incrementally applied through hydraulic jacks. The reaction to these loads is provided by a truss system anchored to nearby support points. As loads increase, settlement measurements are recorded, and the relationship between load and settlement helps determine the soil's behavior under pressure. This method offers a practical approach to evaluating the soil's load-bearing capacity, particularly in shallow foundation applications.

Another method employed in the Plate Load Test is the gravity loading platform method. Here, the rigid plate is loaded using a hydraulic jack, and the reaction to the applied load is provided by a loaded platform placed directly above the test area. This approach simplifies the test setup by eliminating the need for a reaction truss system. By measuring settlement under various loads, engineers can assess the soil's response to pressure and determine the appropriate bearing capacity for foundation design. Both methods of the Plate Load Test provide valuable insights into soil behavior, aiding in the safe and efficient design of structures atop various soil types.

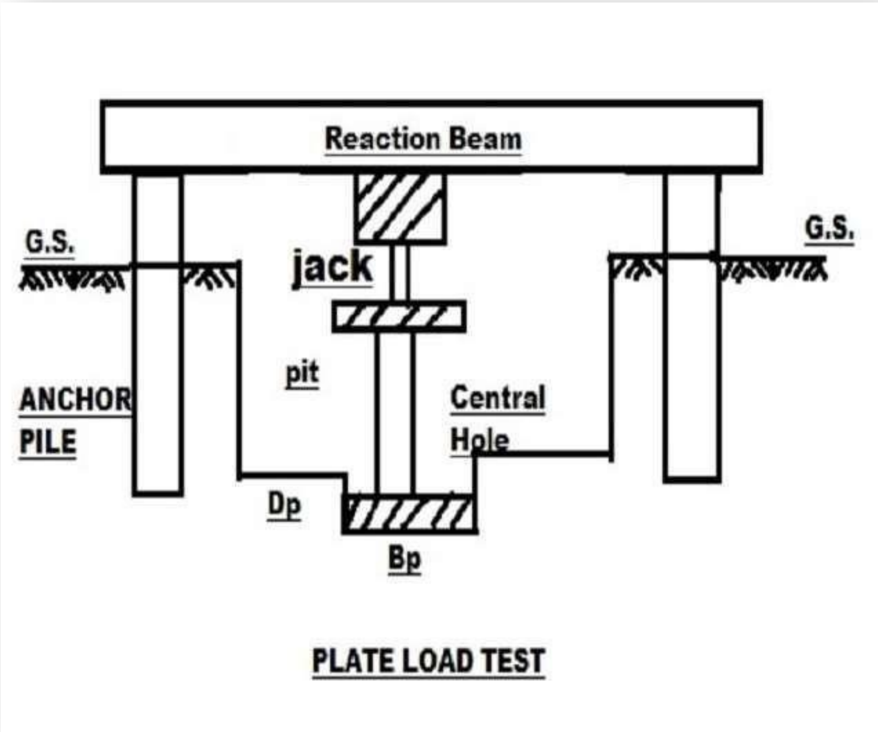


**Figure 2.1 Gravimetric Plate Load Test**

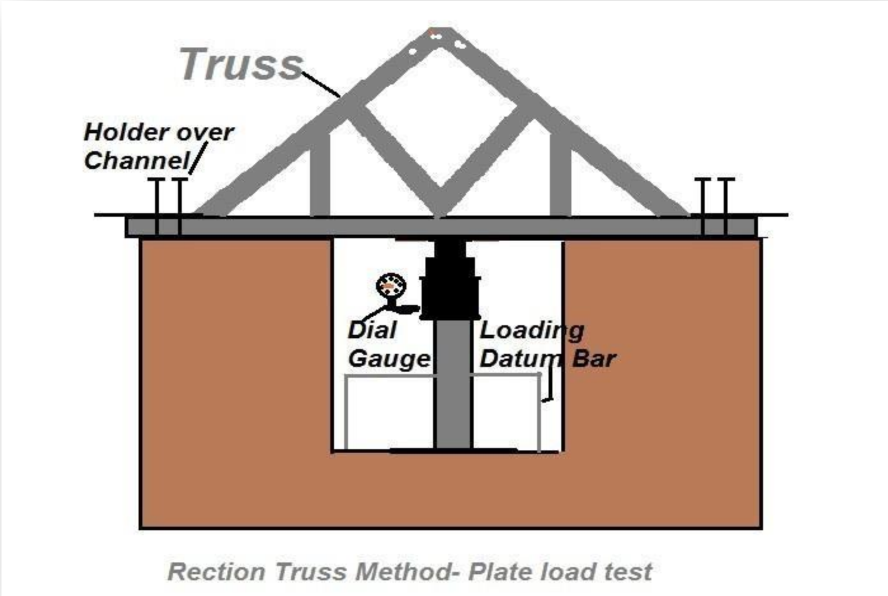


**Figure 2.2 Reaction Truss Apparatus**

## 2.5 Standard Penetration Test

Split spoon samplers, featuring an outer diameter of 50.8 mm and an interior diameter of 33.8 mm, are employed for Standard Penetration Tests (SPT) conducted in boreholes. Equipped with a cone end, these samplers play a critical role in assessing the in-situ density of cohesive less soils and evaluating the relative strength or deformability of rocks.

### 2.5.1 Method of SPT

Method An automatic trip device is employed to initiate repeated hits from a 63.5 kg weight, falling freely from a height of 760 mm. These hits are necessary to achieve a penetration depth of 450 mm. Each blow from a 450mm projectile is counted as one hit, with 75mm of penetration considered equivalent to one blow. This process aids in determining the depth of disturbed soil at the bottom of the borehole and identifies obstacles like large pebbles or cobblestones. If 50 blows are completed within the stipulated time, the starting and ending depths of the borehole must be recorded in the borehole record using specific symbols.

### 2.5.2 Correction of N value

Various factors influence the standard penetration test (SPT) penetration number, N, at a given depth. These factors include the efficiency of the SPT hammer, sampling technique, rod length adjustment, and borehole diameter. These elements help establish the relationship between test results and soil properties.

For instance, a significant aspect of this correlation concerns the energy transmitted by the hammer and drill rods. Sixty percent of the theoretical maximum energy ratio (ERM) is typically utilized. The hammer energy correction, denoted as N60, is applied to the measured blow counts represented by N. For rod lengths ranging from less than 3 meters to more than 10 meters, the correction factor is multiplied by 0.75. This accounts for an average energy ratio of 60%, which is standard practice when the field's ERM varies between 30% and 90%. The equation is expressed as follows:

$$N_{cor} = C_N N E_h C_d C_s C_b$$

**Figure 2.3 N60 Formula**

- N = measured penetration number
- CH= hammer efficiency (%)
- CB= correction for borehole diameter
- CS= sampler correction
- CR= correction for rod length

| Country | Hammer Type | Hammer Release | $C_H$ (%) |
|---|---|---|---|
| Japan | Donut<br>Donut | Free Fall<br>Rope and pulley | 78<br>67 |
| USA | Safety<br>Donut | Rope and pulley<br>Rope and pulley | 60<br>45 |
| Argentina | Donut | Rope and pulley | 45 |
| China | Donut | Free fall<br>Rope and pulley | 60<br>50 |

**Figure 2.4 Variation of hammer efficiency with hammer type and hammer release**

| Variable | $C_S$ |
|---|---|
| Standard sampler | 1.00 |
| With liner for dense sand and clay | 0.80 |
| With liner for loose sand | 0.90 |

**Figure 2.5 Variation of sampler correction factor with sampler type**

| Diameter (mm) | Diameter (inches) | $C_B$ |
|---|---|---|
| 60 – 120 | 2.4 – 4.7 | 1.0 |
| 150 | 6 | 1.05 |
| 200 | 8 | 1.15 |

**Figure 2.6 Variation of borehole correction factor**

| Rod length (m) | $C_R$ |
|---|---|
| > 10 | 1.0 |
| 6 – 10 | 0.95 |
| 4 – 6 | 0.85 |
| 0 – 4 | 0.75 |

**Figure 2.7 Variation In rod Length**

## 2.6 George P. Schmertmann Work on Settlement

The specific settlement prediction formula involves the empirical correlation with terms like soil compressibility (Cc), SPT N-value ( N60 ), foundation width (Bf), saturated unit weight of the soil (γ sat), foundation depth (Df ), and applied load (qapplied), is not directly attributed to a specific individual or researcher. Empirical correlations are often derived from statistical analyses of observed settlements in the field.

**S Predicted= (2×Cc×N60×Bf×γ sat×Df)**/ Q applied

**Figure 2.8 Schmertmann Formula**

The use of empirical correlations to estimate settlement based on geotechnical parameters has been a common practice in geotechnical engineering. Researchers and practitioners develop these correlations through empirical studies, often based on a large dataset of field observations.

One prominent example of an empirical correlation related to settlement is Schmertmann's Ratio**,** which is commonly used to estimate settlement based on SPT N-values. Schmertmann's Ratio is derived from statistical analyses of field data and is attributed to the work of George P. Schectman, a geotechnical engineer.

The conditions under which such empirical correlations come into use are often when there is a need for a quick and simplified method to estimate settlement in preliminary geotechnical analyses. These correlations are typically applied in the early stages of a project when detailed site investigations, laboratory testing, and sophisticated numerical modeling may not have been conducted. They provide a useful tool for initial assessments and feasibility studies.

It's crucial to recognize that empirical correlations have limitations, and their application should be done with care. Site-specific conditions, soil variability, and other factors can influence the accuracy of these correlations. As the project progresses, more detailed investigations and analyses are typically conducted to refine settlement predictions. Consulting with a geotechnical engineer is always recommended to ensure accurate and reliable results for specific project conditions.

The variables used are:

- **Soil Compressibility (Cc):**

Represents the soil's volume change potential under applied loads.

Obtained from laboratory tests.

- **Corrected SPT N-Value (N60):**

Indicates the soil's stiffness and resistance to penetration.

Derived from the Standard Penetration Test (SPT) and corrected to N60.

- **Foundation Width (Bf):**

Lateral dimension of the foundation base.

- **Saturated Unit Weight of the Soil (γ):**

Reflects the weight of saturated soil, considering pore water influence.

Affects effective stress and settlement behavior.

- **Foundation Depth (Df):**

Vertical dimension from ground surface to foundation base.

Deeper foundations may experience different soil conditions and settlement behavior.

- **Applied Load (q applied):**

External load exerted on the foundation.

Magnitude and distribution of loads significantly impact settlement.

In summary, empirical correlations aim to capture the intricate relationship between soil and foundation parameters and their impact on settlement behavior. While these correlations offer quick estimates, their reliability hinges on site-specific conditions. Therefore, additional testing, site-specific data, and engineering judgment are crucial for accurate settlement predictions, particularly in critical projects. Consulting with a geotechnical engineer is indispensable for precise estimations.

The formula, a simplified empirical correlation for settlement prediction, draws from geotechnical principles, considering factors like soil compressibility, foundation width, and applied load. Though it provides a swift estimate, caution is necessary, especially when dealing with site-specific conditions. For critical projects, consulting with a geotechnical engineer and conducting detailed analyses ensures more accurate predictions.

George P. Schmertmann's work on settlement predictions, notably the development of empirical correlations like Schmertmann's Ratio, involved statistical analyses of field data. This process typically includes data collection on foundation settlements, soil parameters, and regression analysis to identify correlations. Correlations are then developed and validated against additional field data or case histories. Refinement may occur iteratively based on new data or real-world applications, ensuring the correlation's reliability and accuracy in estimating settlement for shallow foundations in cohesionless soils.

## 2.7 Meyerhof Method

Named after geotechnical engineers Karl Terzaghi and Edward Arnold Meyerhof, an empirical correlation widely utilized in geotechnical engineering is employed to estimate foundation settlement based on Standard Penetration Test (SPT) results. Settlement prediction is pivotal in evaluating structure performance on soils, and the Meyerhof method offers a swift and pragmatic approach for such estimations.
Meyerhof Equation is given by:

$$S=(C \cdot N \cdot H)/ 1+e0$$

### 2.7.1 Key Components

- **Settlement (S):** Represents the vertical displacement or compression of the soil beneath the foundation**.**
- **Correlation Factor (C):** A dimensionless coefficient derived from empirical studies and local calibration. It adjusts the settlement prediction based on regional or site-specific conditions.
- **SPT N-value (N):** Obtained from the Standard Penetration Test, measuring the soil's resistance to penetration during drilling. The N-value reflects the soil's strength and density.
- **Effective Overburden Pressure (H):** Represents the vertical stress applied to the soil due to the weight of overlying materials. It's a critical parameter in settlement calculations.
- **Initial Void Ratio (e0):** Reflects the ratio of void volume to solid volume in the soil when initially deposited. It indicates the initial state of the soil.

### 2.7.2 Application

The Meyerhof method is highly valued for its simplicity and practicality, making it an ideal choice for quick settlement estimates in geotechnical engineering projects. Its straightforward application allows engineers to rapidly assess foundation settlement based on SPT results, providing valuable insights during preliminary design stages and site evaluations.

### 2.7.3 Limitations

Despite its convenience, the Meyerhof method has inherent limitations that must be considered. The method's reliance on empirical calibration with local data means it may not fully capture the complexities of soil behavior, leading to potential inaccuracies in settlement predictions, especially in regions with unique geological conditions or complex soil profiles. Additionally, the method's simplistic approach may overlook certain factors influencing settlement behavior, necessitating supplementary analyses and site-specific investigations for critical projects to ensure accurate and reliable results.

### 2.7.4 How Meyerhof Method is Different?

The Meyerhof method is one among several empirical correlations devised for settlement prediction in geotechnical engineering, sharing similarities with other approaches developed on analogous principles. While these methods stem from observed correlations in field data, variations in formulation, assumptions, and parameters distinguish them. Here are key differentiators of the Meyerhof method from others:

Empirical Nature: Like many settlement prediction methods, the Meyerhof method relies on empirical factors derived from field data. However, these factors may vary among different methods.

Correlation Factor (C): The Meyerhof method requires site-specific calibration of the correlation factor (C) based on local data, which may differ from other methods utilizing distinct coefficients or incorporating additional variables.

SPT N-Value: The Meyerhof method primarily utilizes the Standard Penetration Test (SPT) N-value as a principal input, whereas other methods might employ alternative soil parameters or combinations thereof.

Applicability and Limitations: Different methods exhibit varying ranges of applicability and limitations, with some being better suited for specific soil types or loading conditions. Understanding these nuances is vital for accurate settlement predictions.

Development Context: Variations in settlement prediction methods often stem from the specific geotechnical conditions and regional practices considered during their development and validation.

Incorporation of Additional Factors: Some methods may integrate additional factors or corrections based on advanced soil mechanics principles, whereas the relatively simple Meyerhof method might lack such refinements.

Examples of alternative settlement prediction methods include those proposed by Terzaghi, Schmertmann, and Bowles. Engineers typically select a method based on available data, complexity of analysis required, and desired accuracy level for the project. It's common practice to employ multiple methods and cross-check their outcomes to ensure a more robust estimation of settlement.

## 2.8 Empirical Method of Burland and Burbidge

The Burland and Burbidge method for settlement estimation in geotechnical engineering is a product of extensive analysis of over 200 case records, providing a robust framework for predicting settlement behavior. This approach emphasizes simplicity and practicality, considering key factors that influence foundation settlement.

At the core of this method is the consideration of the net pressure exerted at the bottom of the foundation. This net pressure represents the vertical stress imposed on the foundation by the overlying soil and structures. Additionally, the method accounts for the lateral dimension of the foundation base, known as the foundation width. Wider foundations have the capacity to distribute loads over a larger area, potentially mitigating settlement.

Another crucial aspect considered is the soil's resistance to penetration during drilling, assessed through the Standard Penetration Test (SPT). The average SPT blow count provides insights into the soil's stiffness and shear strength, which significantly influence settlement behavior. Furthermore, the method acknowledges the soil's historical loading conditions by incorporating the maximum previous effective overburden pressure.

The settlement estimation equation derived from the Burland and Burbidge method combines these factors into a straightforward expression. By considering the interplay between net pressure, foundation width, and soil properties indicated by the SPT results, the method offers a practical tool for predicting settlement behavior in various geotechnical contexts.

The empirical relations can be expressed simply as:

$$\mathbf{S = q * B^{0.7} * Ic}$$

$$\mathbf{Ic = 1.71/N^{1.4}}$$

# Chapter 3

# 3 METHODOLOGY

## 3.1 Plate Load Test

### 3.1.1 Introduction

The plate load test stands as a cornerstone in geotechnical engineering, offering insights into soil behavior crucial for designing stable foundations. This detailed methodology delineates the comprehensive process of executing a plate load test, spanning from meticulous preparation to exhaustive post-test analysis. By adhering to this methodology, engineers can garner precise data essential for informed decision-making in foundation design.

### 3.1.2 Preparation and Setup

A meticulous preparation phase sets the stage for a successful plate load test. Site selection entails identifying a representative location devoid of debris or vegetation that may skew results. Plate selection, crucial for accurate load distribution, necessitates choosing a steel plate of appropriate diameter and thickness. Instrumentation installation is pivotal; meticulous placement of dial gauges or electronic sensors around the plate's perimeter ensures accurate settlement measurements. Furthermore, the establishment of a robust load application system, be it hydraulic jacks or mechanical frames, guarantees controlled load application—a fundamental aspect of the test's integrity. In certain scenarios, excavation of a test pit beneath the plate offers deeper soil insights, provided strict safety measures are adhered to.

### 3.1.3 Procedure

Once meticulously prepared, the plate load test unfolds through a series of meticulously orchestrated steps. Initial measurements, capturing baseline reference elevations of instrumentation devices, lay the foundation for subsequent settlement readings. Plate placement, characterized by meticulous alignment and level verification, is imperative for accurate results. Load application, executed gradually in increments, allows the soil to acclimate between each step, while settlement monitoring provides real-time insights into soil behavior. Load removal, mirroring the application process, offers critical data on soil recovery dynamics. Post-test measurements, including final settlement readings and residual settlement assessments, conclude the test phase, paving the way for in-depth data analysis.

### 3.1.4 Post-Test Procedures

Post-test procedures play a pivotal role in extracting meaningful insights from collected data. Data processing, involving meticulous analysis of settlement readings and load increments, facilitates the derivation of crucial parameters such as bearing capacities. Interpretation of test results offers invaluable insights into soil load-bearing capacities, settlement characteristics, and deformation behavior. Report preparation, a meticulous documentation process encompassing methodology, observations, and analysis findings, serves as a comprehensive reference for design considerations. Lastly, recommendations based on test results guide foundation design, construction practices, and further site investigations.

## 3.2 Standard Penetration Test

### 3.2.1 Introduction

The Standard Penetration Test (SPT) serves as a cornerstone in geotechnical engineering, offering crucial insights into soil properties and behavior essential for foundation design and construction. This detailed methodology provides a comprehensive guide to conducting an SPT, encompassing every stage from meticulous preparation to exhaustive post-test analysis. By adhering to this methodology, engineers can acquire accurate and reliable data, thereby facilitating informed decision-making in geotechnical projects.

### 3.2.2 Preparation and Setup

A thorough preparation phase lays the groundwork for a successful SPT, ensuring accurate results and safety. Site selection involves identifying a representative location devoid of obstructions and with easy access for drilling equipment. Clearing the area of debris, vegetation, and loose soil facilitates drilling operations and minimizes interference with test results. Selection of appropriate drilling equipment, such as hand augers or rotary drilling rigs, depends on soil conditions and site accessibility. Careful borehole preparation is essential, with drilling performed to the desired depth while maintaining verticality and cleanliness to avoid contamination of soil samples. Installation and calibration of instrumentation devices, including the split-spoon sampler and drilling rod, are imperative to facilitate the SPT procedure and ensure accurate data collection.

### 3.2.3 Procedure

Once the preparation and setup are complete, the SPT procedure unfolds systematically, guided by meticulous execution and data recording. Drilling operations commence with the insertion of the split-spoon sampler into the borehole, followed by the application of downward force to penetrate the soil. Standard penetration is achieved by raising and dropping the standard hammer from a specified height onto the sampler, with blow counts recorded for each increment. Sample recovery after each set of blows allows for visual inspection and characterization of soil properties, contributing to comprehensive data collection. Depth measurements track the advancement of the sampler through the soil layers, providing insights into soil stratigraphy and resistance to penetration. Post-test procedures involve meticulous data processing and analysis, including calculation of key parameters such as N-values and interpretation of test results to assess soil stability and suitability for foundation design.

### 3.2.4 Post-Test Procedures

Post-test procedures are critical for extracting meaningful insights from collected data and informing subsequent engineering decisions. Data analysis entails processing the collected data using appropriate software or analysis methods to derive key parameters and soil properties. Interpretation of test results involves evaluating soil stratigraphy, strength characteristics, and engineering properties in comparison with design criteria and project requirements. Report preparation is a meticulous process that documents the SPT methodology, procedures, observations, and results in detail. Including relevant data plots, tables, and analysis findings enhances the comprehensiveness and clarity of the report, supporting conclusions drawn from the test. Recommendations based on the test results and analysis guide foundation design, construction considerations, and any additional testing or site investigations necessary to refine soil characterization and improve design accuracy.

### 3.2.5 Additional Considerations

Further research and case studies may provide deeper insights into specific applications and variations of the SPT methodology, enriching the understanding and utilization of this fundamental geotechnical test. Ongoing advancements in drilling technology and data analysis techniques may also influence the future evolution of SPT practices, enhancing its effectiveness and applicability in diverse engineering contexts. Continuous learning and adaptation to emerging technologies and methodologies ensure that geotechnical engineers remain at the forefront of innovation, driving progress and excellence in the field.

## Chapter 4

# 4 SITE CHARACTERISTICS

## 4.1 Sites

The sites encompassed in the data that has been used for the FYP are as follows:

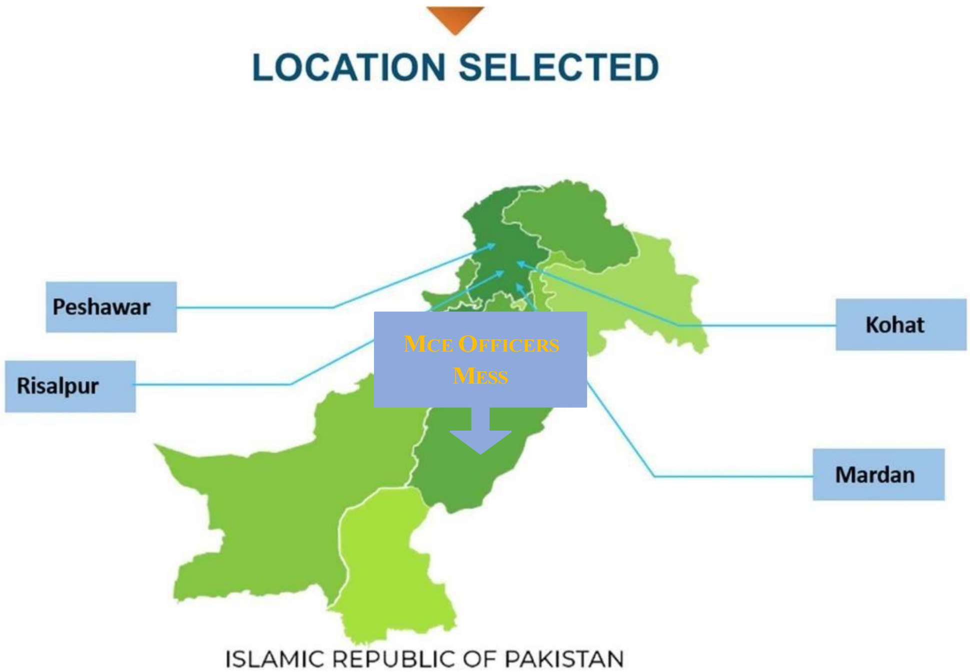


**Figure 4-1 Sites**

## 4.2 Conditions of the Sites

### 4.2.1 Geology

#### 4.2.1.1 Peshawar:

Peshawar resides within the Peshawar Basin, characterized by Quaternary alluvium deposits comprising sand, silt, clay, and gravel. These deposits rest atop sedimentary rocks from the Paleocene and Mesozoic eras, including sandstones, siltstones, shales, and limestone. The region's geology is intricate due to its proximity to the Himalayan Mountain range, resulting in tectonic activity and folding of rock layers. Additionally, the area is intersected by several active faults.

#### 4.2.1.2 Risalpur Cantt:

Risalpur lies on the Potohar Plateau, characterized by sedimentary rocks from the Paleocene and Mesozoic periods, including sandstones, siltstones, shales, and limestone. These rocks overlay basement rocks from the Precambrian era, composed of granite and gneiss. Similar to Peshawar, Risalpur is also intersected by several active faults.

#### 4.2.1.3 Kohat Cantt Soldiers Mess:

Kohat is situated within the Kohat Basin, sharing similarities with Peshawar and Risalpur in terms of sedimentary rock composition and active faults. Like the other regions, Kohat's geological formations include sandstones, siltstones, shales, and limestone, overlaying Precambrian basement rocks of granite and gneiss.

### 4.2.2 Climate

#### 4.2.2.1 Temperature:

All three regions experience a hot dry climate characterized by scorching summers and cool winters. Summer temperatures average around 36°C (96°F), occasionally surpassing 45°C (113°F), while winter temperatures average around 12°C (59°F).

#### 4.2.2.2 Rainfall:

Peshawar receives an average annual rainfall of approximately 400 millimeters, with the majority occurring during the monsoon season from July to September. Risalpur receives around 700 millimeters annually, and Kohat approximately 500 millimeters, with similar rainfall patterns and peak precipitation during the monsoon season.

### 4.2.3 Seismicity

Situated near the Himalayan Mountain range, all three regions are prone to high seismic activity due to the collision of the Indian and Eurasian tectonic plates. Classified as zone 2B seismic hazard zones, indicating significant seismic activity, the regions experienced a notable earthquake in 2023 with a Richter scale reading of 7.7.

### 4.2.4 Soil Profile

The soil profiles across the selected sites exhibit similarities, reflecting the underlying geology. Comprising layers influenced by sandstone, siltstone, shale, and conglomerate formations, typical soil profiles include loose to dense alluvial soil overlaying sandstone, siltstone, and shale layers. Beneath the shale layer, conglomerate or limestone may be present, contributing to varying engineering properties such as shear strength, compressibility, and permeability, which impact structural design and construction considerations.

# Chapter 5

# 5 RESULTS

## 5.1 General

A comprehensive series of geotechnical tests were executed, supplemented by data collection from previously conducted tests across various locations to amass valuable insights. These tests encompassed Plate Load Test, Standard Penetration Test (SPT), Unconfined Compression Strength Test, and analysis of Atterberg limits of soil samples. Furthermore, statistical analyses were meticulously conducted utilizing IBM SPSS software to ascertain correlations and derive equations, facilitating the establishment of relationships between settlement values obtained from each test.

## 5.2 SPT Boreholes

In locations where Standard Penetration Test (SPT) borehole tests were conducted, the predominant soil type identified up to the required depth was predominantly silt clay or clayey silt, with minimal instances of gravely soil types. This suggests that the soil composition in these areas primarily consists of fine-grained particles, with some presence of sand and gravel admixture.

The typical depth of the boreholes ranged around 35 feet, deemed sufficient for capturing the soil layer characteristics at the respective sites. An observable trend emerged as borehole depth increased: the number of blows required to drive the sampler augmented. This phenomenon is attributed to the densification and compaction of soil at greater depths, rendering penetration more challenging.

A total of 30 boreholes were initially recorded for analysis. However, subsequent removal of outliers and instances with potential recording errors led to the utilization of 23 boreholes in the final analysis.

| | | | |
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**ANNEX-B**

## Borehole Logs

| | |
|---|---|
| Bore Hole No | 1 |
| Date of Boring | 22 March,2022 |
| Type of Boring | Hand Percussion |
| Ground Water Table | Nil |
| Final Depth | 30ft |
| Logged by | Anwar Ali , simal & Yaqoob |

| Material Description | Classification | Sample No. | Depth ( ft ) | SPT Blows 1st 6" | SPT Blows 2nd 6" | SPT Blows 3rd 6" | N Value | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | 1 | | | | | |
| L.L=26.3%<br>P.L=23.2%<br>PI=3.1% | ML | | 2 | | | | | |
| | | | 3 | | | | | |
| | | | 4 | 2 | 2 | 3 | 5 | |
| | | | 6 | | | | | |
| | | | 8 | 3 | 4 | 4 | 8 | |
| | | DS/SS | 10 | | | | | |
| | | | 12 | 3 | 4 | 5 | 9 | |
| | | | 14 | | | | | |
| SAND =94.0 %<br>FINES =6.0% | SP | | 15 | | | | | |
| | | | 16 | 5 | 7 | 8 | 15 | |
| | | | 17 | | | | | |
| | | | 18 | 6 | 8 | 11 | 19 | |
| L.L=24.8%<br>P.L=18.1%<br>PI=6.7% | | | 20 | | | | | |
| | | | 22 | 6 | 10 | 12 | 22 | |
| | CL-ML | DS/SS | 25 | | | | | |
| | | | 26 | | | | | |
| | | | 28 | 10 | 11 | 14 | 25 | |
| | | | 30 | | | | | |

**Figure 5.1 Borehole Np.1 with N-Value**

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|---|---|

**ANNEX-B**

**Borehole Logs**

| | |
|---|---|
| Bore Hole No | 1 |
| Date of Boring | 03 Sep, 2022 |
| Type of Boring | Percussion |
| Ground Water Table | Nil |
| Final Depth | 30ft |
| Logged by | Haider & Asghar |

| Material Description | Classification | Sample No. | Depth ( ft ) | SPT & CPT Blows | | | N Value | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | | | 1st 6" | 2nd 6" | 3rd 6" | | |
| | | | 1 | | | | | |
| | | | 2 | | | | | |
| | | | 3 | | | | | |
| Gravel=43.0% | | SS | 4 | 01 | 01 | 01 | 02 | CPT TEST |
| Sand=17.0% | **Filling Material** | | 5 | | | | | |
| Fines=40% | | | 6 | | | | | |
| | **(Bricks, shaper Organic )** | SS | 8 | 02 | 02 | 03 | 05 | CPT TEST |
| | | | 10 | | | | | |
| | | | 11 | | | | | |
| | | | 12 | | | | | |
| | | SS | 13 | 01 | 01 | 1.5 | 2.5 | SPT TEST |
| | | | 14 | | | | | |
| | | | 15 | | | | | |
| | | | 16 | | | | | |
| | | | 18 | | | | | |
| | | | 19 | | | | | |
| | | SS | 20 | 02 | 02 | 02 | 04 | SPT TEST |
| | | | 22 | | | | | |
| | | | 24 | | | | | |
| | | | 25 | | | | | |
| | **CLAY** | SS/UDS | 26.5 | 01 | 02 | 02 | 04 | SPT TEST |
| L.L=35.8% | | | 28 | | | | | |
| P.L=22.6% | | | 29 | | | | | |
| | | | 30 | | | | | |

**Figure 5.2 Borehole No.2 with N-Value**

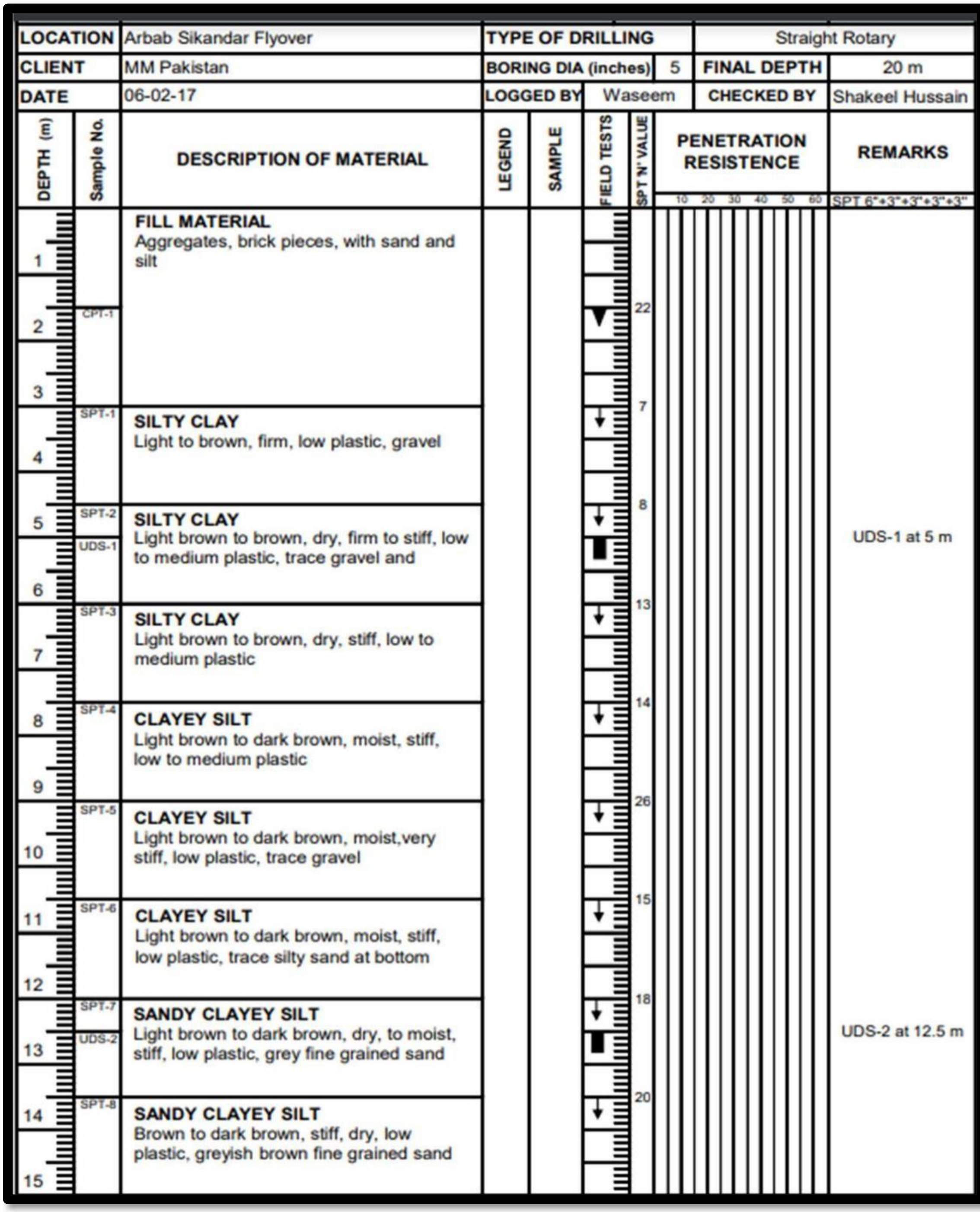


**Figure 5.3 Borehole No.3 with N-Value**

**Chapter 6**

# 6 ANALYSIS AND DISCUSSION

## 6.1 IBM SPSS

The "International Business Machine Statistical Package for the Social Sciences," commonly known as SPSS, stands as a globally recognized and powerful tool employed for statistical analysis. Within our project scope, SPSS has played a pivotal role in deriving both correlation and prediction equations based on presented coefficients.

Correlation analysis conducted through SPSS illuminates the degree of association between two or more variables, shedding light on the extent to which changes in one variable correspond to changes in another. This analytical approach enables us to discern the strength and direction of relationships between variables, offering valuable insights into patterns and trends within the dataset.

In contrast, regression analysis carried out via SPSS delves deeper into the predictive capabilities of the variables under scrutiny. By identifying coefficients that best fit a model equation, regression analysis facilitates the formulation of predictive equations that elucidate the relationship between variables. These equations can take various forms, including linear, logarithmic, or exponential, depending on the nature of the data and the underlying relationships being explored. Through regression analysis, SPSS empowers researchers to forecast outcomes and make informed decisions based on data-driven insights.

## 6.2 Pearson’s Correlation Coefficient

It is the test statistics that measures the statistical relationship, or association, between two continuous variables. It is known as the best method of measuring the association between variables of interest because it is based on the method of covariance. It gives information about the magnitude of the association, or correlation, as well as the directionof the relationship. It lies between +1 to -1.

There are 5 degrees of this coeffiecient

1. Perfect Correlation = +1
2. High Degree = 0.75-0.99
3. Moderate Degree =0.50.75
4. Low Degree = 0.25-0.50
5. No Correlation < 0.25

## 6.3 Settlement Prediction

Regression Analysis was used again to develop relation between the loads exerted on the soil and the settlement that it undergoes with respect to that loading through the plate load test. 4 different locations were selected for this analysis. Each of these have different settlements so tailor-made equations were found for each location separately through linear regression analysis based on our collected data.

It is important to note that these predictions are for the settlement of the plate. Settlement of the foundation can easily be extrapolated from the following formula:

**S (footing) = S (foundation) x (B (footing) / B (plate)**

Where:

- S (footing) is the settlement of the footing (in meters)
- S (foundation) is the settlement of the foundation (in meters)
- B (footing) is the width of the footing (in meters)
- B (plate) is the width of the plate (in meters)

## 6.4 Burland and Burbidge Equation

Comparing SPT and PLT results by using the equation.

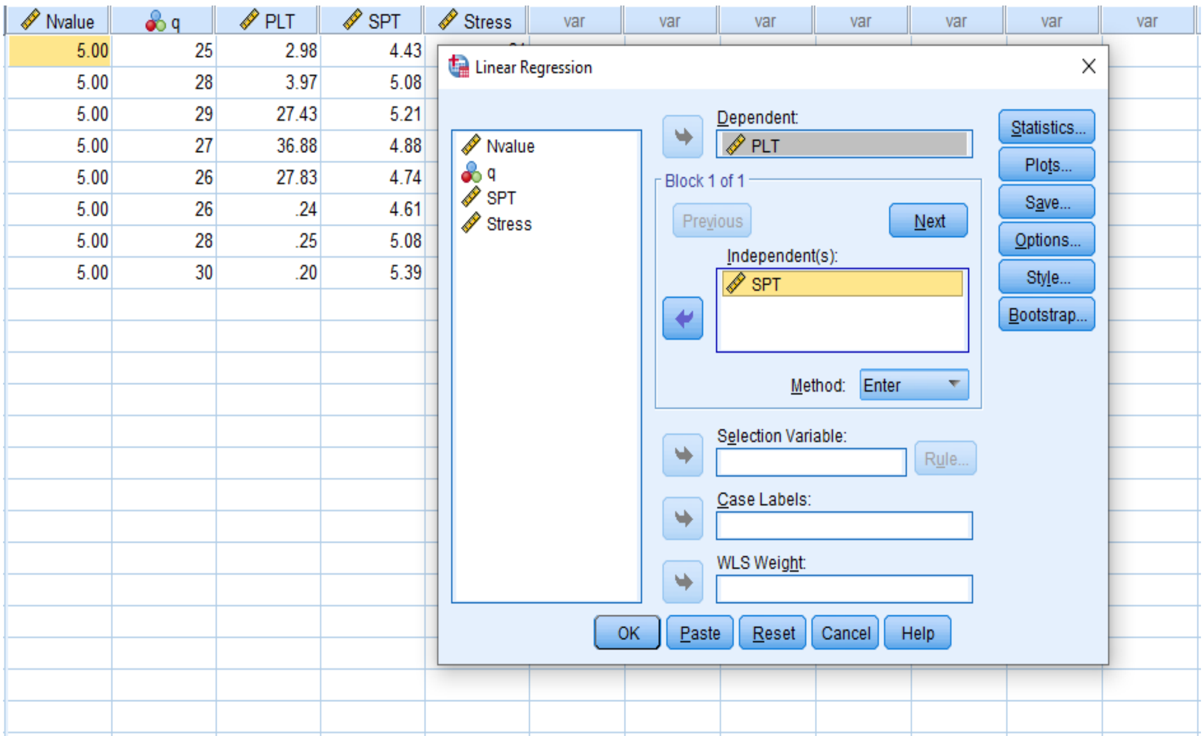


**Figure 6-1 Data Input**

The results of SPT(mm) are obtained from the equation:

***S Predicted= 1.71x(qxB^0.7)/N^1.4***

Now we used the regression analysis software to obtain the co relations between SPT and PLT tests.

## Regression

[DataSet0]

**Descriptive Statistics**

| | Mean | Std. Deviation | N |
|---|---|---|---|
| PLT | 12.4728 | 15.43374 | 8 |
| SPT | 4.9270 | .32339 | 8 |

**Correlations**

| | | PLT | SPT |
|---|---|---|---|
| Pearson Correlation | PLT | 1.000 | -.002 |
| | SPT | -.002 | 1.000 |
| Sig. (1-tailed) | PLT | . | .498 |
| | SPT | .498 | . |
| N | PLT | 8 | 8 |
| | SPT | 8 | 8 |

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | SPT[b] | . | Enter |

a. Dependent Variable: PLT

b. All requested variables entered.

**Figure 6-2 Liner Regression**

Using this we can easily obtain a value of SPT using the following equation.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | R Square Change | F Change | df1 | df2 | Sig. F Change |
| 1 | .002[a] | .000 | -.167 | 16.67032 | .000 | .000 | 1 | 6 | .996 |

a. Predictors: (Constant), SPT

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | .007 | 1 | .007 | .000 | .996[b] |
| | Residual | 1667.397 | 6 | 277.899 | | |
| | Total | 1667.403 | 7 | | | |

a. Dependent Variable: PLT

b. Predictors: (Constant), SPT

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | Correlations | | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Zero-order | Partial | Part | Tolerance | VIF |
| 1 | (Constant) | 12.949 | 96.176 | | .135 | .897 | | | | | |
| | SPT | -.097 | 19.483 | -.002 | -.005 | .996 | -.002 | -.002 | -.002 | 1.000 | 1.000 |

a. Dependent Variable: PLT

**Figure 6-3 Results**

$$PLT_{mm} = (-0.097x\ B^{0.7}\ x\ SPT_{mm}) + 12.49$$

**Figure 6-4 Regression Equation**

Here SPT is dependent value whereas PLT is a independent variable. We can also go for the other way around keeping the PLT as dependent variable and SPT as independent variable. For that we will have to re-run the SPSS regression analysis and find out the new equation of correlation.

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics: R Square Change | F Change | df1 | df2 | Sig. F Change |
|---|---|---|---|---|---|---|---|---|---|
| 1 | .002[a] | .000 | -.167 | .34930 | .000 | .000 | 1 | 6 | .996 |

a. Predictors: (Constant), PLT

**ANOVA[a]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | .000 | 1 | .000 | .000 | .996[b] |
| | Residual | .732 | 6 | .122 | | |
| | Total | .732 | 7 | | | |

a. Dependent Variable: SPT

b. Predictors: (Constant), PLT

**Coefficients[a]**

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. | Correlations Zero-order | Partial | Part | Collinearity Statistics Tolerance | VIF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (Constant) | 4.928 | .163 | | 30.193 | .000 | | | | | |
| | PLT | -4.240E-5 | .009 | -.002 | -.005 | .996 | -.002 | -.002 | -.002 | 1.000 | 1.000 |

a. Dependent Variable: SPT

**Figure 6-5 Regression Results**

Now using this we can easily obtained the other equation:

Here using above variable and constants we know the equation as;

$$B^{0.7} \times SPT_{mm} = (-0.000042 \times PLT_{mm}) + 4.928$$

**Figure 6-6 Regression Equation**

These data are from the areas of KPK. Using these equations now we can easily obtain settlement predicted values. This makes it easier for us to understand how if one test cannot be performed at one location allows us to perform other settlement test and convert values for more clarity and accurate prediction.

Now to make it more convenient for the user or the geo technical engineer let us assume the values for B=1m, 1.5m, 2m, 2.5m and put up again:

For **1m width** of foundation:

$$PLT_{mm} = (-0.097 \times SPT_{mm}) + 12.49$$

For **1.5m width** of foundation:

$$PLT_{mm} = (-0.12 \times SPT_{mm}) + 12.49$$

For **2m width** of foundation:

$$PLT_{mm} = (-0.15 \times SPT_{mm}) + 12.49$$

For **2.5m width** of foundation:

$$PLT_{mm} = (-0.184 \times SPT_{mm}) + 12.49$$

Similarly, for the SPT mm prediction:

For **1m width** of foundation:

$$SPT_{mm} = (-0.0000425 \times PLT_{mm}) + 4.928$$

For **1.5 m width** of foundation:

$$1.328 \times SPT_{mm} = (-0.0000425 \times PLT_{mm}) + 4.928$$

For **2 m width** of foundation:

$$1.624 \times SPT_{mm} = (-0.0000425 \times PLT_{mm}) + 4.928$$

For **2.5 m width** of foundation:

$$1.899 \times SPT_{mm} = (-0.0000425 \times PLT_{mm}) + 4.928$$

There are numerous other methods of co relation mentioned in the literature which can be used to predict the settlement using the SPT data and then predict the PLT based settlement using these co relations given here.

This is way forward toward greater ease where geo technical engineers can become more and more precise about settlement prediction where they is un availability of PLT test performance.

# CHAPTER 7

# 7 SIGNIFICANCE

## 7.1 Introduction

Geotechnical engineering, the backbone of sound structural design, becomes particularly nuanced when dealing with diverse geological landscapes such as those found in Khyber Pakhtunkhwa (KP), Pakistan. The correlation between Standard Penetration Test (SPT) and Plate Load Test (PLT) emerges as a critical focal point for estimating settlement in KP soils, offering a tailored approach to geotechnical analysis. This exploration seeks to delve into the multifaceted significance of this correlation within the specific context of KP.

## 7.2 Site-Specific Considerations

Khyber Pakhtunkhwa's topographical and geological diversity demands a site-specific understanding of soil behavior. The correlation between SPT and PLT provides a nuanced lens through which to interpret and predict settlement patterns, considering the unique soil properties of the region. By homing in on this correlation, engineers can navigate the complexities of foundation design, ensuring structures are grounded on stable soil in diverse conditions specific to KP.

## 7.3 Foundation Design and Cost-Efficiency

Settlement considerations are paramount in foundational design, and an intricate correlation between SPT and PLT stands as a cost-effective solution. If SPT data proves reliable in predicting settlement, the need for supplementary, often more expensive tests such as PLT could be diminished. This not only optimizes geotechnical investigations but also streamlines the foundation design process, a crucial factor in the economic feasibility of construction projects in KP.

## 7.4 Construction Safety

The correlation between SPT and PLT directly impacts construction safety, a non-negotiable aspect of any structural endeavor. Accurate settlement estimation is not merely a matter of structural integrity but a prerequisite for averting issues such as differential settlement, which could compromise the safety of the structure. By establishing a robust correlation, engineers contribute to the design of foundations that not only meet safety standards but mitigate the risk of settlement-related failures during and post-construction.

## 7.5 Infrastructure Development and Empirical Correlations

As Khyber Pakhtunkhwa undergoes substantial infrastructure development, the correlation between SPT and PLT becomes a linchpin in the process. Reliable settlement estimation methods are pivotal for the successful construction of roads, bridges, and buildings. Empirical correlations derived from local soil conditions not only enhance the efficiency of the design process but also contribute to the creation of resilient infrastructure, tailored to withstand the unique geotechnical challenges of the region.

## 7.6 Research and Development

Beyond its immediate applications, the correlation between SPT and PLT for settlement estimation in KP soils is a catalyst for ongoing research and development in geotechnical engineering. This exploration deepens our understanding of soil behavior, opening avenues for innovations in design methodologies and construction practices. The insights derived from this correlation transcend regional applications, potentially serving as a template for other areas with similar soil conditions, thereby contributing to the broader knowledge base of geotechnical engineering.

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