**UNIVERSITI TEKNOLOGI MARA**

# DEVELOPMENT OF AN EMPIRICAL MODELLING FRAMEWORK FOR ESTIMATING PHYSICAL SOIL PROPERTIES USING STANDARD PENETRATION TEST (SPT) *N*-VALUES

**NOR ASHIKIN BINTI YAHAYA**

**PhD**

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Thesis submitted in fulfilment
of the requirements for the degree of
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**(Civil Engineering)**

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# ABSTRACT

Soft soils present significant challenges in geotechnical engineering due to their low shear strength, high compressibility and poor accessibility for site investigation. Reliable subsurface characterisation is essential for engineering design and foundation planning. The Standard Penetration Test (SPT) is widely used because it provides rapid and economical field data for subsurface evaluation. However, the determination of physical soil properties still depends largely on laboratory testing, which is time-consuming and may delay engineering decision-making. Accordingly, this study aimed to identify the surface and subsurface soil profile, analyse SPT *N*-values, determine the physical soil properties of subsurface soils, establish correlations between SPT *N*-values and physical soil properties, and develop empirical prediction models for estimating physical soil properties to support preliminary geotechnical assessment. The study was conducted at PT21044, Cyberjaya, Mukim Dengkil, Selangor. A total of 31 boreholes were drilled to approximately 30 m, with SPT conducted at 1.5 m intervals. Laboratory tests were performed to determine Moisture Content, Bulk Density, Specific Gravity and Particle Size Distribution. Pearson Correlation Analysis was used to evaluate relationships between SPT *N*-values and physical soil properties, while Multiple Linear Regression (MLR) analysis was employed to develop empirical prediction models. The developed models were validated using independent borehole datasets from Lot 120185 and Lot 120188, where paired sample *t*-tests evaluated the agreement between predicted and measured values. The results demonstrated a strong positive correlation between depth and SPT *N*-value ($r = 0.901$), confirming the expected increase in soil resistance with depth. Pearson Correlation Analysis and Multiple Linear Regression established significant relationships between SPT *N*-values and the selected physical soil properties, demonstrating that SPT data can be reliably used to estimate these properties in soft soils. Four empirical prediction models were developed. The Moisture Content and Specific Gravity models achieved coefficients of determination ($R^2$) of 72.55% and 86.75%, respectively, while the Clay Content and Bulk Density models recorded $R^2$ values of 89.88% and 72.34%, respectively. Validation results showed good agreement between predicted and laboratory-measured physical soil properties, with paired sample *t*-tests indicating no statistically significant differences ($p > 0.05$). These findings confirm the reliability and applicability of the developed empirical models for preliminary subsurface characterisation. The novelty of this study lies in the development and validation of an integrated empirical modelling framework that sequentially estimates Moisture Content, Specific Gravity, Clay Content and Bulk Density from SPT *N*-values and depth. The proposed framework provides a rapid and cost-effective decision-support tool for preliminary site assessment, foundation planning and engineering decision-making, thereby reducing the time and cost associated with laboratory testing while improving the efficiency of preliminary geotechnical investigations. Furthermore, the developed framework provides a practical bridge between field investigation data and preliminary geotechnical assessment, supporting more efficient and informed engineering decision-making for soft soil developments.

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# LIST OF SYMBOLS

**Symbols**

| | |
|---|---|
| Clay | Clay Content |
| D | Depth |
| $d_{10}$ | Maximum Size of the Smallest 10% of the Sample |
| $d_{30}$ | Maximum Size of the Smallest 30% of the Sample |
| $d_{60}$ | Maximum Size of the Smallest 60% of the Sample |
| $G_s$ | Specific Gravity |
| LL | Liquid Limit |
| N | Measured SPT N-value During Field Assessment |
| p | Probability Value Used to Determine Statistical Significance |
| PI | Plasticity Index |
| PL | Plastic Limit |
| r | Pearson Correlation Coefficient |
| $R^2$ | Coefficient of Determination |
| w | Moisture Content |
| $\rho_b$ | Bulk Density |

# LIST OF ABBREVIATIONS

**Abbreviations**

| | |
|---|---|
| BH | Borehole |
| BS | British Standard |
| CL | Clay |
| CPT | Cone Penetration Test |
| LL | Liquid Limit |
| MC | Moisture Content |
| PI | Plasticity Index |
| PL | Plastic Limit |
| PSD | Particle Size Distribution |
| SI | Site Investigation |
| SPT | Standard Penetration Test |
| UiTM | Universiti Teknologi MARA |

# CHAPTER 1
# INTRODUCTION

## 1.1 Research Background

Understanding surface and subsurface soil profiles is important in geotechnical site investigations. The surface soil profile, as the uppermost layer of the ground, is formed through weathering and environmental processes. In contrast, the subsurface profile consists of deeper stratified materials that have developed over geological time. Each soil layer exhibits distinct physical characteristics that influence soil behaviour under loading and groundwater conditions, thereby affecting foundation performance and structural interaction (Omolaiye et al., 2024).

Surface soils can be identified through visual inspection, topographic surveys and the mapping of site features, including vegetation, drainage patterns, water bodies and surface deposits. These observations provide preliminary information on site conditions and assist in planning subsequent subsurface investigations. However, rapid urban development, increasingly complex ground conditions and the growing demand for resilient infrastructure have highlighted that surface observations alone are insufficient for reliable subsurface characterisation. Consequently, integrated site investigation approaches combining surface assessment, in-situ testing and laboratory investigation are recommended to improve the accuracy and reliability of geotechnical evaluations (Dibia, 2024).

Subsurface conditions, consisting of horizons of Clay, Silt, Sand, gravel or rock are influenced by prolonged geological processes including deposition, weathering and compaction. Geological and topographical information, including regional geological maps, facilitates the preliminary interpretation of subsurface conditions before detailed field investigations are conducted. Soft soils, such as Peat and Silty Clay, are commonly associated with lowland topography and are widely distributed within the Quaternary alluvial deposits of Selangor (Minerals and Geoscience Department, 2014). Accurate identification of these subsurface profiles is essential, as incorrect interpretation may lead to inappropriate foundation selection, structural instability and costly remedial works (Omolaiye et al., 2024).

After establishing the soil profile, Standard Penetration Test (SPT) N-values are obtained during borehole drilling to determine the penetration resistance of soil layers at designated depths. The test is performed by driving a standard split-barrel sampler into the soil using a 63.5 kg hammer falling freely through a height of 760 mm. The first 150 mm penetration is regarded as the seating drive, while the number of blows required to penetrate the subsequent 300 mm is recorded as the SPT N-value in accordance with BS 1377-9. Owing to its simplicity, cost-effectiveness and practical applicability, the SPT remains one of the most widely adopted in-situ tests for preliminary subsurface characterisation and geotechnical assessment (Abu Bakar et al., 2023).

The precision and comprehensiveness of site investigation data significantly influence all subsequent stages of design and construction. In challenging ground conditions such as those encountered in Cyberjaya, inadequate site investigation may lead to technical, economic, and safety-related consequences. Consequently, site investigation forms the fundamental basis for reliable geotechnical assessment and informed engineering decisions (Almohammedi, 2024). The integration of SPT data with comprehensive borehole logs facilitates the establishment of accurate subsurface profiles that reflect both lithology and engineering behaviour (Omolaiye et al., 2024).

Laboratory testing is essential for determining soil physical and mechanical properties, complementing field measurements. Laboratory tests, such as Moisture Content analysis, Atterberg limits, Dry and Bulk Densities, Specific Gravity, Particle Size Distribution (PSD), One-Dimensional Consolidation and Strength Tests including Consolidated Undrained Triaxial Compression provide accurate measurements of soil behaviour under different conditions by (Craig, 2004). Parameters such as the Plasticity Index (PI) and Liquid Limit (LL) are instrumental in classifying cohesive soils and predicting their volume change tendencies. Additionally, density and grain size distribution significantly affect compressibility and permeability (Murthy, 2002). Standard laboratory procedures conducted in accordance with BS 1377 provide reliable measurements of soil index properties, supporting consistent soil characterisation and informed engineering decisions regarding foundation selection and ground improvement measures (British Standards Institution, 1990). Laboratory results provide a framework for correlating field test outcomes and developing predictive relationships.

The correlation between SPT *N*-values and laboratory-measured physical soil properties has been extensively investigated because it facilitates more efficient

subsurface characterisation, particularly when comprehensive laboratory testing is constrained by time or cost (Ibrahim et al., 2023). Empirical and statistical correlations have been established that correlate *N*-values with Moisture Content, Density, Specific Gravity, Plasticity, Strength Parameters and other soil indices (Baharuddin et al., 2020). Correlations are especially significant in tropical residual soils, where the variability in soil formation and weathering profiles results in different behaviour that may not be adequately represented by individual testing methods (Rahman et al., 2022).

Additionally, SPT-based empirical correlations have been widely applied to estimate physical soil properties, including Moisture Content, Specific Gravity, Density and soil classification parameters, thereby supporting more efficient subsurface characterisation and preliminary geotechnical assessment (Razali et al., 2025). Many published correlations were established within particular climatic and geological contexts and may not be universally applicable across all regions. Consequently, site-specific correlations derived from local borehole and laboratory data provide improved accuracy and reliability in engineering applications.

Recent developments in statistical modelling have facilitated the incorporation of various variables into predictive frameworks, thereby improving the estimation of soil properties based on measurable field parameters, including SPT *N*-values and depth. Statistical tools such as regression analysis, logarithmic transformations and model diagnostic metrics (e.g., $R^2$ and *p*-values) offer a systematic method for quantifying relationships among variables and enhancing prediction accuracy (Montgomery & Runger, 2021). To address these challenges, this study proposes an empirical modelling framework based on Pearson Correlation Analysis and Multiple Linear Regression (MLR) to establish relationships between SPT *N*-values, depth and selected physical soil properties including Moisture Content, Specific Gravity, Bulk Density and Clay Content. The proposed framework provides a systematic approach for estimating physical soil properties from readily available SPT data, thereby supporting more efficient preliminary site investigations.

## 1.2 Problem Statement

Soft soil environments especially in swampy or low-lying tropical region areas like PT 21044, Cyberjaya present considerable challenges for geotechnical site investigations due to their complicated stratigraphy, higher compressibility and poor engineering characteristics. The subsurface at this site primarily consists of unconsolidated alluvial deposits of Clay and Silt in saturated conditions, exhibiting significant variability in strength and composition. The identified conditions complicate the assessment of surface and subsurface soil profiles, increasing the risk of misinterpreting soil layering and bearing capacity which may lead to foundation instability or excessive settlement (Holtz et al., 2011). Moreover, the soft organic-rich soils prevalent in these environments generally exhibit low shear strength and are susceptible to disturbance during sampling, which may increase the complexity of field investigations. SPT is a widely used in-situ method for evaluating subsurface soil resistance and remains a reliable technique for soft soil characterisation when conducted in accordance with standard testing procedures. Nevertheless, factors such as soil disturbance, groundwater conditions and operator variability may influence the measured SPT N-values, highlighting the importance of appropriate interpretation and empirical modelling to improve the estimation of physical soil properties (Razali et al., 2025).

SPT is widely used in geotechnical site investigations to determine soil penetration resistance at various depths because of its simplicity, cost-effectiveness and widespread application. In soft soil environments such as PT 21044, Cyberjaya, SPT N-values typically reflect the low penetration resistance associated with highly compressible and high-moisture soils. The measured SPT N-values provide valuable information for identifying soft soil layers and assessing subsurface conditions, although their interpretation should consider factors such as soil variability, groundwater conditions and sample disturbance. Furthermore, careful borehole logging and appropriate laboratory testing complement SPT data, providing a more comprehensive understanding of subsurface conditions and supporting foundation assessment (Abu Bakar et al., 2023). The challenges associated with soft soil investigations are further compounded by practical and environmental constraints. Saturated ground conditions and low bearing capacity often restrict site accessibility, requiring specialised drilling equipment and temporary working platforms to facilitate

field investigations. Waterlogged conditions may also increase the difficulty of soil sampling, particularly in clayey soils, requiring careful sampling procedures and quality control to obtain representative soil specimens (Jolivet et al., 2023). These additional requirements increase the cost and duration of site investigations and present operational and safety challenges. Furthermore, difficult ground conditions may affect field operations and require careful execution and interpretation of investigation data to ensure reliable subsurface characterisation (Almohammedi, 2024).

Laboratory testing is essential for determining the physical soil properties that govern soil behaviour and support geotechnical assessment. The laboratory programme typically includes the determination of Moisture Content, Plasticity Index, Bulk Density, Specific Gravity and Particle Size Distribution using standard testing procedures. In soft and saturated soils such as those found in Cyberjaya, laboratory testing may require additional time and careful sample handling to preserve representative soil conditions because of the high Moisture Content and the susceptibility of these soils to disturbance during sampling and transportation (Paniagua et al., 2019). These issues may harm the reliability of test results and postpone the availability of critical design parameters. Furthermore, limited site accessibility caused by waterlogged ground conditions and the need for specialised drilling platforms often restrict the extent of site investigation by reducing the number of boreholes and recoverable soil samples, particularly in soft soil environments. Consequently, laboratory datasets alone may not sufficiently characterise subsurface conditions due to the inherent spatial variability of soil deposits. This limitation is often compounded by budgetary and time constraints, which may reduce the scope of field and laboratory investigations, particularly for projects involving soft ground conditions. As a result, insufficient site investigation data may increase geotechnical uncertainty and affect the reliability of engineering assessments (Purdy et al., 2021). Field-derived SPT N-values and laboratory-measured physical soil properties provide complementary information for subsurface characterisation. Establishing reliable empirical relationships between these datasets improves the interpretation of subsurface conditions and supports more informed engineering assessments. Such relationships are particularly valuable during the preliminary stage of site investigation, when rapid estimation of physical soil properties is required (Baharuddin et al., 2020). These challenges emphasise the need for an integrated empirical modelling framework that combines field-derived SPT N-

values with laboratory-measured physical soil properties to improve the interpretation of subsurface conditions in soft soil environments.

Researchers have proposed empirical correlations between SPT N-values and physical soil properties to estimate soil parameters during the preliminary stage of site investigation, particularly when laboratory test results are limited or pending (Rahman et al., 2022). Although these empirical correlations have demonstrated practical value, most were developed using data from different geological environments. Consequently, their direct application to Malaysian soft soils may be limited because of differences in soil composition, depositional environment and moisture conditions (Razali et al., 2025). The application of non-local models in regions such as Cyberjaya may reduce the accuracy of estimating physical soil properties because of local geological variability. Furthermore, many existing empirical models do not fully consider the combined influence of variables such as depth, SPT N-values and soil characteristics, particularly under tropical soft soil conditions (Ibrahim et al., 2023). The identified limitations emphasize an important problem in modern geotechnical practice that lack of measured local background information and statistically reliable models that effectively relate field data such as SPT N-values with laboratory testing to determined soil properties.

This research presents an empirical statistical modelling framework based on Pearson Correlation Analysis and MLR to estimate physical soil properties from SPT N-values and depth. The aim is to enhance the precision and effectiveness of soil property estimation in the soft ground conditions of Cyberjaya and similar terrains. The model integrates field data with laboratory test measured physical soil properties, thereby reducing the dependence on extensive laboratory testing during the preliminary stage of site investigation, particularly in areas with challenging site conditions or limited resources (Purdy et al., 2021). The proposed framework facilitates quick and dependable subsurface characterization, improving preliminary analysis and assisting in more informed engineering design decisions. The proposed framework employs statistical techniques, including regression analysis and variable transformation, to establish statistically reliable prediction models that improve the estimation of physical soil properties, reduce uncertainty and support cost-effective geotechnical site investigations (Zhang et al., 2023). This approach improves safety, minimizes delays and optimizes the decision-making process in geotechnical engineering.

## 1.3 Objectives of Research

The objectives of the study are:

a) To identify the surface and subsurface soil profile
b) To determine the SPT *N*-value from the engineering borehole log results.
c) To evaluate the physical properties of subsurface soils based on laboratory testing results.
d) To establish the relationships between SPT *N*-values and selected physical soil properties.
e) To develop an empirical modelling framework for estimating physical soil properties using SPT *N*-values to improve the reliability of subsurface characterisation.

## 1.4 Scope of Study

The study is conducted at PT 21044, Cyberjaya, located in Mukim Dengkil, Daerah Sepang, Selangor Darul Ehsan that involve an area of approximately 152 acres. The site is located within a quaternary geological formation defined by unconsolidated alluvial deposits, predominantly comprising Peat, Clay and Silt (Minerals and Geoscience Department, 2014). The topography is primarily flat and low-lying, marked by prevalent waterlogged conditions particularly during the rainy seasons.

SPT were conducted at 1.5 m intervals across 31 boreholes to evaluate the resistance of soil layers at different depths, extending to a maximum depth of 30 m or until competent ground was encountered. The SPT results provided N-values, which serve as practical indicators of soil penetration resistance for evaluating subsurface conditions. The test data were recorded in engineering borehole logs containing detailed descriptions of soil strata, groundwater levels and SPT blow counts. Field investigations were carried out under challenging wet ground conditions, requiring temporary working platforms to access the designated borehole locations. Undisturbed samples were collected from cohesive soils, while disturbed samples were obtained at each sampling interval for laboratory testing. This phase of the study provided a comprehensive profile of subsurface conditions for evaluating the vertical variability of soil layers (Abu Bakar et al., 2023).

Laboratory tests were conducted on the collected samples to evaluate the physical and index properties of the subsurface soils. The tests included measurements of Moisture Content (w), Atterberg limits (LL, PL, PI), Bulk and Dry Densities (ρb, ρd), Specific Gravity (Gs), and grain size distribution. The parameters are essential for understanding soil plasticity, compressibility, unit weight and classification which affect soil behaviour under loading and environmental conditions (Zhang et al., 2023).

Following the evaluation of soil properties, the study progressed to a statistical analysis examining the correlation between SPT N-values and particular geotechnical parameters. The correlations primarily address Moisture Content, Specific Gravity, Bulk Density and PSD given their importance in the strength and classification of soft soils. Statistical analyses were performed using Pearson Correlation Analysis to evaluate the relationships among the variables, while Multiple Linear Regression (MLR) was employed to develop the empirical prediction models. These analyses were implemented using Minitab 21. The established relationships provide a practical approach for estimating physical soil properties from SPT N-values during the preliminary stage of site investigation when laboratory test results are not yet available (Kennedy, 2024). Integrating field and laboratory data also improves the interpretation of subsurface conditions under constraints related to accessibility, time and project cost (Purdy et al., 2021).

This research developed an empirical modelling framework to estimate selected physical soil properties based on SPT N-values and depth. The framework employed MLR and model validation techniques to develop predictive equations. The models were calibrated using local soil data from PT 21044 to ensure their applicability to Malaysian soft soil conditions. The integration of laboratory and field data within a unified empirical modelling framework improves the efficiency of preliminary site investigations and supports foundation planning and early engineering assessment (Almohammedi, 2024).

## 1.5 Significance of Study

The analysis of the stratification and composition of surface and subsurface soil profiles is essential in geotechnical site investigation. This research contributes to the understanding of the soft soils in PT 21044, Cyberjaya where the presence of swampy and Peaty terrains poses challenges for visual classification and layer

differentiation. The characterization of these soils through borehole logs, SPT profiles and geological observations produce critical understanding for the identification of suitable foundational layers, thereby reducing the risks related with foundation failure and differential settlement conditions, enhancing decision-making in feasibility studies and pre-construction evaluations (Holtz et al., 2011). The presence of thick Peat in the upper layer and variable soft soils below complicates ground behaviour, requiring precise identification and differentiation of surface and subsurface soil profiles. The site's stratification is analysed and interpreted using geological data and visual observations to recommend appropriate foundation measures based on the existing ground conditions (Holtz et al., 2011).

This research offers a systematic interpretation of SPT data in soft soil conditions specifically in tropical alluvial terrains. The examination of 31 boreholes with SPT N-values at 1.5-meter intervals provides a substantial dataset of in-situ tests, enhancing the accuracy of soil strength assessment at different depths. Conducting SPTs under challenging site conditions can incur significant costs and time, particularly in regions with elevated groundwater levels. Therefore, effective interpretation of SPT N-values contributes to more accurate subsurface characterisation and supports informed engineering decision-making during site investigation (Kennedy, 2024). This database can be utilized by engineers, developers and regulatory bodies for preliminary risk assessments and initial site classification prior to the completion of comprehensive geotechnical reports.

The research provides a thorough assessment of essential soil properties, such as Moisture Content, Atterberg Limits, Density and Specific Gravity through systematic laboratory testing of both disturbed and undisturbed samples. The parameters are critical for the classification of soil types and the prediction of their behaviour under structural loads. This research connects field testing with laboratory testing providing data correlations that enhance the understanding of soft soil characteristics within the Malaysian context (Zhang et al., 2023). The findings may aid consulting engineers in validating laboratory results against field conditions and assist academic researchers in expanding soil property datasets for future modelling and classification studies. Data on plasticity and moisture are essential for assessing volume change potential while density and grain size provide findings into the engineering behaviour of cohesive and granular soils. The laboratory results establish a foundation for subsequent correlation and

modelling tasks, thereby improving soil characterization and design validation (Almohammedi, 2024).

This study is significant for establishing statistical correlations between SPT N-values and selected physical soil properties through Pearson Correlation Analysis and MLR. The identified correlations facilitate prediction, enabling the estimation of physical soil properties based on SPT N-values and depth. In conditions where laboratory testing is postponed or laboratory results are not yet available, these empirical models serve as a valuable estimation tool for supporting preliminary site investigations. This is consistent with previous studies that support the application of empirical prediction methods for improving the efficiency of geotechnical investigations (Rahman et al., 2022). The proposed statistical approach provides engineers and site investigators with rapid analysis, enhanced efficiency and improved resource planning under complex ground conditions.

This research presents an integrated empirical modelling framework, developed MLR for estimating physical soil properties based on SPT N-values and depth. The developed framework can be incorporated into geotechnical databases, allowing practitioners to conduct rapid preliminary site assessments and validate engineering interpretations before laboratory test results become available. The locally calibrated empirical models improve their applicability to Malaysian soft soil conditions, particularly in alluvial deposits such as those found in Cyberjaya. Furthermore, the novelty of this study lies in the development and validation of a sequential empirical modelling framework that estimates Moisture Content, Specific Gravity, Clay Content and Bulk Density from SPT N-values and depth. This study contributes to the development of a national geotechnical database while supporting more efficient and cost-effective preliminary site investigations (Kennedy, 2024).

## 1.6 Thesis Layout

This layout ensures that the thesis is systematically structured, comprehensive and discusses all important aspects of developing and validating an empirical modelling framework for estimating physical soil properties using SPT *N*-values.

Chapter 1 presents the background of the study, emphasizing the significance of accurate soil characterisation in geotechnical engineering, particularly for foundation planning in soft soil regions such as PT 21044, Cyberjaya. This chapter provides an

overview of soil mechanics and highlights the importance of subsurface investigation in construction projects. It discusses the challenges associated with soft soil investigations and the need for effective interpretation of SPT *N*-values together with laboratory testing to measured physical soil properties. The problem statement establishes the need for a reliable and efficient approach to correlate SPT *N*-values with physical soil properties, thereby supporting preliminary site investigation and reducing reliance on extensive laboratory testing. The research objectives are presented, focusing on identifying the surface and subsurface soil profile, determining SPT *N*-values, evaluating the physical soil properties, establishing correlations between SPT *N*-values and selected physical soil properties and developing an empirical modelling framework for estimating physical soil properties using SPT *N*-values. The chapter also defines the study scope, which is geographically confined to a 152-acre site in Cyberjaya and highlights the significance of the study in supporting preliminary geotechnical assessment.

Chapter 2 provides a comprehensive review of the literature related to the SPT, physical soil properties and empirical modelling approaches in geotechnical engineering. This chapter begins with the historical development and standard procedures of the SPT, highlighting its applications and considerations in soft soil investigations. The discussion then extends to the physical soil properties, including Moisture Content, Atterberg Limits, Bulk Density, Specific Gravity and Particle Size Distribution, explaining their influence on soil behaviour and subsurface characterisation. Previous studies on empirical correlations between SPT *N*-values and soil properties are reviewed, with emphasis on their applicability to local geological conditions and the research gap addressed in this study. The chapter concludes by discussing the statistical methods adopted, including Pearson Correlation Analysis and MLR, which provide the basis for developing the empirical modelling framework.

Chapter 3 describes the methodology adopted in this research, covering the planning, execution and analysis stages. The chapter begins with a description of the study area, including its geological setting within Quaternary alluvial deposits and the occurrence of soft soil under waterlogged conditions. Field investigations are then described, where a total of 31 boreholes were drilled to depths of approximately 30 m with SPT conducted at 1.5 m intervals. Disturbed and undisturbed soil samples were collected for laboratory testing. Laboratory procedures for determining Moisture Content, Atterberg Limits, Atterberg Limits, Specific Gravity, Bulk Density and

Particle Size Distribution are subsequently presented. Statistical analyses were performed using MINITAB 21, where Pearson Correlation Analysis was applied to evaluate the relationships between SPT *N*-values and physical soil properties, while MLR was used to develop the empirical prediction models. Model development, validation and calibration procedures are also described to ensure the reliability and applicability of the developed empirical modelling framework. The limitations of the study, including its geographical coverage and focus on selected physical soil properties, are also presented.

Chapter 4 presents the findings from the field investigations, laboratory testing and statistical analyses. The chapter begins by presenting the SPT *N*-values obtained at different depths together with the corresponding laboratory testing to measured physical soil properties. Graphs and tables illustrate the variation of soil properties and subsurface conditions across the study area. Pearson Correlation Analysis and MLR were applied to establish empirical relationships between SPT *N*-values and selected physical soil properties, including Moisture Content, Atterberg Limit, Specific Gravity, Bulk Density and Clay Content. The developed regression models together with their coefficients of determination ($R^2$) are presented and discussed. The empirical models were subsequently validated using independent datasets to evaluate their predictive capability and applicability. The findings are also compared with previous studies and the limitations associated with local geological variability are discussed.

Chapter 5 discusses the overall findings of the study and presents the conclusions and recommendations for future research. The chapter summarises the successful development and validation of the empirical modelling framework for estimating physical soil properties using SPT *N*-values. The practical contribution of the proposed framework in supporting preliminary subsurface characterisation and foundation planning is highlighted. The findings are compared with previous empirical studies, emphasising the advantages of developing locally calibrated models for Malaysian soft soil conditions. Finally, the study limitations are discussed, together with recommendations for future research, including extending the modelling framework to additional soil properties and different geological settings.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Background of the Study Area

Geotechnical engineering has undergone significant developments in recent decades, driven by advances in in-situ testing, laboratory methodologies and analytical approaches for interpreting soil behaviour (Briaud, 2023). The rising prevalence of infrastructure projects on marginal or soft ground requires accurate subsurface characterization as a critical component for ensuring safe and economically viable design (Das & Sobhan, 2018). The Standard Penetration Test (SPT) is widely utilized in field testing due to its simplicity, cost-effectiveness and capacity to produce continuous resistance data with depth. SPT data, while empirical, are crucial for multiple geotechnical design decisions, especially during Initial Site Investigations (SI) (Craig, 2004).

The study area at PT 21044, Cyberjaya, Selangor is located within a Quaternary geological formation defined by unconsolidated alluvial deposits, comprising Peat, Clay and Silt (Minerals and Geoscience Department, 2014). Deposits of this type are typically associated with low-lying, swampy environments and are characterized by high natural water content, decreased effective stress and weak interparticle bonding. The conditions identified result in soils with high compressibility and low shear strength, making them subject to considerable settlement and bearing capacity failure if not properly characterized (Holtz et al., 2011). Geological and geomorphological mapping is crucial for identifying stratigraphic variations and anticipating problematic soil layers before undertaking comprehensive field testing.

Soft soils, common in coastal or low-lying areas, typically exhibit high compressibility and low strength, creating major difficulties for construction activities. Site investigation is important for recognizing these conditions and guiding the choice of suitable construction and ground improvement methods (Jamsawang et al., 2016). The presence of Peat or highly compressible soils may result in significant settlements and instability. Site investigation is essential for identifying these materials and evaluating their scope and properties to prevent expensive remedial actions and construction delays (Jamsawang et al., 2016). Areas with soft soil may display irregular

layering, potentially impacting the performance of foundations and other structures. SI provides the important information required to model these variations and to design accordingly (X. Li et al., 2025).

Soft soils in tropical regions, such as Malaysia exhibit significant geographical variation due to factors such as weathering, depositional history and different groundwater conditions. The variation complicates the interpretation of borehole data and increases uncertainty in design when soil profiles are not accurately defined (Amah et al., 2021). Multiple studies demonstrate that combining SPT *N*-values with important soil properties such as Moisture Content, density and grain size distribution improves comprehension of subsurface behaviour and strengthens confidence in engineering assessments, particularly in situations where extensive laboratory testing is limited (Baharuddin et al., 2020). In soft alluvial and Peat-rich soils, such correlations are especially significant, as conventional sampling methods often lead to disturbance and unreliable laboratory measurements.

Environmental factors also influence the engineering behaviour of soils in the study area. In Cyberjaya, increased annual rainfall and prolonged waterlogging influence soil suction, effective stress and permeability, thereby affecting the penetration resistance recorded during the SPT (Osman, 2013). Studies demonstrate that seasonal variations in moisture significantly affect SPT *N*-values and soil stiffness, particularly in fine-grained and organic soils (Youd et al., 2001). The observations demonstrate the fundamental combining of field data, laboratory results and statistical analysis to accurately characterize soil behaviour under defined conditions.

Recent advancements in geotechnical practice emphasize the use of empirical data and statistical methodologies to enhance the analysis of test outcomes. Statistical tools such as regression analysis and multivariate modelling allow engineers to identify predictive relationships between SPT *N*-values and soil properties, thus reducing dependence on comprehensive field and laboratory programs (Montgomery & Runger, 2021). The application of these techniques improves efficiency and cost-effectiveness, while enabling more objective making decisions in geotechnical design. The integration of SPT data, laboratory measurements and statistical modelling creates a comprehensive framework for analysing subsurface conditions in soft soil environments which supports the current study.

### 2.1.1 Surface and Subsurface Soil Profile

Understanding the surface and subsurface soil profile is crucial in geotechnical investigations, especially in areas characterised by soft soils such as Peat, Silt and Clay. The study area at PT 21044, Cyberjaya, is situated within Quaternary alluvial deposits characterised by highly compressible soils, low shear strength and heterogeneous stratification, which increase the complexity of predicting ground response under loading conditions (CREAM, 2023). These conditions require comprehensive soil profiling to simplify precise design and construction planning. Borehole drilling was conducted to depths of up to 30 metres or until competent ground was encountered to characterize the vertical and lateral variability of the subsurface layers. Borehole logs documented significant observations, including variations in layer colour, consistency, Moisture Content and the presence of organic matter. The borehole logs provide valuable insights into the geological history and subsurface stratigraphy of the site and assist in determining appropriate foundation types, foundation depths and ground improvement measures (Look, 2021).

The site's hydrological conditions, characterized by frequent rainfall and elevated groundwater levels, present additional challenges. Water ingress during drilling can disrupt soil stratification and slow down the recovery of undisturbed samples. The issue is especially significant in saturated Peaty soils, which can collapse or deform during extraction, resulting in misinterpretation of field conditions (Huat et al., 2014). These limitations were mitigated through strategies including temporary working platforms and casing systems were employed to maintain sample integrity and ensure the reliability of data collection. Surface profiling is essential for identifying weak zones or unsuitable bearing layers that could lead to differential settlement or structural failure if not properly addressed. The presence of thick Peat layers in the upper strata may require preloading, removal or stabilization prior to the beginning of construction. The precise differentiation of these layers is essential for the design of cost-effective and safe foundations, especially in contexts where soil strength and behaviour exhibit significant variation with depth (Al Shukri & El Rawi, 2000).

The accuracy of subsurface profiling is frequently influenced by the number and spatial distribution of boreholes. Although linear interpolation between boreholes is commonly used to estimate subsurface stratigraphy, this approach may not adequately capture local geological variability, particularly in heterogeneous soft soil deposits.

Consequently, insufficient site investigation data may lead to the inaccurate identification of weak soil layers, thereby increasing geotechnical uncertainty and the risk of excessive settlement or foundation-related problems during construction and maintenance service (Almohammedi, 2024). Overall, comprehensive and systematic site investigations are essential for understanding soft soil environments and accurately characterising subsurface conditions. A detailed subsurface profile forms the foundation for developing empirical prediction models that relate SPT *N*-values to physical soil properties, thereby supporting reliable preliminary geotechnical assessment and reducing the time and cost associated with laboratory testing.

### 2.1.2 Sustainable Practices in Geotechnical Engineering

Sustainable geotechnical engineering practices are essential for effectively managing construction activities on soft ground, particularly in rapidly urbanizing regions such as Cyberjaya. The focus on sustainability comes from the need to minimize environmental impact, optimize resource utilization and guarantee the long-term effectiveness of infrastructure. In areas characterized by problematic soils such as Peat and alluvial Clay, the use of inappropriate or unsustainable ground treatment methods may lead to excessive material consumption, increased environmental impact and potential long-term structural instability (Indraratna et al., 2010). A primary strategy for achieving sustainability in geotechnical engineering involves minimizing physical site disturbance by using efficient investigation methods. The integration of empirical models applying SPT results, together with laboratory testing, effectively reduces costs and mitigates environmental degradation. Engineers may save energy, time and materials by utilizing statistical correlations between SPT *N*-values and important soil properties, thus minimizing unnecessary sampling (Hashim et al., 2005). This method is especially applicable in soft ground regions where access is limited and handling the soil requires care.

Sustainable soil improvement techniques such as preloading, vertical drains and soil stabilization using industrial by-products including fly ash and ground granulated blast furnace slag have gained increasing attention. These methods enhance soil strength and reduce settlement while promoting the reuse of waste materials in line with circular economy principles (Basha et al., 2005). In the soft Peat environment of Cyberjaya such methods serve as viable alternatives to more invasive deep foundation

systems which tend to be expensive and resource demanding. Another sustainable strategy involves the use of predictive modelling based on Multiple Linear Regression (MLR). Statistical tools optimize design decisions by minimizing reliance on full-scale testing thereby reducing the necessity for repeated drilling and sampling. These models facilitate the early identification of problematic areas and guide targeted interventions thereby enhancing efficient and environmentally sustainable planning (Kumar et al., 2016b). Sustainable practices in geotechnical engineering aim to reconcile the technical demands of soil investigation with the environmental, economic and social aspects of construction. Implementing these strategies in soft soil environments such as PT 21044 enhances engineering reliability while supporting infrastructure development that aligns with sustainability, resilience and climate adaptation objectives (Ng et al., 2015).

## 2.2 Site Investigation (SI)

SI represents the initial and critical phase in the analysis, design and selection of a foundation system. This document presents essential information regarding the geological, physical and geotechnical characteristics of subsurface materials, which is important for the safety, sustainability and cost-efficiency of construction in civil engineering projects (El-Reedy, 2017). The effectiveness of these projects is significantly influenced by a comprehensive understanding of ground conditions as site investigation serves as a protective measure against geohazards such as landslides, subsidence and foundation failure (Han et al., 2025). Significant infrastructure projects depend on comprehensive site investigations to evaluate the properties, behaviour and geological conditions of subsurface materials and to identify potentially hazardous ground conditions (Clayton et al., 2014). In practice, site investigation (SI) generally commences with a desk study, during which geological maps, historical data and prior site reports are examined to establish a foundational understanding of the site. Subsequent to this, reconnaissance surveys are conducted, employing visual observations to corroborate desk findings and to identify undocumented features, including drainage paths, surface water, vegetation and prior land use. These steps are particularly critical in low-lying and swampy areas such as Cyberjaya, where seasonal fluctuations in water levels can significantly influence both surface and subsurface conditions (Minerals and Geoscience Department, 2014).

Subsurface exploration constitutes the fundamental aspect of site investigation, encompassing borehole drilling, test pits and in-situ testing methods including the SPT. This study involved conducting SPTs at 1.5-meter intervals across 31 boreholes, reaching depths of up to 30 meters. The tests produced SPT *N*-values and both disturbed and undisturbed samples for subsequent laboratory analysis. These samples are essential for assessing soil parameters such as Moisture Content, plasticity index, grain size distribution and density which inform the choice of foundation type (shallow or deep) and the necessity for ground improvement measures (Bowles, 1997). In regions characterized by soft soils, such as Cyberjaya which is underlain by Peat and alluvial Clays, the significance of SI is increased. This is attributed to the low shear strength, high compressibility and irregular layering of these soil types (Das & Sobhan, 2018). An effectively conducted SI facilitates the identification of engineering risks and informs decisions regarding ground treatment or foundation modification. Groundwater investigation is an essential aspect of site investigation. High water tables, prevalent in alluvial deposits may reduce effective stress and shear strength, resulting in significant settlement or slope failure if not properly managed. Assessing the depth of the groundwater table facilitates the design of dewatering systems, waterproofing measures or alternative foundation configurations, thereby mitigating project delays and structural failures (Clayton et al., 2014).

The reliability of SI is contingent upon the quality and distribution of field data. Insufficient or restricted investigations may not adequately account for the spatial variability of soft soils, thereby elevating the risk of foundation settlement, collapse or design inaccuracies (Omar et al., 2011). When borehole or test pit data are limited, engineers often rely on interpolation or extrapolation to estimate subsurface conditions. This may increase uncertainty in subsurface characterisation and result in costly design modifications or remedial measures during construction (Saha et al., 2022). Inadequate collection of comprehensive subsoil information may result in accidents, economic losses, project delays and disruptions to public services such as water, energy and transportation systems (Burland et al., 2012). Although the addition of boreholes and laboratory tests raises the expenses and time required for site investigation, a comprehensive assessment is ultimately more cost-effective than dealing with the repercussions of insufficient soil data (Saha et al., 2022). Finally, SI encompasses the identification of subsurface hazards including buried utilities, old foundations, contaminants and voids, all of which are essential for ensuring worker safety and

maintaining long-term structural integrity. The precision and comprehensiveness of site investigation data significantly affect all subsequent phases of design and construction. In challenging environments such as Cyberjaya, neglecting this phase may result in technical, economic, and safety-related setbacks. Thus, site investigation serves not merely as an initial phase but as the fundamental basis for all informed geotechnical decisions (Clayton et al., 2014).

### 2.2.1 Purpose and Importance of Site Investigation

The SPT *N*-value serves as a commonly used geotechnical index to determine the relative density, strength and stiffness of subsurface soils. The Moisture Content, grain size distribution, proportion of fine particles and organic matter significantly impact soil resistance and deformability (Cong et al., 2025). The SPT is essential to the initial evaluation of subsurface conditions, particularly in complicated soil settings. The SPT provides valuable field information for soil profiling; however, the interpretation of SPT *N*-values requires consideration of local geological conditions, soil variability and testing procedures to ensure meaningful engineering evaluation. The samples consist only of disturbed soil, providing them generally unsuitable for accurate strength or deformation testing in laboratory settings. The SPT blow count (*N*-value) serves as an empirical tool for estimating soil properties, including density and shear strength. However, the disturbed condition of the samples limits direct comparisons between in-situ and laboratory test results, especially concerning strength-related parameters (Modeer et al., 2016).

SI methods are crucial for obtaining in-situ measurements of subsurface conditions, which are frequently challenging to evaluate accurately through laboratory testing alone. The methods of geotechnical investigation constitute fundamental components in subsurface exploration, involving a systematic approach that includes borehole drilling, penetration testing, and soil sampling to characterize site stratigraphy, groundwater conditions, and geotechnical behaviour at depth (Das & Sobhan, 2018). In areas characterized by soft soils such as the Peaty and alluvial deposits of Cyberjaya and the Langat River Basin, accurate subsurface profiling is particularly important due to the high variability, compressibility, and relatively low shear strength of these deposits (Mitchell & Soga, 2005). Common site investigation methods include SPT, Mackintosh Probe (MP), boreholes and geophysical methods such as Electrical

Resistivity Tomography (ERT) and Seismic Reflection surveys. These tools facilitate the development of a detailed ground model that accurately represents the site's geomorphology, lithology and soil behaviours, thereby directing subsequent engineering design and analysis (Mitchell & Soga, 2005). The SI process commences with desk studies and site reconnaissance, proceeds to field testing and laboratory classification and finally ends in the formulation of a ground model. This model consolidates all findings and is continuously updated during construction as new data become available (Eslami et al., 2020). A comprehensive site investigation facilitates the immediate identification of geotechnical hazards, including weak layers, elevated groundwater levels or subsurface voids, thus assisting in the prevention of project delays, unforeseen expenses or structural failures (Ku et al., 2016).

### 2.2.2 Site Investigation Methods

The main objective of SI in geotechnical engineering is to find accurate and reliable information regarding the geological, hydrogeological and geotechnical characteristics of surface and subsurface soil layers before work begins (Ishak et al., 2022). The process is particularly crucial in soft soil areas such as PT 21044, Cyberjaya which generally consist of challenging materials including Peat, highly compressible Clays and Silt. The soils in challenging indicate higher water content, reduced shear strength, increased compressibility and irregular layering factors that can substantially influence construction safety, structural performance and project costs if not properly recognized and addressed during the design phase (Jamsawang et al., 2016). Site investigation delineates soil stratification, assesses groundwater conditions, and estimates essential soil parameters including undrained shear strength, tip resistance, cohesion, friction angle, and unit weight (X. Li et al., 2025). The parameters are critical for assessing the load-bearing capacity of soils, estimating settlement behaviour and identifying areas of weakness or geohazards, including voids, fractured strata, or Peat layers (Ishak et al., 2022). Subsurface investigation is needed for describing the continuity and characteristics of subsurface layers, thereby mitigating geotechnical uncertainty and enhancing risk-informed design. Due to the inherent variability and heterogeneity of soft soils, accurate site data allows reliable evaluations of ground behaviour and helps in mitigating foundation failure, slope instability, and construction delays (X. Li et al., 2025).

Geotechnical data obtained from site investigations, including borehole logs and field test results, are commonly classified in accordance with BS 1377-2:1990, which classifies soils based on particle size distribution and plasticity characteristics. Although this classification system provides a standardised framework for soil identification, it should be interpreted together with regional geological conditions. Integrating geological knowledge with adequate borehole spacing and depth improves the interpretation of subsurface conditions and reduces the risk of misclassifying soil strata (Patel, 2019). Errors arising from sudden stratigraphic variations, non-homogeneity or subsurface anomalies can be further reduced through additional laboratory and field testing. A comprehensive site investigation program is essential for regions characterized by soft, heterogeneous soils including the Peat and alluvial deposits found in Cyberjaya. This supports the design of foundations, slopes, retaining structures and ground improvement measures, ensuring compatibility of all structural components with site-specific ground conditions (Holtz et al., 2011). Borehole drilling, complemented by comprehensive borehole logs, facilitates the identification of essential parameters such as layer transitions, soil classifications, Moisture Content, and organic matter indicate elements critical for differentiating between competent and weak strata for establishing appropriate foundation depths and types (Baharuddin et al., 2020).

Additionally, in-situ testing methods, including the SPT and Cone Penetration Test (CPT), along with laboratory analyses, create the methodological basis of SI programs. The tests facilitate the indirect estimation of properties such as compressibility, permeability, and soil strength, which are important for formulating construction strategies in soft and saturated soils (Prakash & Jain, 1992). Furthermore, groundwater assessment is essential, as variations in water table levels affect pore water pressure, effective stress, and long-term settlement behaviour. The precise assessment of these conditions ensures that foundation designs include important characteristics such as drainage systems or water table controlling (Mallo & Umbugadu, 2012). In summary, site investigation is fundamental to all geotechnical assessments, particularly in complicated ground conditions such as those found in Cyberjaya. By conducting accurate field and laboratory investigations, engineers can effectively minimize uncertainties, improve design reliability, and provide the safe and cost-effective implementation of civil engineering projects.

#### *2.2.2.1 Borehole Drilling*

Borehole logs are a fundamental component of geotechnical site investigations, offering direct access to subsurface conditions and enabling detailed characterization of soil and rock layers. These logs are compiled during drilling activities and record the depth, composition, thickness, and visual characteristics of each encountered layer. Rotary wash boring is one of the most commonly adopted borehole drilling methods for geotechnical site investigations in Malaysia, particularly in alluvial deposits, due to its suitability for penetrating saturated clay, silt and sand layers while facilitating soil sampling and in-situ testing (Department of Standards Malaysia, 2006). At the site in Cyberjaya, boreholes are typically drilled to depths exceeding 30 metres to identify competent bearing strata beneath the thick soft alluvial deposits. These boreholes also facilitate the recovery of disturbed and undisturbed soil samples for laboratory analysis, which is essential for determining critical physical and mechanical properties of each stratum, including Moisture Content, organic content, compressibility, and strength.

Borehole logs often include visual classifications of soil types such as sub-angular coarse-grained Sand and provide insight into the geological history of the deposits. These logs are especially valuable in identifying problematic or variable layers, such as Peat lenses or organic-rich soils, which might be missed by in-situ tests like the CPT. Once detected, these layers can be further evaluated in the laboratory to confirm their geotechnical properties, including high compressibility, low shear strength, and poor load-bearing capacity, all of which may require ground improvement or foundation modifications (Remmers et al., 2019). Despite their importance, borehole logs present certain limitations. Because of economic constraints, boreholes are often limited to a few locations across a site. This results in discrete point data, which must be interpolated to develop a complete subsurface profile (Q. Li et al., 2025). Such interpolation introduces uncertainties, particularly in heterogeneous soft soil environments, where small changes in stratigraphy can significantly affect design outcomes.

In order to overcome these spatial limitations, borehole data is often integrated with geophysical survey techniques, such ERT or seismic reflection methods. This combined approach allows for the development of a more continuous and accurate subsurface model, improving the identification of geological anomalies or

discontinuities that might not be evident from borehole logs alone (Remmers et al., 2019). Furthermore, borehole logs are also used to calibrate geophysical data and improve the accuracy of subsurface interpretations. For instance, correlations between geophysical responses and borehole-derived properties can refine soil models and enhance the reliability of geological stratification predictions (Sudha et al., 2009). Overall, borehole logs when used alongside laboratory data and geophysical methods form an integrated system for building comprehensive ground models that support foundation design, slope stability assessments, excavation planning, and groundwater control strategies.

#### *2.2.2.2 Standard Penetration Test (SPT)*

SPT is recognized as the most common and widely used in-situ geotechnical test for subsoil exploration and site investigation, particularly in soft ground conditions. Its popularity stems from its simplicity, cost-effectiveness, and ability to provide both soil strength data and physical soil samples during testing, which are essential for identifying soil type and properties at various depths (Yadhunandan & Anbazhagan, 2025). The SPT is especially valuable in cases where obtaining undisturbed samples is difficult, such as in gravelly, Sandy, Silty, or weak rock formations (Patel, 2019). It is indispensable in preliminary subsoil investigations and is often the only available source of information for foundation and pile design in many regions (Bortolozo et al., 2019). The SPT *N*-value (number of blows required to drive the sampler 30 cm into the soil) is a widely used geotechnical index reflecting the relative density and strength of subsurface soils. It is influenced by factors such as Moisture Content, Grain Size Distribution, fine particles, organic matter and test procedure variables such as drilling methods, borehole size and hammer energy (Yadhunandan & Anbazhagan, 2025). Corrections for overburden pressure and energy are commonly applied to improve reliability (Yadhunandan & Anbazhagan, 2025).

SPT *N*-values serve as a classification tool for soil strength and foundation suitability. Specifically, *N*-values of 20 or less indicate weak, highly compressible soils that are generally unsuitable for foundations. Values ranging from 30 to 50 represent moderately competent soils, while *N*-values of 50 or greater correspond to very stiff or dense soils that can support heavy structures, including high-rise buildings (Cong et al., 2025). There are empirical correlations between N-values and soil compressibility,

shear modulus and shear wave velocity, which are critical for foundation design and settlement prediction (Fabbrocino et al., 2015). One of the most common in situ tests is the SPT. The SPT is an in-situ penetration complex test that gives information of geotechnical soil properties. In the United Kingdom, the test is carried out using a standard procedure which is described in the British Standard: BS 1377- 9:1990 (Coduto, 2001). The reason of performing SPT is to measure the standard penetration resistance, called *N*-value here which is the blow count required penetrating through a 150 mm soil interval.

The *N*-value provides engineers with a rough measure of the density of the soil and SPT measures the penetration resistance provided by soil at varying depth used many empirical geotechnical engineering formulas (Ali et al., 2017). In addition, the test was initially developed for determining the relative density of cohesionless soils. That is a test in a borehole within which both the SPT test and the results can be used to obtain bearing capacity, relative density, settlement of granular soil and evaluate the estimated strength of cohesive soil. The limitations of SPT in engineering site investigation mean there are a few problems. Often this test takes more people to conduct, such as the need for one person to run the machine, one to note the bore log, and one to keep the water running to ensure the machine is running. The backlashes are more times it needs more manpower and times money to complete one test and more ability to bore deeper. This test is made on the thick-walled sample tube test as shown in Figure 2.1 with 50 mm outside diameter, 35 mm inside diameter, and having 45 cm in length at least. The driving is generated by blows of a slide hammer with a mass of 63.5 kg falling from an elevation of 75 cm into the ground at the bottom of a borehole.

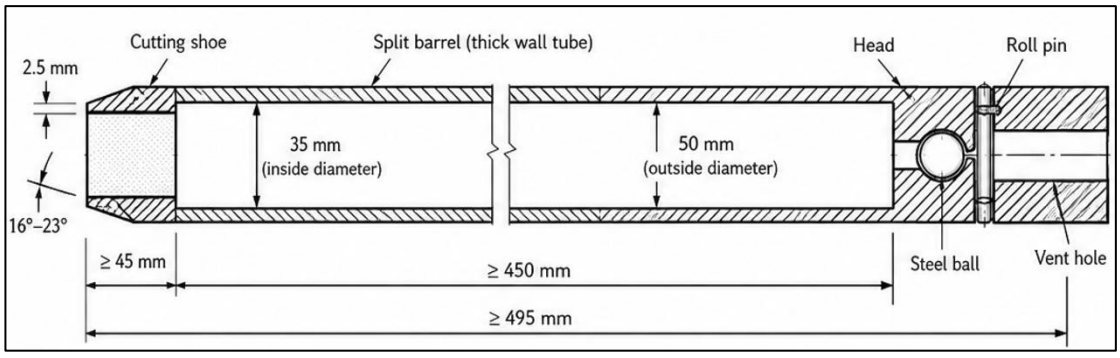
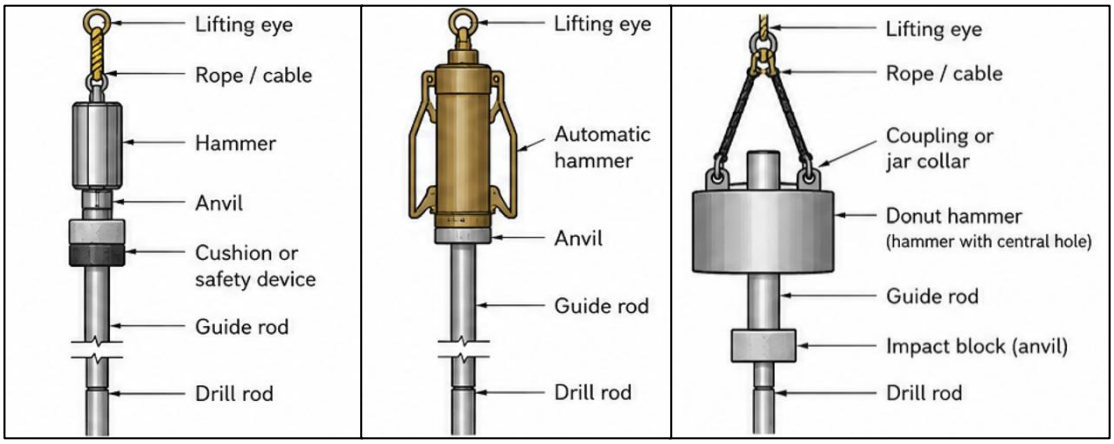



Figure 2.1 Split-Barrel Sampler Assembly for the SPT (BS 1377-9: Part 1:1990).

In cases where 50 blows of the blow count are not sufficient to advance the sample through 15 cm it was counted if 15 additional blows were necessary to advance the sampler through 30 cm, the number of blows required to advance the sampler another 30 cm, having first been advanced 15 cm. The ground density is indicated by and many empirical geotechnical engineering formulae use the blow count. Currently in use there are basically two primary types of hammers, this is the safety hammer and the automatic hammer. A third type of hammer was the donut hammer which was used almost exclusively since 1970. Still, it is far from being in use today for safety reasons.




Safety Hammer Automatic Hammer Donut Hammer

Figure 2.2 The SPT Hammer Types (Mayne, 2016).

The test aims to provide an indicator of the relative density of granular deposits from which undisturbed samples are difficult to obtain, for example on Sands and Gravels. The widespread use is due simply because the test is simple and inexpensive. For instance, in Gravels, Sands, Silts, Clay with Sands or Gravels and weak rock where bore holes are not a good indicator of strength of grounds and it may not be possible to gather enough good quality of bore hole samples, then approximate parameters estimated from the soil strength is a valuable guide. SPT are also useful to alternate the sampling in order to verify the strength conditions where the quality of the undisturbed sample is suspect such as very Silty or very Sandy Clays, hard Clays. If the samples are found to be too disturbed, a strength measurement method such as the plate test may be needed. In granular soils, the soil may become loosened when the test is carried out below groundwater level. Drivers may want to continue driving the sampler past the

distance set out above, drilling newly added rods in some circumstances. Use of SPT results is highly dependent on the type of soil with the most useful results being obtained from fine grained Sands, more useful results are obtained from coarser Sands and Silty Sands, and the SPT results obtained from Clays or gravelly soils may be very poorly representative of the true soil conditions.

### 2.2.3 Sampling Procedures

In geotechnical site investigations, the drilling process produces both disturbed and undisturbed soil samples, each with different testing and analytical functions. Each type contributes clearly to the comprehension of soil behaviour and informs suitable engineering design choices. Disturbed samples are typically more accessible and cost-effective to obtain. These are appropriate for laboratory tests in which the natural structure of the soil is not essential. These are frequently utilized to determine index properties including Moisture Content, Specific Gravity, Atterberg limits, particle size distribution, organic matter content, and compaction characteristics. These tests are critical for fundamental soil classification, evaluating borrow materials, and determining suitability for filling, grading, or general construction activities (Tamiru et al., 2025). These samples are generally employed when the investigation highlights general soil characteristics over detailed mechanical behaviour.

Undisturbed samples are essential to investigating soil behaviour in conditions that closely reflect its in-situ state. The samples maintain the original structure and Moisture Content of the soil, which is essential for conducting advanced laboratory tests that assess properties such as shear strength, compressibility, consolidation, permeability, and void ratio. Tests including one-dimensional consolidation, unconfined compression, direct shear and permeability assessments require undisturbed specimens to provide reliable data for engineering design and safety evaluations (Tamiru et al., 2025). Obtaining high-quality undisturbed samples presents significant challenges in soft Clays and Peat soils, related to their low shear strength and elevated compressibility. These soils exhibit high sensitivity, where even minor disturbances during sampling can modify their properties, resulting in sample distortion (Holtz et al., 2011). Consequently, careful consideration is required during sampling, frequently using thin-walled, seamless cylinders that are carefully inserted into the soil to reduce

disturbance. Notwithstanding these precautions, it is prevalent for laboratory processing durations to extend due to challenges in managing such samples.

When high-quality undisturbed samples are unavailable or their reliability is uncertain, engineers frequently improve laboratory results with empirical correlations based on in-situ test data, including the SPT and CPT (Holtz et al., 2011). This integrated method addresses the shortcomings of disturbed or low-quality undisturbed samples, thereby improving the precision of soil behaviour predictions in design.

## 2.3 Laboratory Investigation

Laboratory classification tests produce critical soil index properties that characterize the physical and engineering behaviour of soils. The tests were performed in accordance with BS 1377-2:1990, which outlines the methods for classifying soils for civil engineering applications (BS1377, 1990). Laboratory testing for Moisture Content, Specific Gravity, Atterberg Limits and PSD is essential for the classification and evaluation of soils, especially soft and saturated soils in civil engineering. The tests are performed in accordance with standards such as BS 1377-2:1990 to ensure consistency and reliability in results, which are essential for design and construction decisions in geotechnical engineering (Amah et al., 2021).

Laboratory testing is essential in geotechnical engineering, providing consistency and reliability in soil classification across various projects and geographical areas (Md Nujid et al., 2024). The integration of tests including Moisture Content, Specific Gravity, Atterberg limits and particle size distribution provides a thorough understanding of soil characteristics particularly in soft and saturated soils that exhibit instability (Amah et al., 2021). The tests enable engineers to evaluate essential engineering properties such as shear strength, compaction potential, permeability and erodibility, which are crucial for foundation design, slope stability and ground improvement planning (Shriful Islam et al., 2019). Furthermore, they help in identifying problematic soils, including those characterized by high plasticity, high compressibility or low strength, which might require specialized construction methods or treatment (Md Nujid et al., 2024). The data obtained support the selection of suitable soil improvement methods, such as chemical stabilization, which enhances the long-term performance of structures in challenging ground conditions (Shriful Islam et al., 2019).

The properties of soil have a substantial effect on engineering projects, as the stability and performance of structures constructed on or within the soil are invariably affected by these characteristics. Soils are categorized into three main types: organic, cohesionless, and cohesive soils. Cohesive soils are characterized by their cohesive properties, resulting from the attractive forces between particles and their interactions with water molecules. The small particle sizes of these soils lead to a tendency for aggregation, which defines their characteristics. The cohesion of cohesive soils leads to their sticky and plastic properties, requiring significant effort for engineering applications.

Cohesive soils exhibit a significant characteristic whereby traditional sieve analysis tests prove insufficient for their classification. The diminutive dimensions of cohesive particles inhibit their passage through the standard apertures of conventional sieves, thus rendering it unfeasible to determine their granular size and, subsequently, their water content. Engineers should employ alternative techniques, including the observation of particle settling velocities in water, to determine the particle size distribution of cohesive durable soil.

Cohesive soils are predominantly composed of Clays, but also include a combination of Silt-Clay and Clay Sand, with Clay as the primary constituent (Coduto, 2001). In contrast to granular soils, these soils generally display unfavourable engineering characteristics that present difficulties for construction endeavours. Cohesive soils, which exhibit elevated water content and plasticity, may result in settlement, instability, insufficient drainage and negatively impact the long-term performance of structures constructed on or within them. Engineers and geotechnical professionals must first comprehend the properties of cohesive soils to make informed decisions in the design and construction of structures.

Cohesive soils, defined by their small particle size, plasticity and adhesive properties allow engineers to develop strategies that reduce potential risks and improve the stability and durability of design projects. Cohesive soils pose considerable challenges to the engineering field owing to their inherent cohesive properties and fine particle dimensions. An in-depth understanding of the properties of cohesive soils, along with the application of appropriate testing and engineering methods, allows professionals to manage and mitigate the risks linked to these complex soil types effectively. Engineers must account for the specific characteristics of cohesive soil

during the engineering and construction phases to ensure the effective and sustainable development of infrastructure projects.

### 2.3.1 Characteristics of Soft Soil

The behaviour and stability of soil in geotechnical engineering are strongly influenced by the characteristics of soft soil deposits. These properties are important in evaluating potential geotechnical hazards and ensuring the long-term performance of foundations and earth structures. Soft soils are commonly associated with high natural Moisture Content, high compressibility, low shear strength and low bearing capacity. In Malaysia, these deposits are typically found within Quaternary alluvial formations and frequently comprise Peat, Clay, Clayey Silt and loose Sand (CREAM, 2023).

Organic soils, particularly Peat, generally exhibit high compressibility and low shear strength because of their high organic content, resulting in excessive settlement under applied loading. Similarly, loose Sand deposits with high Moisture Content may experience reduced stiffness and strength, whereas Clayey Silt soils possess a large proportion of fine particles that contribute to low permeability, high compressibility and poor drainage characteristics. These engineering characteristics make soft soils highly susceptible to excessive deformation and differential settlement unless appropriate foundation or ground improvement measures are adopted (Briaud, 2023).

The instability of soft soil deposits during excavation and construction has been widely reported in previous studies. Excessive settlement, bearing capacity failure and slope instability are among the common geotechnical problems associated with soft soils because of their low shear strength and high compressibility. Consequently, proper identification and characterisation of soft soil deposits are essential for reliable geotechnical assessment and foundation design (Mohamad et al., 2015).

As presented in Table 2.1, the major soft soil types exhibit different physical characteristics that influence their engineering behaviour. Among these properties, Moisture Content plays an important role in affecting soil compressibility and strength, providing the basis for investigating its relationship with SPT *N*-values in the present study.

Table 2.1
Characteristics of Major Soft Soil Types Reported in Previous Studies

| Soil Type | Moisture Content | Compressibility | Shear Strength | Main Geotechnical Issue | Reference |
|---|---|---|---|---|---|
| Peat | Very High | Very High | Very Low | Excessive settlement | (CREAM, 2023) |
| Clay | High | High | Low | Consolidation settlement | (Briaud, 2023) |
| Clayey Silt | Moderate High | High | Low | Low bearing capacity | (Mohamad et al., 2015) |
| Loose Sand | Moderate | Moderate | Low (when saturated) | Excessive deformation | (Huat et al., 2014) |

The issue of soft ground arises when the foundation lacks sufficient strength to support the structure, resulting in inadequate bearing capacity and excessive post-construction settlement. This situation requires the exploration of suitable approaches and engineering solutions to mitigate the problem (Mohamad et al., 2015). The presence of soft soils can significantly influence the overall stability of embankment structures constructed on these deposits. Settlement, which refers to the deformation of soil under applied loading, may adversely affect the bearing capacity of the foundation and the long-term stability of the embankment. In addition, elevated groundwater levels commonly found in soft soil deposits can further increase settlement and deformation by reducing the effective stress and stiffness of the foundation soils, thereby compromising structural stability (Abdrabbo et al., 2024). Coastal plains and quaternary sediments in Malaysia frequently contain soft soil deposits, including organic Peat soils and alluvial deposits (Kaniraj & Joseph, 2006). Due to its extensive area, spanning both the west and east coasts of Peninsular and East Malaysia, construction projects commonly encounter issues related to soft ground (Minerals and Geoscience Department, 2014). There is a necessity for soft soil criteria to ensure that soil deposits perform adequately in construction projects and that these criteria are comprehended. Understanding the characteristics of soft soil enables engineers to implement appropriate measures to mitigate potential risks, ensuring the stability and longevity of structures built on soft soil deposits. Innovative solutions to address challenges posed by soft soil deposits in geotechnical engineering necessitate further research and studies.

#### *2.3.1.1 Soft Soil Criteria*

Soft soils are generally defined as soil deposits with high natural Moisture Content, low shear strength, high compressibility and low bearing capacity. These soils are commonly encountered in low-lying coastal plains, river floodplains, reclaimed areas and other waterlogged environments where groundwater levels remain relatively high. In Malaysia, soft soils predominantly comprise Peat, Soft Clay, Clayey Silt and loose Sand deposited within Quaternary formations. Their engineering behaviour is strongly influenced by their physical properties, mineral composition and depositional environment, which directly affect foundation performance and ground stability (Minerals and Geoscience Department Malaysia, 2014).

The physical characteristics of soft soils are commonly evaluated through laboratory testing of parameters such as Moisture Content (*MC*), Liquid Limit (*LL*), Plastic Limit (*PL*) and Specific Gravity ($G_s$). These parameters are widely used for soil classification and provide important information regarding compressibility, consistency and strength behaviour. Accurate determination of these properties enables engineers to assess ground conditions and select appropriate foundation systems or ground improvement techniques (Das & Sobhan, 2018).

Figure 2.3 illustrates a typical subsurface profile of tropical soft soils commonly encountered in Malaysia, while Table 2.2 summarises the general characteristics and engineering behaviour of the principal soft soil types. Although these soils are generally classified as soft ground, each possesses distinct physical characteristics that influence its engineering response under loading conditions (CREAM, 2023). As shown in Figure 2.3 and Table 2.2 although all soft soils generally exhibit low shear strength and high compressibility, each soil type possesses distinct physical characteristics that influence its engineering behaviour. Peat is dominated by organic matter and exceptionally high Moisture Content, whereas Soft Clay and Clayey Silt are primarily governed by their mineral composition and plasticity. Loose Sand differs because of its granular structure and susceptibility to instability under saturated conditions. These differences highlight the importance of detailed laboratory characterisation and accurate soil classification prior to foundation design and construction (Briaud, 2023).

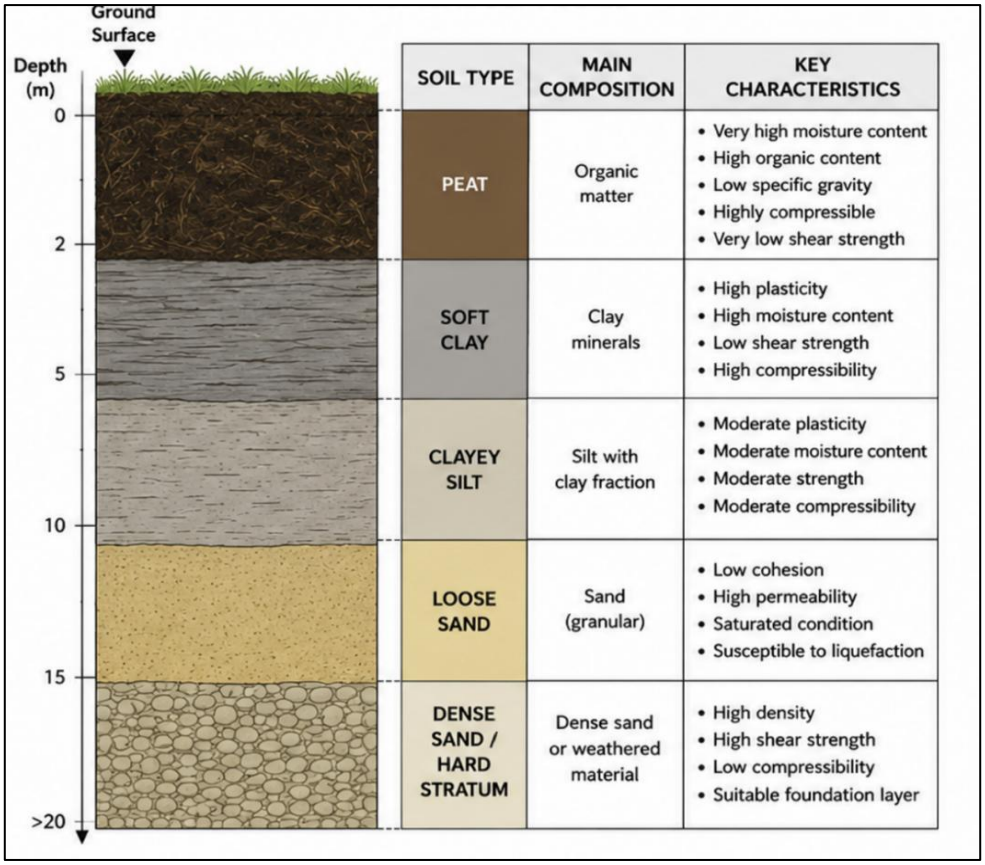



Figure 2.3 Typical Subsurface Profile of Tropical Soft Soils (Briaud, 2023).

Table 2.2
General Characteristics of Major Soft Soil Types

| Soil Type | Main Composition | Typical Physical Characteristics | Engineering Behaviour |
|---|---|---|---|
| Peat | Organic matter | Very high Moisture Content, low Specific Gravity, high Organic Content | High compressibility, very low bearing capacity, excessive settlement |
| Soft Clay | Clay minerals | High plasticity, high Moisture Content, low permeability | Low shear strength, high settlement potential |
| Clayey Silt | Silt with clay fraction | Moderate plasticity, moderate Moisture Content | Moderate compressibility and low strength |
| Loose Sand | Granular soil | Low cohesion, saturated condition | Susceptible to instability and liquefaction |

Source: Adapted from (CREAM, 2023), (Das and Sobhan, 2018) and (Briaud, 2023).

### *2.3.1.2 Peat Soil Criteria*

Peat is a material consisting of partially decomposed plant matter or organic substances. Plant material remains intact, leading to the formation of Peat under acidic and anaerobic conditions. Peat is characterized by a dark brown to murky black coloration as a soil type. It can typically be categorized as dark brown spongy amorphous Peat and spongy fibrous Peat. Decayed wood and roots are also present in the Peat continues to accumulate, consisting of decomposed leaves and plant materials (Omar & Jaafar, 2000).The maximum thickness is 20 meters from the surface downward. Up to 65% comprises the highest concentration of organic matter and includes various animals and insects. Peat develops in wet environments. Furthermore, Peat possesses the distinctive characteristic of being waterlogged within its ecosystem, functioning effectively as a natural sponge. The formation of peat under permanently waterlogged and anaerobic conditions is illustrated in Figure 2.4.

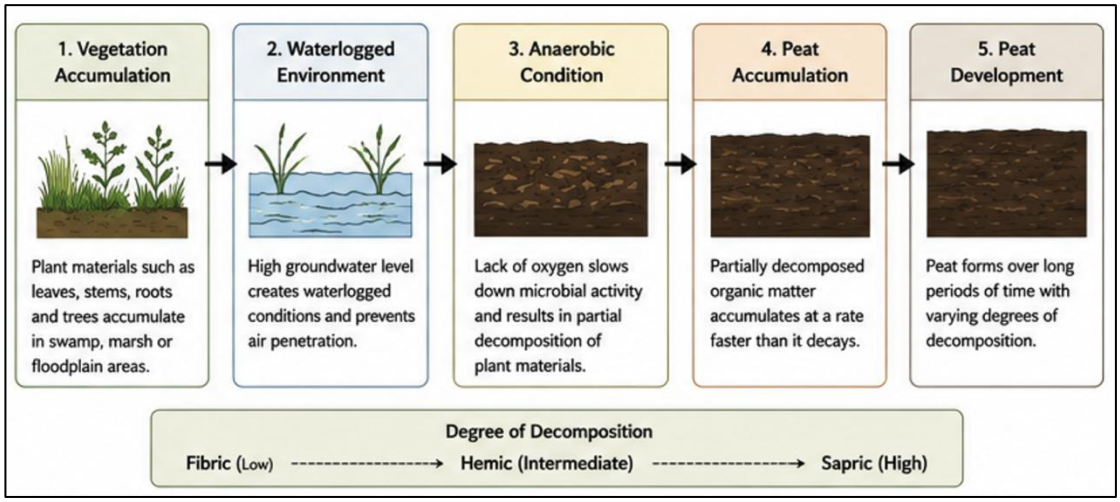



Figure 2.4 Formation Process of Peat under Waterlogged and Anaerobic Conditions (Parkir et al., 2025)

Additionally, Peat is characterized by low nutrient content, low dissolved oxygen levels, and acidic conditions, often associated with low water regimes (Rahman et al., 2013). Peat results from the accumulation of organic matter at a rate that exceeds its decay. Peat is defined and described in various ways by soil scientists and engineers. Peat is classified as a soil with an organic content exceeding 35%, according to soil

scientists. Organic soils typically contain between 20% and 75% organic matter, while Peats are defined as soils with over 75% organic content. The primary distinction between a soil scientist and a geotechnical engineer lies in a fundamental difference (Zainorabidin & Wijeyesekera, 2007).

Peat soil is an organic soil that develops in waterlogged and anaerobic environments. It is distinguished by a significant presence of partially decomposed plant materials, including cellulose, lignin and humic substances leading to organic matter contents that generally surpass 50% by dry weight (Abu Bakar et al., 2020). Peat, from a geotechnical standpoint, is characterized by very high natural water content, low Bulk Density, low shear strength, and high compressibility. These properties considerably diminish its load-bearing capacity and produce it particularly exposed to the possibility of harm or damage to excessive settlement and long-term creep under structural loading (Huat et al., 2014).

In tropical regions like Malaysia, Peat soils are typically fibrous and exhibit significant heterogeneity with depth. This variability complicates site investigation, foundation design and the application of empirical correlations highlighting the need for careful characterization and the use of indirect prediction methods such as SPT-based modelling (Zainorabidin & Wijeyesekera, 2007). The typical laboratory physical properties of Malaysian peat soils reported in previous studies are summarised in Table 2.3.

Table 2.3
Summary of Typical Physical Properties of Malaysian Peat Soils Reported in Previous Studies

| Physical Property | Reported Range | Engineering Significance |
|---|---|---|
| Degree of decomposition | H3–H7 | Indicates the degree of peat decomposition |
| Moisture Content, *MC* (%) | 230.89–2683 | High water retention and compressibility |
| Organic Content (%) | 56.10–99.42 | Governs the behaviour of peat soil |
| Fibre Content (%) | 5.67–80.00 | Used for peat classification (Fibric, Hemic and Sapric) |
| Ash Content (%) | 3.65–7.32 | Indicates inorganic mineral content |
| Specific Gravity, $G_s$ | 0.69–1.39 | Lower than mineral soils because of high organic matter |

| Physical Property | Reported Range | Engineering Significance |
|---|---|---|
| Liquid Limit, *LL* (%) | 136.11–309 | Indicates high water adsorption capacity |
| Plastic Limit, *PL* (%) | Non-plastic | Difficult to determine because of fibrous structure |
| pH | 3.00–4.15 | Represents acidic peat environment |
| Permeability | 0.89 m/day | High permeability due to porous structure |

Source**:** Adapted from (Pakir et al., 2025).

Table 2.3 summarises the typical laboratory physical properties of Malaysian peat soils reported in previous studies. Peat generally exhibits exceptionally high Moisture Content, high Organic Content and relatively low Specific Gravity compared with mineral soils. These physical characteristics explain the high compressibility, low shear strength and excessive settlement commonly associated with peat deposits. The laboratory data presented in previous studies provide a useful benchmark for comparison with the laboratory results obtained in the present study and further support the understanding of peat behaviour in tropical environments (Pakir et al., 2025).

### 2.3.2 Moisture Content, $w$

Natural Moisture Content is a fundamental property measured in soil classification and geotechnical investigations. The test involves determining the water content of a soil sample, typically by oven drying and weighing, as outlined in BS 1377-2:1990. This test is routinely performed for both soft and saturated soils to assess their in-situ condition and suitability for engineering purposes (Abd Malik et al., 2023). Moisture Content testing is conducted to quantify the amount of water present in soil, which is fundamental for evaluating compaction behaviour, compressibility and load response in saturated soils.

The results provide essential input for estimating soil volume change and drainage characteristics, as soil deformation cannot occur without moisture migration and the data are widely used for soil classification, assessment of construction suitability and evaluation of strength and stability characteristics (Amah et al., 2021). The Moisture Content of soil is expressed as the ratio of the mass of water to the mass of oven-dried soil and is calculated in accordance with BS 1377-2:1990.

The Moisture Content of a soil sample is calculated using Equation (2.1),

$$\text{Moisture Content,} \quad w = \frac{Mw}{Md} \text{x } 100\% \tag{2.1}$$

Where, w represents the Moisture Content (%), $M_w$ denotes the mass of water in the soil sample, and $M_d$ represents the mass of the oven-dried soil.

Alternatively, according to BS 1377-2:1990, Moisture Content may be calculated from the measured masses before and after oven drying, using the Equation (2.2),

$$\text{Moisture Content,} \quad w = \frac{M_2 - M_3}{M_3 - M_1} \text{x } 100\% \tag{2.2}$$

Where $M_1$ represents the mass of the empty container, $M_2$ represents the mass of the container and the wet soil before oven drying, and $M_3$ represents the mass of the container and the oven-dried soil after drying.

The Moisture Content of soil is closely related to its engineering behaviour. Soft alluvial soils and peat deposits generally exhibit exceptionally high Moisture Content because of their high organic matter and water retention capacity, resulting in lower penetration resistance and reduced soil stiffness. Conversely, soils with lower Moisture Content generally become denser and exhibit higher SPT *N*-values because of the increase in effective stress. In cohesive soils such as Clay, variations in Moisture Content alter the soil consistency from hard to plastic, thereby influencing workability, compressibility and strength. Furthermore, the Atterberg Limits, including the Liquid Limit, Plastic Limit and Plasticity Index, are closely associated with Moisture Content and are widely used to classify cohesive soils and predict their engineering performance (Gunn et al., 2003).

Previous studies have reported considerable variations in Moisture Content among different soil types because of differences in mineral composition, organic matter and depositional environment. Table 2.4 summarises the typical Moisture Content reported for selected soil types from previous studies.

Table 2.4
Summary of Typical Moisture Content of Different Soil Types Reported in Previous Studies

| Soil Type | Moisture Content (%) | Remarks | Reference |
|---|---|---|---|
| Peat | 230.89–2683 | Extremely high due to high organic content | (Pakir et al., 2025) |
| Soft Clay | High (typically, >40%) | High plasticity and compressibility | (Huat et al., 2014) |
| Clayey Silt | Moderate | Moderate water retention | (Das & Sobhan, 2018) |
| Sand | Low | Free-draining granular soil | (Das & Sobhan, 2018) |

Source: Adapted from (Pakir et al., 2025), (Huat et al., 2014) and (Das & Sobhan, 2018).

As presented in Table 2.4, Moisture Content varies considerably according to soil type. Peat exhibits the highest Moisture Content because of its high organic matter and water retention capacity, whereas granular soils generally possess much lower Moisture Content because of their larger particle sizes and higher permeability. These differences significantly influence soil compressibility, density and penetration resistance, demonstrating that Moisture Content is an important parameter in interpreting soil behaviour and establishing empirical relationships with SPT *N*-values (Pakir et al., 2025).

### 2.3.3 Atterberg Limits and Plasticity Index (*PI*)

The Atterberg limits are standardized tests used for soil classification, determining the critical water content limits at which fine-grained soils, including Clays and Silts, transition between various states of consistency. The limits include the Shrinkage Limit (*SL*), Plastic Limit (*PL*), Liquid Limit (*LL*) and Plasticity Index (*PI*), which collectively define the moisture-dependent behaviour of cohesive soils (Aizaz, 2024). The limits are determined using standardized laboratory procedures outlined in BS 1377 Part 2, with results presented as a percentage of water content in relation to the dry mass of the soil sample (Elbadry, 2017). The Atterberg Limits are essential parameters in soil mechanics and geotechnical engineering due to their simplicity and reliability. The *LL* refers to the water content at which soil transitions from a plastic to a liquid state, indicating the beginning of flow and a significant decrease in shear strength.

The transition is typically identified using the Casagrande cup or fall-cone method, both of which offer reliable means of assessment (Aizaz et al., 2024). The *PL* indicates the minimum water content at which soil retains its plasticity, allowing it to be formed into threads of about 3 mm in diameter without cracking. Below this limit, the soil transitions to a brittle state, leading to the formation of fractures (Kolawole et al., 2020). The *SL* is defined as the water content at which further moisture loss does not lead to additional volume reduction, indicating the transition from the semi-solid to the solid state (Elbadry, 2017).

The Plasticity Index (PI) is calculated as the numerical difference between the Liquid Limit (LL) and the Plastic Limit (PL), as expressed in Equation (2.3)

$$PI = LL - PL \tag{2.3}$$

Where *PI* represents the Plasticity Index (%), *LL* represents the Liquid Limit (%) and *PL* represents the Plastic Limit (%).

The *PI* represents the range of water contents over which a fine-grained soil exhibits plastic behaviour. Higher *PI* values generally indicate greater clay content, higher water adsorption capacity and increased compressibility. The classification of soil plasticity based on the *PI* is summarised in Table 2.5**.** The *PI* provides a practical basis for classifying the degree of soil plasticity according to the range of *PI* values. Higher *PI* values generally indicate greater clay content, increased water adsorption capacity and higher compressibility, whereas lower *PI* values represent soils with lower plasticity and reduced susceptibility to volume change. Consequently, the *PI* is widely used to evaluate the consistency and engineering behaviour of cohesive soils (Holtz et al., 2011).

Table 2.5
Classification of Soil Plasticity Based on Plasticity Index (*PI)*

| PI Range | Description |
|---|---|
| 0 | Non-Plastic |
| 1-5 | Slightly Plastic |
| 5-10 | Low Plasticity |
| 10-20 | Medium Plasticity |
| 20-40 | High Plasticity |
| >40 | Very High Plasticity |

Source: Adapted from (Holtz et al., 2011).

Table 2.6 demonstrates that the Atterberg Limits vary considerably according to soil type and mineral composition. Peat generally exhibits the highest *LL* because of its high organic matter and water retention capacity, whereas Soft Clay commonly possesses higher *PI* values than Clayey Silt because of its greater clay mineral content. In contrast, Clayey Silt generally exhibits lower *LL* and *PI* values, indicating lower plasticity and compressibility. These differences demonstrate that the Atterberg Limits provide valuable information for evaluating soil consistency and engineering behaviour under varying moisture conditions.

Table 2.6
Comparison of Atterberg Limits for Different Soil Types Reported in Previous Studies

| Soil Type | *LL* (%) | *PL* (%) | *PI* (%) | Remarks | Reference |
|---|---|---|---|---|---|
| Peat | 136–309 | NP | NP | Highly organic | (Pakir et al., 2025) |
| Soft Clay | 45-90 | 20-40 | 20-50 | High plasticity | (Huat et al., 2014) |
| Clayey Silt | 30-50 | 18-28 | 10-25 | Medium plasticity | (Das & Sobhan, 2018) |
| Clay | 35-80 | 18-35 | 15-45 | Cohesive Soil | (Head, 1992) |

Figure 2.5 illustrates the Atterberg Limits and the corresponding consistency states of fine-grained soils as a function of increasing water content. The figure shows how the soil transitions through each state with moisture variation, providing a clear visual reference for understanding soil behaviour under different water contents. The

Atterberg limits are crucial for characterizing soft and saturated soils, particularly in areas like Cyberjaya, where fine-grained soils prevail in the subsurface profile. Soil shows the Atterberg limits and associated consistency states of fine-grained soils in relation to increasing water content. The figure illustrates the transition of soil through different states in response to moisture variation, serving as a clear visual reference for understanding soil behaviour under different water contents, consistency, workability and ease of deformation in these environments are significantly influenced by moisture conditions, which are effectively quantified by the Atterberg limits (Amah et al., 2021). These parameters are essential for predicting soil behaviour under different field moisture conditions including volume change potential, sensitivity, and stability.

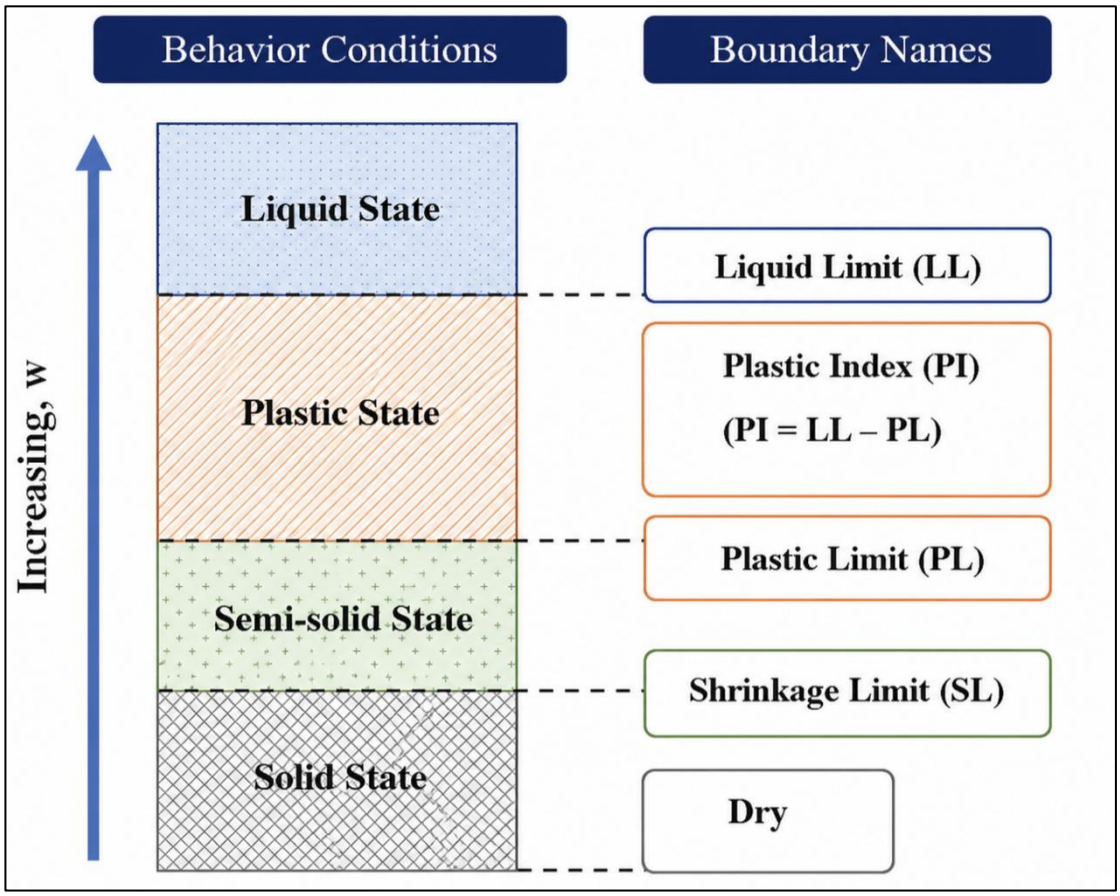



Figure 2.5 Consistency of Soils as Indicated by Atterberg Limit (Holtz et al., 2011)

As the water content of fine-grained soils increases, the soil experiences a systematic sequence of consistency transitions defined by the Atterberg Limits when the water content is below the *SL*, the soil exhibits solid behaviour; as Moisture Content rises past the shrinkage limit but stays below the *PL*, the soil transitions into a semi-

solid state. Soil demonstrates plastic behaviour between the *PL* and *LL*. However, when water content exceeds the *LL*, the soil behaves as a viscous liquid with significantly reduced shear strength (Zhao et al., 2022). This progression offers a framework for analysing the impact of moisture on soil structure, strength and deformation properties.

The standardized testing procedures outlined in BS 1377-2:1990 provide consistency, repeatability and reliability in the determination of *LL*, *PL* and *PI* facilitating meaningful comparisons of soil properties across various sites and projects (Holtz et al., 2011). Additionally, semi-empirical relationships often exist between the Atterberg limits and essential engineering properties, including shear strength, compressibility and permeability. These limits are especially useful in scenarios where direct measurement of mechanical properties is challenging, time-consuming or expensive (Das & Sobhan, 2018).

In soft soils with low to medium plasticity (*PI* = 15–40%), SPT *N*-values frequently show significant variation with depth, indicating the intrinsic heterogeneity of the deposits. These soils are classified as inorganic with low to medium plasticity (Cavallaro et al., 2003). High-plasticity Silts and Clays are typically linked to low bulk or dry density and elevated plasticity index values, which correlate with low SPT *N*-values, indicating loose, compressible and weak soil conditions (Cavallaro et al., 2003). The relationships underscore the significance of Atterberg limits in the interpretation of in-situ test results and the evaluation of subsurface variability.

The Atterberg Limits are valuable indicators of the consistency and plasticity characteristics of fine-grained soils. Together with Moisture Content and particle size distribution, these parameters provide important information for interpreting soil behaviour and supporting the correlation between physical soil properties and SPT *N*-values developed in the present study.

### 2.3.4 Bulk and Dry Density

Bulk Density ($\rho_b$**)** and Dry Density ($\rho_d$) epresent the mass of soil per unit volume under natural and oven-dried conditions, respectively. These physical properties are widely used in geotechnical engineering to evaluate soil compactness, porosity and bearing capacity (Das & Sobhan, 2018). In soft soils, $\rho_d$ is generally lower because of the high Moisture Content and large void ratio, whereas $\rho_b$ varies depending on the degree of saturation and soil composition. Consequently, both parameters

provide valuable information for assessing subsurface conditions and foundation performance during geotechnical site investigations (Briaud, 2023).

$\rho_b$ and $\rho_d$ are determined in accordance with BS 1377-2:1990. $\rho_b$ is defined as the mass of soil per unit total volume under natural conditions, whereas $\rho_d$ represents the mass of oven-dried soil per unit total volume. The corresponding equations are presented in Equations (2.4) and (2.5), respectively.

$$\rho b = \frac{M_t}{V} \tag{2.4}$$

Where ρb represents the Bulk Density (Mg/m³), Mt represents the total mass of the moist soil specimen (Mg), and V represents the total volume of the soil specimen (m³).

$$\rho d = \frac{M_d}{V} \tag{2.5}$$

Where $\rho_d$ represents the Dry Density (Mg/m³), $M_d$ represents the mass of the oven-dried soil specimen (Mg), and $V$ represents the total volume of the soil specimen (m³).

$\rho_b$ and $\rho_d$ provide important information on soil compactness, porosity and compressibility. In soft soils, lower $\rho_d$ is generally associated with higher Moisture Content and larger Void Ratio, whereas soils exhibiting higher $\rho_d$ generally possess greater stiffness and higher penetration resistance. Consequently, these parameters are commonly used together with SPT *N*-values to evaluate subsurface conditions and foundation performance (Das & Sobhan, 2018).

In natural soft alluvial deposits, particularly in low-lying and swampy areas, bulk density reflects the combined effects of high Moisture Content, organic matter and relatively low in-situ stress, resulting in lower dry density and greater soil compressibility. According to British Standards Institution (1990), $\rho_b$ is defined as the mass of a known volume of soil, whereas $\rho_d$ is determined by oven-drying the soil specimen and expressing the mass per unit volume on a dry basis. These parameters are important indicators of soil compaction and density conditions, as higher bulk and dry

density values are generally associated with greater penetration resistance SPT *N*-values and increased soil stiffness (Kennedy, 2024).

Previous studies have reported that soil density is closely related to in-situ test parameters, indicating that $\rho_b$ and $\rho_d$ are important physical properties for developing empirical relationships to estimate soil strength and stiffness (Yusof & Zabidi, 2018). In soft ground conditions, lower $\rho_d$ values are commonly associated with higher Void Ratios and elevated Moisture Content, particularly in clay and peat deposits. Conversely, soils with higher density generally exhibit greater penetration resistance and improved stiffness. Therefore, $\rho_b$ and $\rho_d$ provide valuable information for distinguishing weak, highly compressible soils from relatively denser soil layers and are important for evaluating settlement potential, bearing capacity and supporting the interpretation of SPT *N*-values in geotechnical site investigations (Memon et al., 2024).

### 2.3.5 Specific Gravity Test, $G_s$

Specific Gravity ($G_s$) testing determines the ratio of the density of soil solids to water, aiding in the identification of soil mineralogy and the calculation of void ratio and degree of saturation, which are critical for classification, compaction and stability analyses in both cohesive and non-cohesive soils (Amah et al., 2021). Specific Gravity is a crucial parameter in soil mechanics, used to determine material properties including void ratio, porosity and weight–volume relationships (Andavan & Pagadala, 2020). In soils that are rich in organic matter or highly weathered, Specific Gravity values are generally lower. Conversely, in dense, mineral-rich Sands and gravels, Specific Gravity is typically higher (Holtz et al., 2011). According to BS 1377-2:1990 – Part 2: Classification Tests, the $G_s$ test is conducted using a small sample of oven-dried soil and a pycnometer or density bottle, aiming to ascertain the relative density of the soil solids in comparison to water. This test is particularly important for fine-grained and organic soils where conventional assumptions of $G_s \approx 2.65$ may not be valid.

The $G_s$ of soil solids determined using the gas jar (density bottle) method is calculated in accordance with BS 1377-2:1990 as presented in Equation (2.6).

$$Gs = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \tag{2.6}$$

Where, $Gs$ is the Specific Gravity of soil solids, $M_1$ is the mass of the empty gas jar, $M_2$ is the mass of the gas jar and oven-dried soil, $M_3$ is the mass of the gas jar containing the oven-dried soil and water, and $M_4$ is the mass of the gas jar filled with water only.

Table 2.7 demonstrates that the $G_s$ of soft soils varies considerably according to soil composition and organic matter content. (Kaniraj & Joseph, 2004) reported the lowest $G_s$ values for organic soils (0.99–1.02), reflecting the high proportion of organic matter and low-density soil particles. In the same study, peat soils exhibited slightly higher $G_s$ values ranging from 1.43 to 1.90, indicating that variations in the degree of decomposition and mineral content influence the density of peat deposits. (Nujid et al., 2020) reported a $G_s$ of 2.27 for marine soil, which is higher than that of peat and organic soils because marine deposits generally contain a greater proportion of mineral particles. Similarly, (Zaini et al., 2022) and (Suwito et al., 2024) reported $G_s$ values of 2.64 and 2.63, respectively, for untreated soft kaolin clay and soft clay. These values are consistent with the typical $G_s$ of inorganic fine-grained soils and indicate a predominantly mineral composition.

Overall, the findings suggest that $G_s$ decreases with increasing organic matter content and increases in mineral soils, making $G_s$ an important parameter for differentiating soft soil types and supporting the interpretation of engineering behaviour.

Table 2.7
Comparison of Specific Gravity ($G_s$) Reported for Different Soft Soil Types

| Soil Type | Specific Gravity ($G_s$) | Engineering Characteristic | Reference |
|---|---|---|---|
| Organic Soil | 0.99-1.02 | High organic matter, highly compressible | (Kaniraj & Joseph, 2004) |
| Peat | 1.43-1.90 | Fibrous, very high Moisture Content | (Kaniraj & Joseph, 2004) |
| Marine Soil | 2.27 | Fine-grained alluvial deposit | (Nujid et al., 2020) |
| Soft Kaolin Clay | 2.64 | Predominantly inorganic clay | (Zaini et al., 2022) |
| Soft Clay | 2.63 | Mineral-dominated clay | (Suwito et al., 2024) |

Variations in $G_s$ may suggest the existence of organic matter, low-density minerals or dense components like iron oxides (Craig, 2004). From a geotechnical modelling perspective, $G_s$ frequently exhibits a positive correlation with Bulk Density, SPT *N*-value and soil strength as increased mineral density is generally linked to denser packing and reduced compressibility. Multiple studies indicate that $G_s$ can be included as an explanatory variable in empirical correlations to enhance the prediction of soil behaviour based on in-situ test data (Baharuddin et al., 2020). In soft alluvial environments, variations in $G_s$ serve to differentiate organic layers from mineral-dominated strata, thus offering further insight into subsurface variability. Tropical soft soils characterized by low $G_s$ often demonstrate insufficient engineering properties, including low bearing capacity, high compressibility and risk to settlement and deformation, thereby requiring stabilization or improvement for construction applications (Adebisi et al., 2016).

### 2.3.6 Particle Size Distribution (PSD)

PSD analysis measures the relative amounts of Gravel, Sand, Silt and Clay present in a soil sample. This analysis aids in soil classification, structural assessment, and the prediction of compressibility and strength, particularly in soft, saturated soils with a high fines content (Amah et al., 2021). The PSD measures the relative proportions of different grain sizes in a soil mass and functions as a classification instrument in soil mechanics. The PSD affects multiple geotechnical properties, such as permeability, shear strength, compressibility and the exposure to piping or internal

erosion (Das & Sobhan, 2017). Well-graded soils which exhibit a varied particle size distribution, generally show lower void ratios and improved shear strength. Conversely, uniformly graded or fine-grained soils exhibit heightened compressibility and diminished permeability.

According to BS 1377-2:1990, PSD is determined using sieve analysis for coarse-grained particles and hydrometer analysis for fine-grained fractions. The particle size distribution curve obtained from sieve and hydrometer analyses is used to evaluate soil gradation. Two parameters commonly used to describe soil gradation are the Uniformity Coefficient ($C_u$) and the Coefficient of Gradation ($C_g$), which are calculated using Equations (2.7) and (2.8) respectively, in accordance with BS 1377-2:1990.

$$C_u = \frac{d_{60}}{d_{10}} \tag{2.7}$$

Where $d_{60}$ is the particle diameter corresponding to 60% passing, and $d_{10}$ is the particle diameter corresponding to 10% passing on the particle size distribution curve.

The Coefficient of Gradation ($C_g$) is expressed as:

$$C_g = \frac{d_{30} x d_{30}}{d_{60} x d_{10}} \tag{2.8}$$

Where d30 is the particle diameter corresponding to 30% passing on the particle size distribution curve.

According to BS 5930:2015, soils may be described based on their gradation characteristics using the values of $C_u$ and $C_g$. In general, gravels are considered well graded when $C_u \geq 4$ and $1 \leq C \leq 3$, whereas sands are considered well graded when $C_u \geq 6$ and $1 \leq C_g \leq 3$. Soils that do not satisfy these criteria are generally classified as poorly graded (Das & Sobhan, 2022).

Sieve analysis is employed to determine the distribution of gravel and sand particles, whereas hydrometer analysis is used to quantify the finer silt and clay fractions. The combined results provide the percentage distribution of soil particles over a range of sizes and form the basis for soil classification. In geotechnical engineering, PSD is an essential index property because the proportion of coarse and fine particles significantly influences permeability, drainage characteristics, compressibility and

shear strength. Consequently, PSD provides valuable information for evaluating the engineering behaviour of soft soils and supports the interpretation of subsurface conditions (Das & Sobhan, 2018).

In the context of soft alluvial and Peat-influenced deposits, particle size distribution is particularly effective in differentiating between Clayey, Silty and Sandy layers that frequently occur in succession. Fine-grained layers with a high Clay fraction typically exhibit reduced SPT *N*-values, elevated Moisture Content and decreased density. Sandier layers exhibit elevated *N*-values and decreased compressibility. Multiple studies demonstrate that PSD based descriptors, when combined with in-situ tests such as the SPT, improve the reliability of empirical correlations for predicting soil strength and deformation characteristics (Phoon & Kulhawy, 1999).

The main aim of sieve analysis is to determine the distribution of particle sizes in a specific soil sample. Understanding the physical properties of soil, such as permeability, compaction characteristics and shear strength requires this information. An engineer can assess the appropriateness of soil for a particular construction project through the analysis of its PSD. In conducting a sieve analysis, consult the guidelines and standards specified in BS 1377-2:1990, Methods of Test for Soils for Civil Engineering Purposes - Part 2: Classification tests, such as sieve analysis and hydrometer procedures, are essential for determining the distribution of coarse and fine soil fractions. The guidelines outline the necessary equipment, the testing procedure and the methodology for result interpretation. Soil classification must comply with the standard BS1377:1990 to ensure consistent and accurate reporting of results.

Overall, PSD is one of the fundamental physical properties used to characterise soft soils. When interpreted together with Moisture Content, Atterberg Limits, Bulk Density and Specific Gravity, PSD provides a comprehensive understanding of soil behaviour and strengthens the development of empirical relationships between physical soil properties and SPT *N*-values in the present study (Das & Sobhan, 2018).

#### *2.3.6.1 Dry Sieve Analysis*

Dry sieve analysis is performed to determine the PSD of coarse-grained soils by separating soil particles using a series of standard sieves in accordance with BS 1377-2:1990. The test provides the percentage of gravel and sand fractions and forms part of the PSD analysis used for soil classification and engineering assessment. Table 2.8 summarises the findings of previous studies on particle size characteristics obtained from dry sieve analysis for different soft soil deposits.

Table 2.8
Comparison of Particle Size Distribution Findings Reported in Previous Studies

| Researcher | Study Area | Soil Type | Main PSD Findings | Relevance to Present Study |
|---|---|---|---|---|
| (Omar & Jaafar, 2000) | Cyberjaya, Selangor | Soft soil (peat, clay and silt) | The soil profile is heterogeneous, consisting of peat, clay and silt. Clay content generally decreases with depth, while silt content increases. Sand layers occur at greater depths | Demonstrates the natural variation of alluvial deposits in the Cyberjaya area and supports the importance of PSD in characterising soil profiles. |
| (Tan et al., 2003) | Klang, Selangor | Soft marine clay | The deposit mainly consists of soft silty clay with occasional sandy layers, reflecting the heterogeneous nature of coastal alluvium. | Indicates that soft clay deposits in Selangor commonly comprise mixed fine-grained materials that influence engineering behaviour. |
| (Nujid et al., 2022) | Kuala Kedah | Marine soil | Particle size distribution was determined using sieve and hydrometer analyses according to BS 1377. PSD was used as a fundamental parameter for soil classification before evaluating engineering properties. | Confirms that PSD is an essential laboratory test for characterising soft soils prior to correlation analysis. |
| (Hamzah & Alias, 2022) | Malaysia | Soft clay | Engineering behaviour is strongly influenced by fine-grained particles, particularly clay and silt, which contribute to high compressibility and low shear strength. | Supports the relationship between soil grading and engineering behaviour adopted in this study. |

Previous studies have reported that soils with higher sand contents generally exhibit higher permeability, lower compressibility and greater penetration resistance than soils dominated by fine particles because of their larger particle sizes and lower specific surface area (Das & Sobhan, 2018). Table 2.8 demonstrates that PSD varies considerably among different soft soil deposits. (Omar and Jaafar, 2000) reported that the Cyberjaya soft soil profile consists predominantly of peat, clay and silt with clay content generally decreasing and silt content increasing with depth, indicating the heterogeneous nature of the alluvial deposits. (Tan et al., 2003) similarly reported that Klang soft deposits are mainly composed of soft silty clay with intermittent sandy layers. (Nujid et al., 2022) further emphasised that Particle Size Distribution analysis using sieve and hydrometer methods is fundamental for soil classification prior to evaluating physical properties. Collectively, these findings indicate that variations in PSD significantly influence permeability, compressibility and soil strength, thereby supporting the interpretation of SPT *N*-values in soft soil deposits.

#### *2.3.6.2 Wet Sieve Analysis*

Wet sieve analysis is commonly adopted for soils containing appreciable amounts of fine particles because washing prevents the aggregation of clay and silt particles that may adhere to coarser grains during dry sieving. Consequently, the method improves the accuracy of particle size determination and provides a more reliable estimation of the coarse soil fraction. This procedure is particularly suitable for soft alluvial and clay-rich soils where particle aggregation frequently occurs and may influence the accuracy of soil classification (Craig, 2004).

#### *2.3.6.3 Hydrometer Analysis*

The Hydrometer analysis is employed to determine the distribution of silt- and clay-sized particles that cannot be accurately measured using mechanical sieving. The method is based on the sedimentation of soil particles in suspension and is specified in BS 1377-2:1990 for fine-grained soils. Hydrometer analysis provides the percentages of silt and clay fractions, which are essential for evaluating the engineering behaviour

of soft soils because these fine particles govern permeability, compressibility, consolidation characteristics and volume change behaviour (Craig, 2004).

For soft alluvial and clay-rich deposits, hydrometer analysis provides valuable information for differentiating fine-grained soil layers and supports the interpretation of SPT *N*-values. Previous studies have shown that soils with higher clay contents generally exhibit increased Moisture Content, lower permeability, higher compressibility and lower penetration resistance than soils containing greater proportions of sand particles (Das & Sobhan, 2018).

## 2.4 Correlation Between SPT *N*-Value and Soil Properties

SPT is frequently used in situ testing within geotechnical engineering, related to its simplicity, reliability, and cost-effectiveness. The combination with conventional borehole drilling operations facilitates the routine obtaining of SPT *N*-values during site investigations, even with the lack of more advanced in-situ tests such as CPT or pressure meter tests (Kulhawy & Mayne, 1990). Consequently, SPT *N*-values are frequently the most accessible field data and have generally been used as empirical indicators of soil resistance, density, and stiffness, especially in the initial phases of geotechnical design and feasibility evaluation (Phoon & Kulhawy, 1999). In the last ten years, extensive research has aimed to establish empirical correlations between SPT *N*-values and fundamental soil properties, such as Moisture Content, bulk and dry density, Atterberg limits, particle size distribution and shear strength parameters. The correlations offer an effective method for indirectly estimating soil behaviour particularly in contexts where laboratory testing is constrained by time, cost or sample disturbance (Bol, 2023). Recent studies indicate that statistically derived relationships between SPT *N*-values and soil index properties generate reliable estimates for engineering analysis, based on the consideration of soil type, stress conditions and local geological context (Nasiri Pishvari et al., 2024).

The significance of SPT based correlations is particularly apparent in soft soil environments, such as alluvial plains and Peat influenced deposits. In these contexts, elevated natural Moisture Content, reduced shear strength and increased compressibility often lead to significant sample disturbance during retrieval, thereby complicating the achievement of high-quality undisturbed laboratory testing (Baharuddin et al., 2020). Empirical correlations derived from in-situ SPT data provide a practical and cost-

effective approach for characterising subsurface conditions and estimating physical soil properties during the preliminary stage of site investigation, particularly when laboratory test results are not yet available (Rahman et al., 2022). In areas like Cyberjaya and the Langat River Basin, characterized by substantial deposits of soft Clay, Silty Clay, and Peat, SPT *N*-values indicate variations in soil consistency, density and stratification with depth. Research in Malaysian soft soils indicates that *N*-values rise with depth due to increased consolidation and reduced organic content. This highlights the importance of correlating *N*-values with soil index parameters to effectively capture vertical variability in ground conditions (Yusof & Zabidi, 2018). The correlations improve the interpretation of borehole data and increase confidence in soil profiling across different geographically deposits. In addition to soil classification and initial assessment, SPT based correlations are significant in both numerical and analytical modelling (M. N. Salleh et al., 2021). In many geotechnical applications, including slope stability analysis, settlement prediction, ground improvement design and in-situ stress evaluation, engineers require representative input parameters that may not be directly measurable at every location. Empirical relationships enable the estimation of important mechanical properties through a singular, easily obtainable parameter specifically the *N*-value. This approach promotes efficient modelling while ensuring acceptable accuracy levels (Kumar et al., 2016).

It is widely recognized that the reliability of SPT based correlations is significantly influenced by local calibration, soil type and testing conditions. Correlations established in one geological context may not be applicable to another without proper validation. The establishment of site-specific and regionally calibrated correlations, exemplified by those suggested for the soft alluvial soils of Cyberjaya, is crucial for enhancing predictive accuracy and minimizing uncertainty in geotechnical design (Rahman et al., 2022). Correlations between SPT *N*-values and soil properties offer a practical and cost-effective framework for estimating subsurface behaviour in soft soil environments. With appropriate statistical analysis and local calibration, these correlations markedly improve the efficiency of site investigations, improve numerical modelling applications, and lead to safer and more cost-effective geotechnical engineering solutions.

### 2.4.1 Correlation Studies in Malaysian Residual Soils

Empirical correlation studies play a critical role in Malaysian geotechnical practice, particularly in residual soils formed under tropical weathering conditions. Malaysian residual soils exhibit unique mineralogical compositions, fabric arrangements and moisture regimes, which differentiate them from transported soils in temperate regions. As a result, locally developed correlations are essential to ensure reliable soil parameter estimation (Bol, 2023). Recent Malaysian studies have demonstrated that correlations between basic index properties such as *PI*, Clay fraction, and *LL* and strength or stiffness parameters can significantly improve preliminary soil characterisation. These correlations are especially useful during early design stages and for cross-validating laboratory test results using simpler index properties (Shimobe et al., 2025). Table 2.9 summarises selected empirical correlation studies conducted on residual soils together with their principal findings and the research gaps identified in previous studies.

Table 2.9
Summary of Previous Empirical Correlation Studies and Identified Research Gaps

| Researcher | Soil Type/ Study Area | Parameter Used | Main PSD Findings | Identified Research Gap |
|---|---|---|---|---|
| (Phoon & Kulhawy, 1999) | Various soils | SPT N-value | Developed empirical correlations using SPT N-values for estimating soil properties. | Depth was not explicitly incorporated as a predictor variable. |
| (Omar & Jaafar, 2000) | Residual Soil, Malaysia | Index properties | Local correlations improved soil characterisation. | Limited statistical validation and dataset size. |
| (Bol, 2023) | Malaysian residual soil | PI, LL, Clay fraction | Local correlations provide better prediction than foreign | Focused on residual soils only. |
| (Liu et al., 2020) | Residual soil | Statistical correlation | Model reliability depends on dataset size and geological | Limited applicability to heterogeneous tropical soils. |
| (Nasiri Pishvari et al., 2024) | Residual soil | Empirical correlations | Recommended local validation before applying empirical models. | Did not incorporate depth or Malaysian soft soils. |

Table 2.9 indicates that previous empirical correlation studies have demonstrated the usefulness of SPT *N*-values and index properties for estimating soil behaviour. However, most studies were developed using residual soils or under different geological conditions, limiting their applicability to Malaysian tropical soft soils. In addition, depth was rarely incorporated as a predictor variable despite its influence on penetration resistance. These limitations justify the development of site-specific empirical prediction models using SPT *N*-values and depth in the present study.

### 2.4.2 Importance of Including Depth in SPT *N*-Value Based Correlations

Early correlation models primarily relied on raw SPT *N*-values without explicitly considering depth or overburden stress effects. Subsequent research has clearly shown that *N*-values are strongly influenced by effective stress, which increases with depth, even within similar soil types. As a result, soils of identical composition may exhibit different *N*-values solely due to confinement effects (S. S. C. Liao & Whitman, 1986). To address this limitation, normalization procedures such as energy-corrected $N_{60}$-values and stress-normalised indices have been widely recommended. These corrections account for variations in hammer energy, borehole conditions, rod length, and effective overburden pressure, thereby improving the comparability of *N*-values across depths (Youd et al., 2001).

In soft soil environments like Cyberjaya, depth plays an even more critical role due to the presence of thick near-surface Peat and soft Clay layers transitioning into denser alluvial deposits at greater depths. Integrating depth as an independent variable allows correlation models to differentiate between weak surficial soils and deeper competent layers, even when overlapping *N*-values are observed (Yusof & Zabidi, 2018). Recent regression-based modelling studies advocate the combined use of SPT *N*-values and depth to enhance prediction accuracy, reduce uncertainty, and improve geotechnical interpretability. This approach is particularly suitable for statistical modelling frameworks such as those implemented in MINITAB, as adopted in the present study (Phoon & Kulhawy, 1999).

### 2.4.3 Correlation with Basic Soil Index Properties

SPT is a commonly utilized in-situ test in geotechnical engineering, recognized for its practicality and historical application in estimating soil resistance parameters (Das & Sobhan, 2017). The operational simplicity and compatibility of SPT *N*-values with routine drilling facilitate their availability in different site investigations (Bowles, 1997). The *N*-values frequently correlate with fundamental soil properties to assist in initial geotechnical design determinations (Kulhawy & Mayne, 1990). In soft alluvial and Peat influenced regions such as Cyberjaya, direct sampling frequently presents challenges, thereby creating empirical correlations based on SPT *N*-values a viable alternative (Baharuddin et al., 2020). The correlations enable engineers to estimate soil behavior, especially in situations where obtaining high-quality undisturbed samples is challenging or where time constraints restrict comprehensive laboratory testing (Nasiri Pishvari et al., 2024).

Empirical correlations have been established to estimate parameters, including the angle of internal friction and cohesion, based on SPT *N*-values in granular and cohesive soils, respectively (Brown & Hettiarachchi, 2008). The correlation between *N*-values and friction angle has been established in Silty and Sandy soils, offering valuable insights for the analysis of shallow foundations (Suzuki et al., 1993). Study on fine-grained soils has indicated a correlation between undrained shear strength and *N*-values, particularly in normally consolidated Clays (Kalantary et al., 2009). Recent developments include the relationships between SPT *N*-values and shear wave velocity, which are essential for dynamic site response analyses (Anbazhagan et al., 2013). The correlations are significant for seismic design and for predicting small-strain stiffness in soils (Maheshwari et al., 2010). Many of these models exhibit a strong dependence on soil type and site-specific conditions, which restricts their general applicability (Rao, 2013).

Researchers have created extended empirical models to estimate properties such as unit weight, modulus of elasticity, and degree of saturation using SPT data for applications in blast loading conditions (Kumar et al., 2016). Although these correlations provide useful information, their application should be approached with caution, particularly when utilized beyond the specific soil types or geological contexts for which they were initially formulated (Kumar et al., 2016). Empirical correlations based on SPT are especially beneficial in the initial stages of projects, where rapid and

economical parameter estimation is required prior to the availability of advanced testing (Craig, 2004). These models generate useful predictions regarding soil behaviour in geotechnical issues, including slope stability, foundation settlement, and deformation assessments (Phoon & Kulhawy, 1999). Statistical analysis indicates enhanced reliability of these correlations, particularly when derived from local datasets in controlled environments (Kumar et al., 2016).

#### *2.4.3.1 Correlation of SPT N-Value and Moisture Content*

The correlation between SPT *N*-values and Moisture Content has significance for the characterization of soft and saturated soils especially in the regions of Cyberjaya and the Langat River Basin. In these environments, soft soils such as Silty Clay and organic Peat deposits frequently display higher Moisture Content which leads to reduced mechanical properties and complicates site investigations. The Moisture Content affects the physical behaviours of soil by impacting effective stress and inter-particle bonding. High Moisture Content results can increase pore water pressure which decreases effective stress and consequently leads to a reduction in stiffness and shear strength within the soil matrix. Thus, soils with increased water content typically demonstrate lowered SPT *N*-values as a result of decreased resistance to penetration during dynamic loading (Yashni et al., 2020). The relationship is especially evident in fine-grained soils where water is retained in micropores that reducing particle-to-particle contact and allowing plastic deformation under loading (Tang et al., 2015).

SPT is a dynamic in-situ test that measures soil resistance to penetration through energy impact. In saturated soils, particularly those exhibiting high saturation levels, a portion of the impact energy is dissipated within the water phase, resulting in reduced recorded *N*-values. The phenomenon is particularly evident in low-permeability soils including Clays and organic Silts where drainage is limited and pore water pressures release slowly during testing (Rahman et al., 2022).

In the Cyberjaya region, characterized by shallow subsoils of soft alluvium and Peat layers, the impact of Moisture Content on SPT results is particularly significant. Field studies indicate *N*-values ranging from 2 to 4 in upper Clayey Silt and Peat layers where Moisture Content surpasses 100% (Baharuddin et al., 2021). The low penetration resistance observed indicates both the soft characteristics of these deposits and their susceptibility to settlement and instability under external loading conditions. Recent

studies in tropical climates indicate that Moisture Content serves as a significant predictor of low *N*-values in saturated soft soils (Naseri et al., 2023). In soft marine Clays of coastal Peninsular Malaysia, a significant inverse correlation exists between natural water content and *N*-values, evidenced by a Correlation Coefficient of $R^2 = 0.72$ (M. N. Salleh et al., 2021). This highlights the importance of integrating moisture data into predictive models for soil strength and deformation behaviour.

Statistical models for soft soils frequently include Moisture Content as an independent variable in regression analysis to estimate *N*-values, particularly during preliminary design phases when comprehensive geotechnical testing is constrained. These models facilitate a quick evaluation of soil consistency and classification, especially in complicated depositional environments where soil characteristics exhibit lateral and vertical variability. In the hydrogeological context of Cyberjaya, which is marked by higher groundwater tables and frequent rainfall, it is essential to understand the influence of moisture on soil strength. This understanding provides theoretical importance and practical relevance for foundation design, excavation support, and infrastructure adaptability. Consequently, Moisture Content should be carefully evaluated together with other geotechnical parameters when analysing SPT data for soft soil profiling in the area.

#### *2.4.3.2 Correlation of SPT N-Value and Atterberg Limit*

Correlations between SPT *N*-values and Atterberg Limits are extensively studied, as Atterberg Limits indicate soil plasticity, water retention capacity and mechanical behaviour under different moisture conditions. *LL* and *PI* serve as important indicators of soil compressibility, consistency and strength especially in soft deposits where conventional strength tests may produce unreliable results due to sample disturbance (Holtz et al., 2011). In cohesive soils, an increase in *LL* and *PI* correlates with improved plastic deformation capacity, whereas resistance to penetration as indicated by the SPT generally reduces (Roslee et al., 2017).

In Malaysian saturated Silty Clays and Peat identified liquid limit values are correlated with reduced *N*-values as soils nearing the liquid state exhibit decreased interparticle friction and effective stress, thereby decreasing resistance during dynamic blow counts (Yusof et al., 2021). The relationship has been supported by statistical analyses indicating strong negative correlations between *PI* and *N*-values in soft fine-

grained strata. Predictive models incorporating both parameters enhance the estimation of strength and compressibility compared to direct shear tests (Salleh & Ibrahim, 2020). Research on Malaysian marine Clays demonstrates that multiple regression models utilizing *LL* and *PI* as independent variables account for up to 75% of the variance in *N*-values, suggesting that soil plasticity significantly influences penetration resistance (Tan et al., 2023).

The observed trends are consistent with theoretical predictions; soils exhibiting higher plasticity retain increased water content and demonstrate greater volumetric deformation, both of which directly decrease soil stiffness and subsequently lower *N*-values. The correlation's strength is influenced by soil type and depositional context; soft soils with low plasticity may exhibit weaker trends unless adjusted for depth and overburden stress (Rahman et al., 2022).

#### *2.4.3.3 Correlation of SPT N-Value and Bulk Density ($\rho_b$)*

Bulk Density ($\rho_b$) indicates the mass of soil solids and voids within a unit volume, serving as a critical parameter for evaluating soil compaction, stiffness and relative density. In field practice, increased $\rho_b$ are typically related to soils that show greater resistance during penetration, leading to higher SPT *N*-values (Das & Sobhan, 2018). The positive correlation is apparent in cohesive and granular compositions, where increased particle spacing and decreased void ratios lead to increased penetration resistance.

Systematic field observations in Malaysian soft alluvium and residual soils indicate that surficial strata characterized by low $\rho_b$, high Moisture Content and weak structural bonds exhibit lower *N*-values in comparison to deeper, more densified layers (Zainorabidin et al., 2016). This pattern is especially evident in transition zones where soft clay or organic layers overlie denser silty sand or sandy clay strata. In general, soils with higher bulk density tend to exhibit greater penetration resistance because denser particle packing provides increased resistance to the penetration of the SPT sampler. Consequently, Bulk Density is frequently regarded as an important parameter for interpreting soil stiffness and supporting empirical correlations with SPT *N*-values (Das & Sobhan, 2018).

Recent predictive models integrate $\rho_b$ and *N*-values as essential indicators for estimating soil stiffness and modulus. $\rho_b$ acts as an intermediary for relative density in

soils where the influence of grain size on *N*-value is less consistent, particularly in different deposits characterized by mixed Clay-Silt grading. The integration of $\rho_b$ into regression models has improved the predictive accuracy of geotechnical properties such as elastic modulus and bearing capacity, especially in the context of foundation design for low-strength soils (Lee & Park, 2021). $\rho_b$ is closely related to soil compaction and penetration resistance. Its predictive capability improves when considered together with parameters such as Moisture Content and depth, which influence effective stress and soil structure. Consequently, $\rho_b$ is frequently used as an important variable in empirical correlations for subsurface characterization when laboratory testing is limited (Das & Sobhan, 2018).

#### *2.4.3.4 Correlation of SPT N-Value and Specific Gravity ($G_s$)*

Specific Gravity ($G_s$) measures the ratio of the density of soil solids to density of water, providing important data regarding soil mineralogy and particle density. Although $G_s$ does not provide a direct measurement of mechanical strength, it indirectly affects soil stiffness and compaction characteristics through mineral composition and organic content. Soils exhibiting higher $G_s$ values, consisting mainly of quartz, feldspar and heavy minerals generally demonstrate increased density and higher SPT *N*-values, particularly in the presence of minimal organic fractions (Holtz et al., 2011).

In the tropical residual soils of Malaysia, $G_s$ is influenced by the type of parent rock and the extent of weathering. Residual Clays originating from granite and schist typically exhibit greater $G_s$ values (2.65–2.75) in contrast to organic-rich alluvial soils (1.80–2.30). Investigations in the Klang and Langat basins demonstrate that increased Specific Gravity relates with higher *N*-values, after considering depth and moisture, indicating greater durability of grain frameworks (Aziz & Mohd Yunus, 2018). This trend indicates that mineralogical composition influences penetration resistance as a secondary factor, enhancing empirical models when integrated with Bulk Density and grain size distribution.

However, the correlation between $G_s$ and SPT *N*-value is less straightforward than that with moisture or density, as $G_s$ does not include the effects of pore fluid or fabric structure. Consequently, $G_s$ is frequently utilized as a supplementary parameter in multiple variables correlations instead of serving as an independent predictor. Recent statistical models demonstrate enhanced prediction accuracy with the inclusion of $G_s$

together with Atterberg Limits and PSD descriptors, underscoring its significant role in characterizing mechanical response (Elkhoury & Bouazza, 2022).

#### *2.4.3.5 Correlation Between SPT N-Value and Clay Content*

The Clay content significantly influences soil mechanical behaviour by affecting cohesion, plasticity, water retention, and particle fabric. Soils with higher Clay percentages generally demonstrate reduced *N*-values, as the platelet-shaped Clay particles enhance interparticle attraction, decrease permeability, and develop plasticity. The previously mentioned conditions all together decrease resistance during dynamic penetration (Holtz et al., 2011). In the soft Clay and Silty Clay deposits of Cyberjaya, Clay contents greater than 40–50% are often correlated with very low *N*-values (<5) in the upper profiles (Rahman et al., 2022).

Comprehensive geotechnical studies in residual and alluvial deposits have measured the inverse relationship between Clay fraction and *N*-values. Statistical analyses indicate that Clay content significantly impacts variability in *N*-value in cohesive soils, when controlled for moisture and void ratio (Md Nujid et al., 2020). This finding aligns with larger empirical frameworks that relate fine content with compressibility and plasticity, highlighting the significance of grain size distribution in penetration resistance modelling.

Additionally, Clay content is frequently combined with plasticity indices and Moisture Content to enhance prediction models, as Clay-rich soils typically demonstrate determined non-linear reactions that single-parameter correlations fail to capture. The inclusion of Clay fraction as an indicator enhances the reliability of *N*-value interpretations, especially in soft organic-rich horizons where conventional mechanical tests exhibit reduced reliability (Sukirman & Osman, 2023).

### 2.4.4 Limitations of Using SPT *N*-Value for Correlation

The SPT whereas commonly used shows significant limitations in its correlation with soil properties especially within soft and different soil profiles. A significant limitation is a lack of energy standardization among various drilling rigs which leads to variability in *N*-values and reduces the reliability of empirical correlations across different sites and projects (Liao et al., 2014). A further limitation

relates to with disturbance effects, particularly in soft soils found in alluvial and Peat-influenced areas like Cyberjaya. The impact of the SPT hammer can generate excess pore water pressure, resulting in artificially low *N*-values (Hird et al., 2020).

The influence of overburden pressure affects *N*-value results as soils at greater depths generally exhibit higher blow counts which may not just reflect increased strength but also confinement. Consequently, depth correction or normalization procedures are essential for making meaningful comparisons, although these introduce additional assumptions and complexity (Salgado, 2015). The SPT generates individual point data and lacks continuity, making it insufficient for stratigraphic interpretation in complex soil profiles unless complemented by additional tests such as CPT or geophysical methods (Parkin & Lunne, 2018).

SPT exhibits constraints in the accuracy of data collected for very soft or very stiff soils as the blow counts may be insufficiently low or excessively high resulting in significant differences between layers. This limits its applicability in essential design contexts without supplementary testing (Zhang et al., 2019). Finally, the correlations established using *N*-values are specific to individual sites and exhibit statistical sensitivity, indicating that their use in different geological contexts may lead to considerable estimation inaccuracies unless corroborated with local soil data (Nguyen et al., 2022).

## 2.5 Development of Empirical Prediction Models

Empirical prediction models are widely employed in physical soil properties to establish mathematical relationships between measurable soil properties and in-situ test results. These models enable the prediction of physical properties from readily available field data, thereby reducing the need for extensive laboratory testing and improving the efficiency of site investigations (Montgomery & Runger, 2021). In the present study, empirical modelling is used to establish relationships between SPT *N*-values and selected physical soil properties of soft tropical soils in Cyberjaya.

Multiple Linear Regression (MLR) is one of the most widely adopted statistical techniques for developing predictive models involving multiple independent variables. The method evaluates the combined influence of several predictor variables on a dependent variable while simultaneously assessing the statistical significance of each variable. In geotechnical engineering, MLR has been extensively applied to develop

empirical relationships between SPT *N*-values and soil properties such as Moisture Content, Atterberg Limits, Bulk Density, Specific Gravity and Particle Size Distribution (Al-Abadi et al., 2023).

The development of empirical prediction models involves several statistical procedures, including correlation analysis, multiple linear regression analysis and significance testing and model validation. These analyses facilitate the identification of significant predictor variables, evaluation of model performance and assessment of the reliability of the developed equations. Such statistical approaches are particularly valuable for tropical soft soils, which commonly exhibit considerable spatial variability and complex relationships among soil properties (Nguyen et al., 2022). In this study, the statistical analyses required for developing the empirical prediction models were performed using Minitab 21, which provides comprehensive statistical functions for regression analysis, correlation analysis and model validation. The software facilitates efficient processing of borehole and laboratory datasets while supporting the development of reliable predictive models for estimating physical soil properties from SPT *N*-values.

### 2.5.1 Utilization of Pearson Correlation in Soil Analysis

Pearson correlation analysis determines the strength and direction of linear relationships among continuous variables. This method is frequently used in soil mechanics to evaluate the relationships between SPT *N*-values and important soil parameters, including Moisture Content, Bulk Density, Specific Gravity, and Plasticity Index (Ningegowda et al., 2023). The Pearson Correlation Coefficient (*r*) enables researchers to determine the direction and strength of relationships, indicating whether they are positive or negative.

The Pearson Correlation Coefficient (*r*) is calculated using Equation (2.9), which measures the strength and direction of the linear relationship between two continuous variables.

$$r = \frac{\Sigma(xi-\bar{x})(yi-\bar{y})}{\Sigma(xi-\bar{x})^2\Sigma(yi-\bar{y})^2} \quad (2.9)$$

Where, $r$ represents the Pearson correlation coefficient, $x_i$ and $y_i$ denote the observed values of the two variables being analysed, $\bar{x}$ and $\bar{y}$ represent the mean values of the respective variables, and *n* denotes the total number of observations used in the analysis.

Correlation analysis simplifies this process by calculating correlation matrix structures, offering both *r*-values and *p*-values for significance testing. A significant negative correlation exists between Moisture Content and SPT *N*-value in Cyberjaya soils, suggesting that higher water content decreases soil resistance (Rahman et al., 2022). Understanding linear relationships is needed for developing empirical models in data-constrained projects.

### 2.5.2 Significance Testing (*p*-value) in the Analysis of Soil Parameters

Significance testing is crucial for assessing the reliability of observed relationships. The *p*-value is widely used to determine the statistical significance of correlation and regression coefficients, typically at a 95% confidence level ($\alpha$ = 0.05). (Ahmad et al., 2025). The decision criterion for statistical significance is commonly expressed as Equation (2.10):

$$p < 0.05 \tag{2.10}$$

Where, *p* represents the probability value obtained from the statistical test. A value of $p < 0.05$ indicates that the observed relationship is statistically significant at the 95% confidence level and is unlikely to have occurred by random chance.

In geotechnical engineering, a statistical approach is employed to validate relationships among variables such as SPT *N*-values, depth, resistivity and Moisture Content (Yusof et al., 2021). A *p*-value below 0.05 in the correlation between the *PI* and *N*-value indicates that plasticity has a significant impact on soil resistance. These conclusions inform the choice of relevant parameters for design models and site assessment.

### 2.5.3 Application of Logarithmic Data Transformation for Enhancing Model Performance

Geotechnical datasets frequently challenge the assumptions of linearity and normal distribution, particularly in soft soil environments. Logarithmic data transformation serves as a typical method for normalizing skewed data and stabilizing variance, thereby enhancing the robustness of correlation and regression models (Chen et al., 2018). The transformation is achieved by applying the logarithmic function to the original data, which helps linearise exponential relationships commonly observed in geotechnical datasets. The logarithmic transformation applied to the SPT *N*-value is expressed in Equation (2.11):

$$\log(N) \tag{2.11}$$

Where, N denotes the Standard Penetration Test (SPT) N-value.

The application of log-transformation to N-values in this study facilitates improved modelling of their relationship with depth and soil properties, including water content and fine fraction. Previous studies have demonstrated that logarithmic transformation improves model accuracy for residual and alluvial soils in Southeast Asia, where soil parameters frequently exhibit exponential trends with depth (Tan & Awang, 2020).

### 2.5.4 Statistical Modelling for The Estimation of Soil Properties

Multiple Linear Regression (MLR) is one of the most widely used statistical techniques for developing empirical models to estimate soil properties from measurable predictor variables. In geotechnical engineering, MLR has been extensively applied to predict parameters such as Undrained Shear Strength, Clay Content, Dry Density and other physical soil properties using variables including SPT *N*-values, depth and Moisture Content (Iqbal et al., 2023). The developed regression models are commonly evaluated using statistical indicators such as the Coefficient of Determination ($R^2$), Adjusted Coefficient of Determination (Adjusted $R^2$), *p*-values and residual analysis. These statistical measures assess the goodness-of-fit of the regression model, determine

the significance of predictor variables and verify whether the assumptions of linear regression are satisfied (Nguyen et al., 2022).

The general form of the MLR model used to establish the relationship between the dependent variable and multiple predictor variables is expressed in Equation (2.12):

$$\mathrm{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta n X n + \varepsilon \tag{2.12}$$

Where**,** $Y$represents the dependent variable (physical soil property), $\beta_0$ is the regression intercept, $\beta_1$ to $\beta_n$ are the regression coefficients, $X_1$ to $X_n$ represent the independent (predictor) variables, and $\varepsilon$ denotes the random error term. In the present study, the dependent variable ($Y$) represents the selected physical soil properties, whereas the predictor variables include the SPT *N*-value and depth.

Statistical modelling provides an efficient approach for estimating soil properties, particularly during preliminary site investigations where comprehensive laboratory testing may be limited. Consequently, empirical prediction models have become valuable tools for supporting geotechnical design by providing rapid and reliable estimates of soil properties from readily available field data such as SPT *N*-values (Phoon & Kulhawy, 1999).

Although numerous empirical prediction models have been developed to estimate soil properties using SPT *N*-values, most previous studies were established under different geological and environmental conditions. Consequently, these empirical correlations may not be directly applicable to Malaysian tropical soft soils because of differences in soil composition, depositional environments and groundwater conditions. Furthermore, many previous studies primarily utilised SPT *N*-values as the sole predictor variable, while limited consideration has been given to the incorporation of depth despite its significant influence on overburden stress and penetration resistance.

In addition, previous empirical studies have mainly focused on predicting engineering properties such as undrained shear strength, compressibility and bearing capacity, whereas comparatively fewer studies have developed prediction models for physical soil properties, including Moisture Content, Bulk Density, Specific Gravity and Particle Size Distribution, using locally calibrated datasets. These limitations highlight the need to develop site-specific empirical prediction models that integrate both SPT *N*-values and depth for predicting the physical properties of Malaysian

tropical soft soils. Accordingly, the present study develops site-specific empirical prediction models using SPT *N*-values and depth as predictor variables to estimate selected physical soil properties of Malaysian tropical soft soils.

# CHAPTER 3
# RESEARCH METHODOLOGY

## 3.1 Surface and Subsurface Soil

This chapter presents the methodology adopted in this study to achieve the research objectives systematically. The methodology comprises the study area description, geological assessment, site investigation, laboratory testing and statistical analyses used to develop the empirical prediction models. The study began with the identification of the geological and environmental characteristics of the study area through geological mapping, field observations and site investigation. These activities provided essential information on the surface and subsurface conditions, including geological formations, soil stratification and groundwater conditions, prior to laboratory testing and statistical modelling.

Engineering borehole logs are subsequently employed to assess the SPT *N*-values. Boreholes were strategically drilled and the SPT was performed at regular intervals to assess soil resistance and acquire *N*-values. These values serve as primary data for subsequent analysis. In addition, soil samples from the boreholes underwent laboratory testing to ascertain the geotechnical properties of the subsurface soils. The soil samples were analysed for several physical parameters including Particle Size Distribution (PSD), Density, Moisture Content and Atterberg Limits to characterize the soils. This analysis aimed to assess the soil's suitability for developing a strength model for soft soils. The preliminary laboratory tests for this study were conducted in the Geotechnical Laboratory of the Civil Engineering Department at UiTM, adhering to the standards specified in BS 1377: Part 2: 1990 for basic properties testing.

The subsequent step entails correlating the SPT *N*-values with the soil properties derived from laboratory test results. Statistical analyses, including regression modelling, were employed to identify and quantify the relationships between *N*-values and soil parameters, such as Moisture Content, Dry Density, Bulk Density, Specific Gravity, Atterberg Limit and PSD. The identified correlations will serve as the basis for constructing a predictive model for soil strength.

The concluding phase emphasizes the construction and validation of the soil properties model utilizing Minitab 21. The model will incorporate SPT *N*-values and soil properties, facilitating predictions of geotechnical behaviour. Validation will involve a comparison of model outputs with actual field and laboratory data to ensure accuracy. This methodology establishes a solid framework for attaining the research objectives and creating a practical tool for initial geotechnical applications. The research process was structured as illustrated in Figure 3.1, following the guidelines outlined in this chapter.

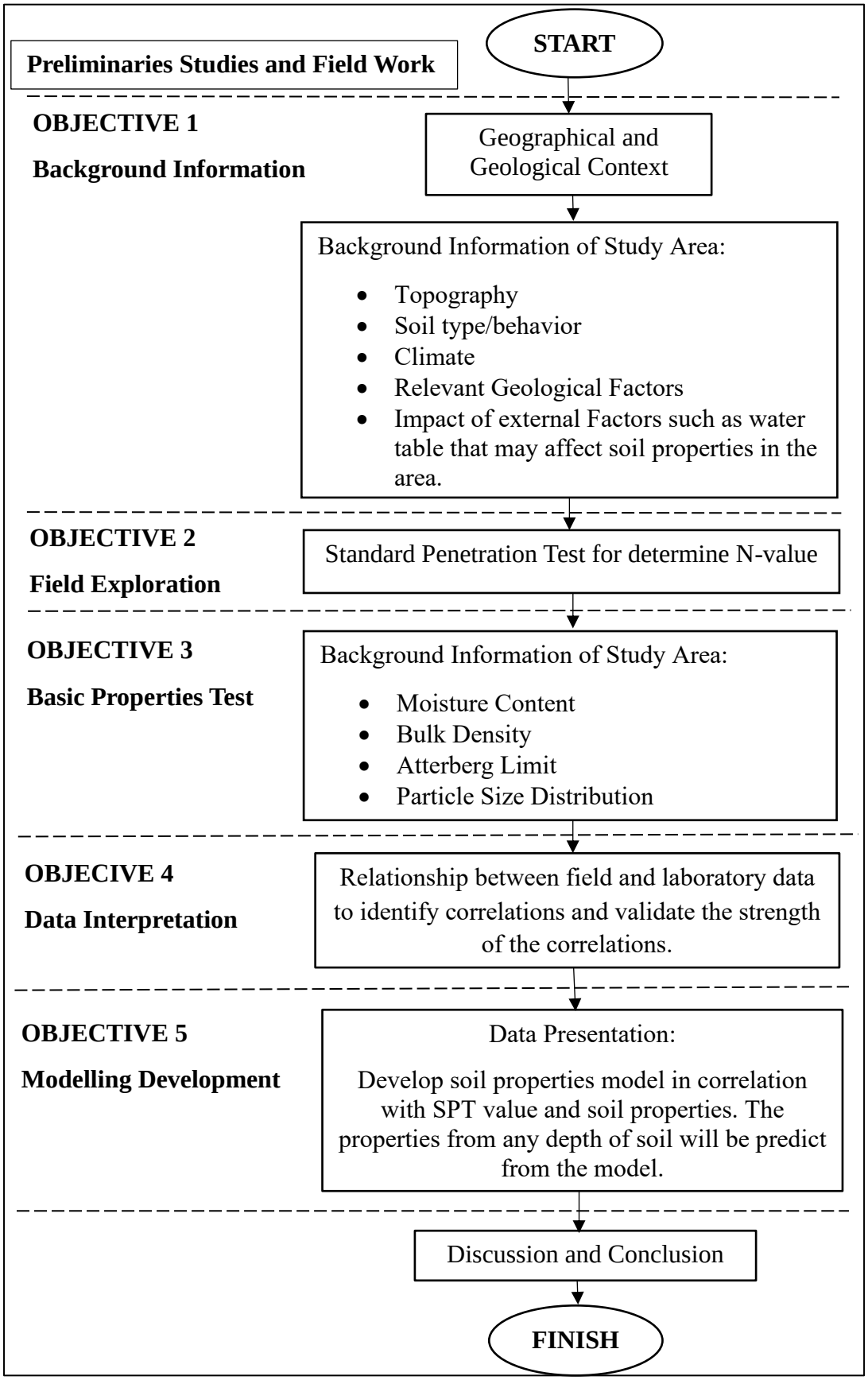


Figure 3.1 A General Framework of Proposed Study

### 3.1.1 Regional Geological Framework

The Selangor Cyber Valley area lies within the Langat River Basin, which is geologically characterized by a combination of metamorphic, sedimentary, igneous and quaternary alluvial deposits (Gobbet & Hutchison, 1973). The granitic rocks form the main mountain ranges in the eastern and northeaster parts of the basin, while the Kenny Hill and Kajang formations dominate, consisting mainly of metamorphosed Sandstone, shale, mudstone and schist (Minerals and Geoscience Department, 2014). Towards the low-lying flatlands, extensive Quaternary alluvial deposits occur along the coastal plains and river valleys. These unconsolidated materials overlie the bedrock and are typically composed of Peat, Clay, Silt and Sandy interbeds, reflecting deposition under fluvio-marine conditions.

The alluvial sequence in this region comprises several stratigraphic units from top to bottom are. The sequence comprises the Beruas Formation (approximately 0.5m to 5.5m thick) with an upper Peat layer followed by the Gula Formation, characterized by Clayey materials and the Kempadang Formation which extends from the hilly regions and reaches a thickness of about 40m to 50m near the coastal zone. Beneath these lies the Simpang Formation, consisting mainly of Sand and gravel with thicknesses varying from several meters at the upland areas to more than 50m, occasionally exceeding 100m, in the low-lying regions (Minerals and Geoscience Department, 2014). The geological conditions at the study site were assessed through the review of existing geological literature, published maps and reconnaissance surveys. The following geological maps were referred to in this study:

a) Geological Map of Selangor (Sheet 94), printed in 1976 by the Directorate of National Mapping Malaysia (Map No. 73 – 76).
b) Geological Map of Teluk Datuk (New Series l7010, Sheet 101), published by the Director General, Minerals and Geoscience Department Malaysia, Ministry of Natural Resources and Environment.
c) Geological Map of Sepang, Negeri Selangor and Negeri Sembilan (New Series L7010, Sheet 102), published by the same department.

### 3.1.2 Geological Map of Study Area

Figure 3.2 shows the geological map of the regional geology, which consists of Alluvium and the Kenny Hill Formation. The areas highlighted in red indicate the geological formations present within the study area and depict the geological framework of the Selangor Cyber Valley site located in the Langat Basin. The map indicates that the region is primarily characterized by Quaternary Alluvium and the Kenny Hill Formation, signifying a transitional geological setting between older metamorphic bedrock and more recent unconsolidated deposits.

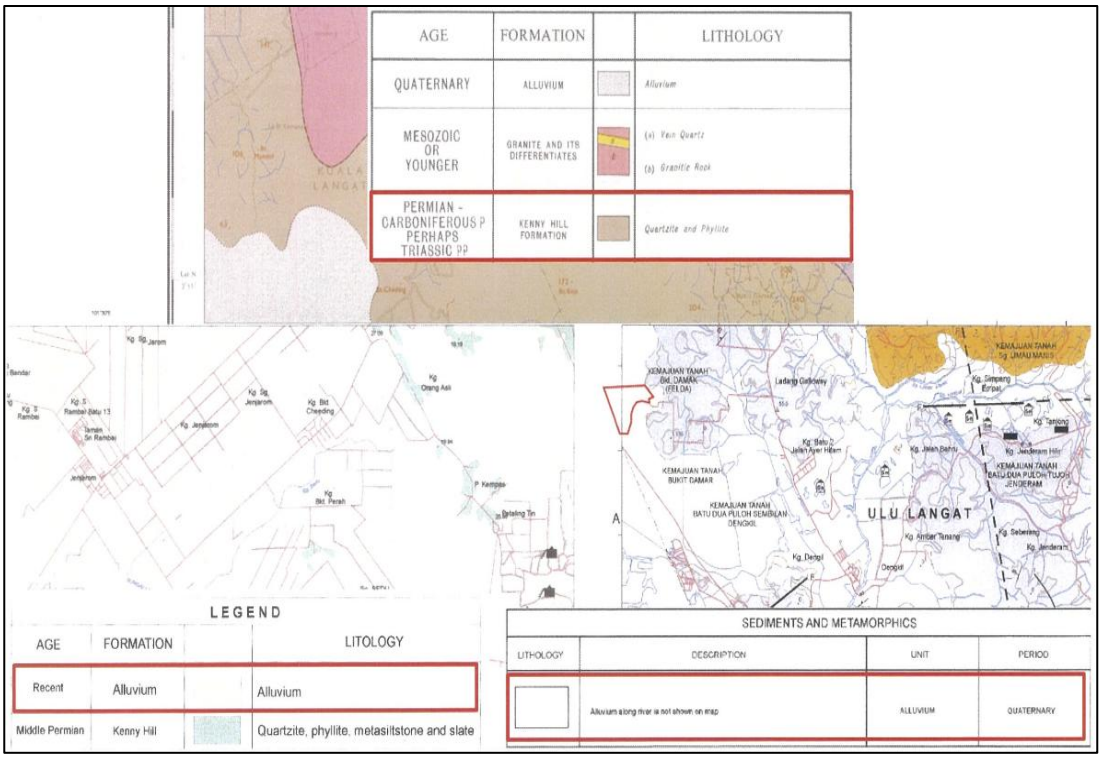



Figure 3.2 General Rock Formation from Geological Map.
Extracted from Geological Map of Selangor (Sheet 94), Geological Map of Teluk Datuk (New Series L7010 Sheet 101) and Geological Map of Sepang Sheet, Negeri Selangor and Negeri Sembilan.

The alluvial deposits consist mainly of soft Clay, Silt, and Peat that extend across the low-lying plains of Dengkil and Sepang. These sediments were deposited under fluvio-marine conditions influenced by the Langat River system. The map further illustrates the surrounding geological formations within the Langat Basin region, which

collectively contribute to the development of a soft and highly compressible soil profile within the study area.

The geological composition therefore indicates a complex depositional environment characterized by the dominance of soft Clay, Silt, and Peat layers in the upper strata. Such geological conditions significantly influence the recorded SPT N-values and govern the overall geotechnical behaviour of the subsurface soils in the Selangor Cyber Valley area.

Figure 3.3 is the general geological map showing the geological formations of Selangor and Kuala Lumpur. Regionally, the project area is surrounded by Alluvium, Beruas Formation and Kenny Hill Formation. The map presents the geological context of Selangor and Kuala Lumpur, highlighting the distribution of major geological formations within the region. The Selangor Cyber Valley site is located in the southern sector and is characterized by extensive alluvial and Peat deposits that overlie the Kenny Hill Formation. The central and eastern regions are defined by the dominance of metamorphic and granitic rocks, which constitute the highland and foothill zones. The map illustrates the geological transition from harder rock formations in the eastern region to softer alluvial plains in the western and southern regions. This geological transition represents an important factor influencing the engineering properties, SPT *N*-values and foundation behaviour within the study area.

The presence of extensive alluvial deposits along the lowland areas, particularly those associated with the Langat River system, contributes to the development of soft and highly compressible soil conditions in the Selangor Cyber Valley area. These geological characteristics play a significant role in controlling the subsurface soil behaviour and the geotechnical response observed within the study site.

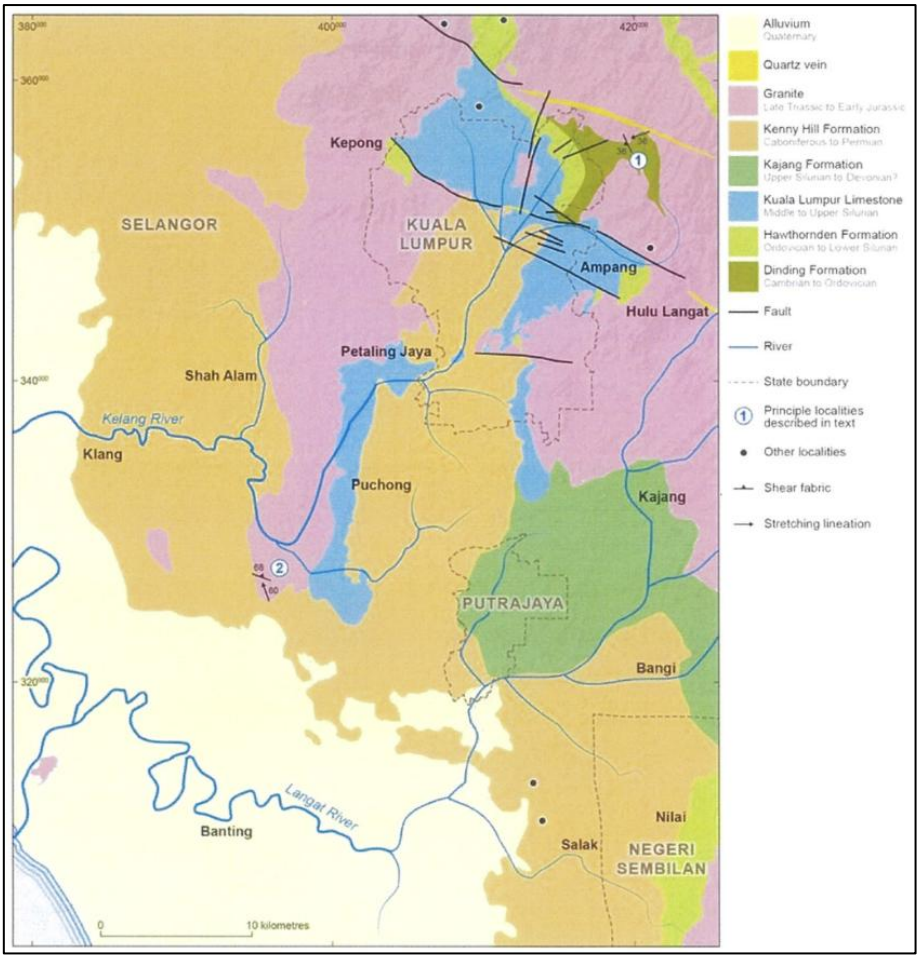



Figure 3.3 General Geological Map of Selangor and Kuala Lumpur (after Mineral and Geoscience Malaysia Department, 2011).
Reference from an article in Bulletin of the Geological Society of Malaysia, Volume 69, May 2020, pp 135-147).

### 3.1.3 Geological Assessment Mapping

The geological assessment mapping utilized a site walkover survey method, entailing systematic observation and data collection directly from the study area. The process commenced with a field reconnaissance survey aimed at assessing site accessibility and identifying significant reference points, including boundary stones and other markers, while also noting the general morphology of the area. This step established a fundamental comprehension of the site's physical attributes and landmarks.

Subsequently, remote imagery comprising aerial photographs, Google Earth images and drone-captured images was analysed to identify zones of instability within

the project area. The zones encompassed recent and relict landslide scars, regions with notable erosion and sites displaying soil creep. The imagery facilitated the examination of overall morphology, indicators of activity and vegetation cover insights into potential geological hazards and land use patterns. A base map of the site was subsequently prepared utilizing the Survey Data Plan as a framework (refer Figure 3.4 for details).

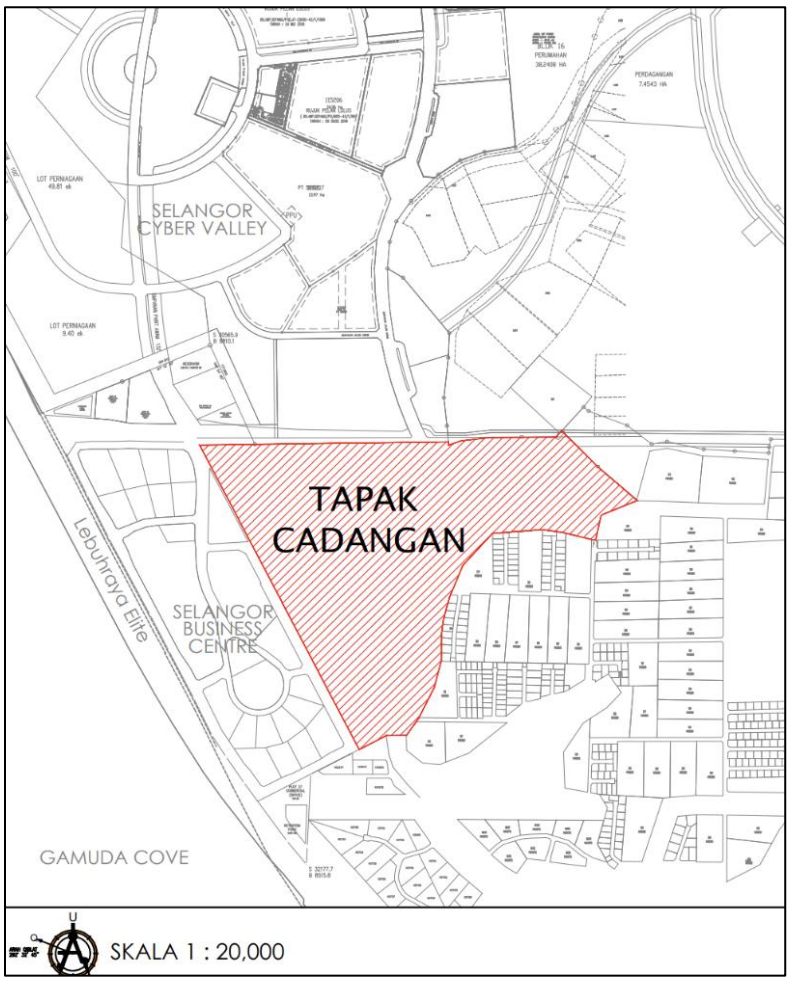



Figure 3.4 Base Map Generated From The Survey Drawing

The base map functioned as a reference for all subsequent fieldwork and geological evaluations. In the course of the field survey, reference points including boundary markers and iron pipes, were identified utilizing Global Positioning System (GPS) technology. Based on these points, comprehensive geological mapping was conducted, documenting site-specific characteristics. Photographs were captured from observation points in each of the four cardinal directions (North, East, South and West) to record panoramic views of the region.

Following the completion of field mapping, the gathered data were synthesized to create a detailed regional and site-specific geology map. This involved the development of detailed 3D subsurface profiles and cross-sections of the study area, providing a clear visualization of the geological structure and composition. This systematic approach ensured an accurate representation of the site's geological conditions, which is essential for project planning and risk mitigation.

The Geological Engineering Mapping is conducted to gather geological and engineering data that can support site investigation analysis. Proper collection of geological data including structure, historical subsidence, rock quality, tension cracks, landslide indicators, springs and supporting data such as the movement of belt conveyor structures, is essential. The data obtained from field observations can be utilized to analyse the occurrence and causes of land instability.

A map indicating the locations of the boreholes from which geologic data is sourced along with the borehole logs detailing the underlying sediments and bedrock is essential for constructing a geologic cross section. The map provides the distance between the boreholes along with an elevation projection and a horizontal scale. The distance between the boreholes is interpreted from the map scale. The scales of the map and the cross-section dimensions are equivalent if the cross-section is intended to maintain the same horizontal scale as the map. The cross-section was enhancing in order for greater detail; it is necessary to reduce the scale ratios. Consequently, when the map scale is set at one inch to forty feet, adjusting the horizontal scale on the cross section to one inch to twenty feet effectively doubles the size of the cross section's horizontal dimension.

### 3.1.4 Local Geomorphology

Field reconnaissance and borehole investigations reveal that the Selangor Cyber Valley site is situated within inland alluvial flatland, previously dominated by lowland swamp forest before land clearing and development occurred. The original vegetation has largely been replaced by oil palm cultivation and secondary shrub growth with only isolated remnants of natural flora remaining. An organic and decomposing vegetation layer, derived from the prior swamp forest, generally envelops the alluvial plain. The region is defined by alluvial sediments that range from soft to very soft comprising Clay, Silty Clay, Silt, Peat and fine Sand lenses. These sediments are

typically saturated and demonstrate high compressibility. The thickness of the alluvial layer varies between 7.5 meters and 16.5 meters, resting upon the more competent materials of the Kenny Hill formation. The upper section is representative of the Beruas formation, consisting of recent terrestrial alluvium that includes Clay, Sandy Clay, Sandy Gravel, and Peat from the Pengkalan Member. These soils often exhibit iron mottling, a reduced concentration of heavy minerals and an absence of cassiterite indicating their non-tin-bearing origin.

The Kenny Hill formation located beneath the alluvial deposits comprises interbedded quartzite, shale, and occasional layers of phyllite. The quartzite consists of angular to sub-angular quartz grains cemented in a silica matrix while the shale is defined by its light colour and non-carbonaceous composition, generally displaying thin bedding with fine laminations. The rock sequence has undergone low-grade metamorphism, leading to a moderately hardened and weathered substrate beneath the softer surficial deposits.

### 3.1.5 Groundwater Condition

Groundwater condition is an important component of site investigation because it influences soil behaviour, effective stress, bearing capacity and settlement characteristics. In soft soil deposits, the groundwater table is generally shallow due to the low permeability and high moisture retention capacity of the soil. Therefore, groundwater observations were carried out during the borehole investigation to determine the groundwater level and to assist in the interpretation of the subsurface conditions.

The groundwater level was observed during the borehole drilling programme upon completion of each borehole. The water level inside the borehole was allowed to stabilise before the groundwater depth was measured relative to the existing ground level. These observations provide information on the groundwater regime within the study area and are important for understanding the behaviour of the underlying soft soil deposits during field investigation.

Figure 3.5 illustrates the groundwater observation carried out during the borehole investigation at the study site. Groundwater levels were observed from the completed borehole after allowing sufficient time for stabilisation before the water level was measured relative to the existing ground level.



Figure 3.5 Groundwater Observation during Borehole Drilling at the Study Site.

The groundwater observations obtained from the site investigation provide supporting information for interpreting the subsurface soil profile and engineering behaviour of the study area. The recorded groundwater levels measured from the borehole investigation are presented and discussed in Section 4.1.5.

### 3.1.6 Description of the Study Sites

The study area is situated in Mukim Dengkil, Daerah Sepang, Selangor Darul Ehsan. Samples from site PT 21044 Cyberjaya were collected for data analysis. The remaining two sites serve as the validation procedure, specifically at Lot 120185 and Lot 120188, both located in Selangor Cyber Valley. The geological map of Peninsular Malaysia, published in 2014 by the Department of Minerals and Geosciences Malaysia (JMG), indicates that the study area comprises two distinct formations namely the

Hawthornden formation and the Kenny Hill formation. The Hawthornden formation contains schist is a moderately strong rock that is undergoing significant weathering processes. The rock of the Kenny Hill formation is characterized by significantly lower strength; thus, it is classified as weak rock. The Cyberjaya area predominantly exhibits a significant expanse of alluvium interspersed with residual soils, primarily consisting of Peaty soils and Clay. The western region of Cyberjaya is characterized by a bedrock primarily composed of buried karstic marble, along with minor occurrences of schist and granite. The western region was utilized for alluvial tin mining in the past.

#### *3.1.6.1 PT 21044 Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor*

The study area is located in Cyberjaya, Selangor. Based on the regional geological map obtained from the Department of Minerals and Geoscience Malaysia (JMG), the study area is underlain predominantly by Quaternary unconsolidated deposits overlying the Kenny Hill Formation, as illustrated in Figure 3.6. The Quaternary deposits mainly comprise Peat, humic Clay and Silt, which are typically characterised by high Moisture Content, high compressibility, low shear strength and significant settlement potential. These characteristics are commonly associated with tropical soft ground conditions and support the selection of the study area for developing empirical prediction models. The Quaternary deposits were formed during the most recent geological period through fluvial and marine depositional processes, resulting in heterogeneous soil profiles with considerable spatial variability in engineering properties.

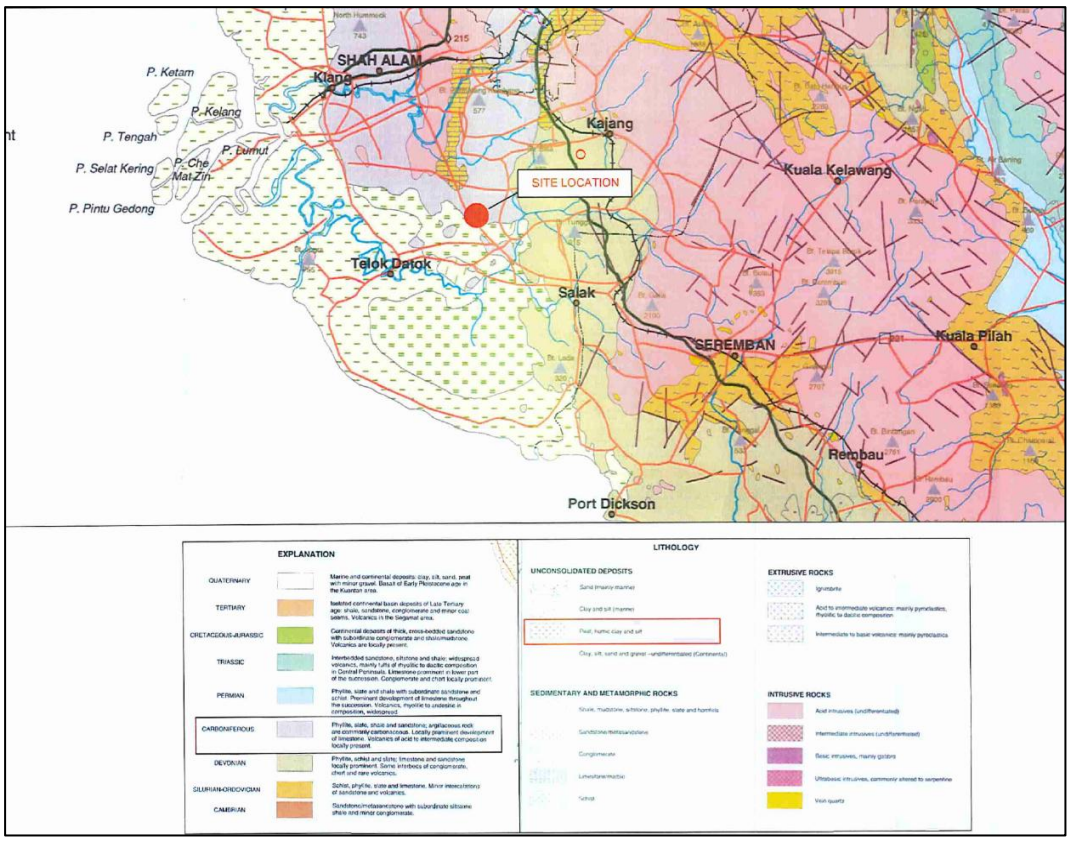



Figure 3.6 Geological Map of The Study Area at Taman Sains Selangor, Mukim Dengkil, Daerah Sepang, Selangor (JMG, 2014)

The site encompasses 152 acres situated on plot PT 21044, adjacent to Selangor Cyber Valley, in Daerah Sepang, Mukim Dengkil, Selangor, as illustrated in Figure 3.7. The site's topography is characterized by a relatively flat landscape accompanied by dense vegetation. The site exhibits wet conditions, as the majority of the area contains a water body with varying depths. A thick layer of Peat is observed constituting the upper soil of the site. In rainy conditions, an increase in water level is observable. Palm trees were observed in the deeper regions of the area. The ground level increased progressively as the presence of Peat material diminished at the site.

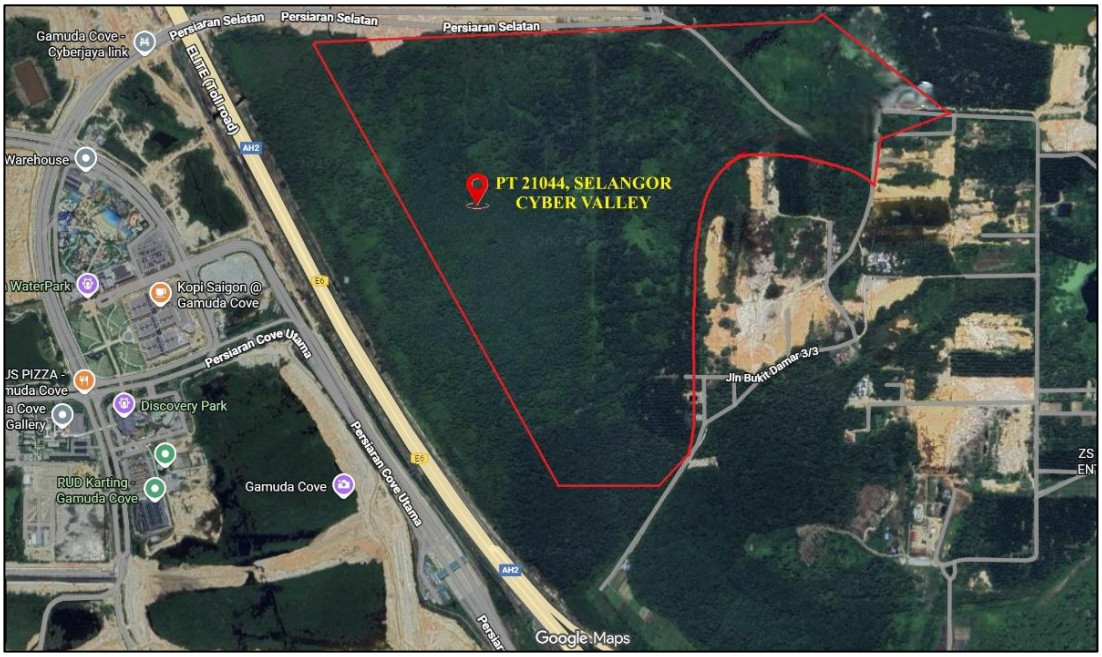



Figure 3.7 The Location of PT 21044 Cyberjaya, Selangor.

Source: Adapted from (Google Maps, 2025)

Figure 3.8 shows the topographical characteristics of PT 21044, Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor. The site is generally flat with ground elevations predominantly below 20 m above mean sea level. Wet surface conditions characterised by standing water and ponded areas are commonly observed, particularly during the rainy season. Dense vegetation consisting of grasses, shrubs and remnants of oil palm trees indicates that the site was previously utilised for oil palm cultivation. The topographical characteristics provide an overview of the existing site conditions prior to the field investigation. The topographical map perspective indicates that the site is situated on flat, low-lying terrain characterized by swamp and Peatland zones, interspersed with areas of oil-palm cultivation. The uniform elevation and lack of distinct drainage channels suggest inadequate surface runoff and a high groundwater table, characteristics commonly associated with alluvial floodplain environments. The observed presence of soft, saturated subsoils in field investigations can be attributed to these conditions. From a geotechnical perspective, the topography indicates that PT 21044 can be classified as soft ground, characterized by low bearing capacity, high settlement potential, and low SPT *N*-values.

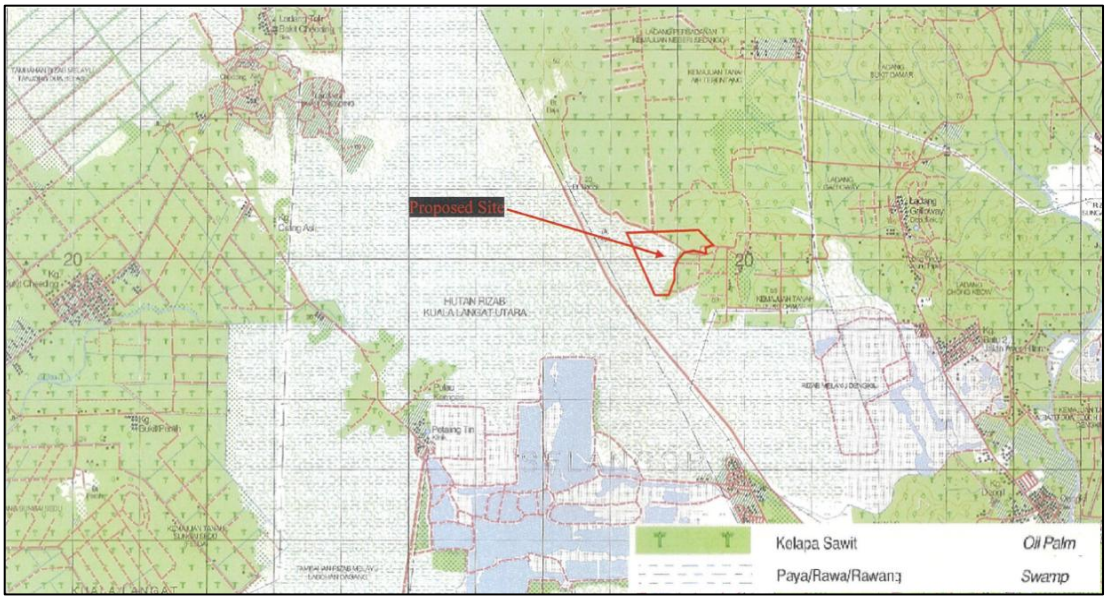



Figure 3.8 Topographical Map of Lot PT 21044 Cyberjaya, Mukim Dengkil, Derah Sepang, Selangor.

Field observations indicated that the northern portion of the site contains sandy deposits, particularly around boreholes BH22 and BH23, as shown in Figure 3.9. This area is believed to have been part of an ancient lake system. At present, the site remains largely inaccessible by vehicles because of persistent waterlogging.



Figure 3.9 Existing of PT21044 Cyberjaya, Selangor

### *3.1.6.2 Lot 120185, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor*

The validation process includes two supplementary sites, one situated at Lot 120185 in Selangor Cyber Valley, within the jurisdiction of Daerah Sepang, Mukim Dengkil, Selangor as display in

Figure 3.10. This site's location indicates its placement within a rapidly developing region. The terrain is predominantly flat to gently undulating, with soil composition likely comprising a mixture of Clay, Silt, and Sand, characteristic of the area. Certain areas display slight variations in elevation resulting from natural topography or prior earthmoving activities. The site features sparse vegetation, comprising grass, shrubs, and scattered trees, which suggests either natural or previously cleared conditions. The site is strategically positioned near highways, including the ELITE and PLUS expressways, providing superior connectivity and suitability for mixed-use developments. Adjacent features comprise residential and commercial developments, underscoring the area's strategic significance within Selangor's growth corridor.




Figure 3.10 The location of Lot 120185, Selangor Cyber Valley.

Source: Adapted from (Google Maps, 2025)

### *3.1.6.3 Lot 120188, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor*

Additionally, Lot 120188 in Selangor Cyber Valley was included in the site validation process as displayed in

Figure 3.11. This region is characterized by its integration of residential, commercial, and industrial zones, supporting the rapid urbanization and economic growth of Sepang. The site is located near infrastructure like the Kuala Lumpur International Airport (KLIA) and Cyberjaya, offering significant connectivity and accessibility.

The area features predominantly flat to slightly undulating terrain, suitable for large-scale construction projects. It experiences tropical climatic conditions with potential environmental challenges such as soil erosion and runoff management, particularly during heavy rainfall. Measures like sediment basins, proper drainage systems, and vegetation control are often implemented to mitigate environmental impacts during development phases.




Figure 3.11 The location of Lot 120188, Selangor Cyber Valley

Source: Adapted from (Google Maps, 2025)

## 3.2 Soil Exploration

The study utilized borehole methodology for the comprehensive site investigation. A total of 39 deep boreholes were drilled. Field tests and samples were collected from each borehole. The analysis was conducted on 25 boreholes at site PT 21044 Cyberjaya, comprising a total of 136 samples. The validity of the data analysis was assessed using 4 boreholes from a similar site along with an additional 8 boreholes from two distinct sites in Mukim Dengkil, Daerah Sepang, Selangor, specifically at Lot 120185 and Lot 120188, both located in Selangor Cyber Valley.

The study utilized borehole methodology for the comprehensive site investigation. A total of 39 deep boreholes were compiled from four Soil Investigation Reports within the study area. Field tests and soil samples were collected from each borehole. The primary analysis was conducted using 25 boreholes from PT 21044, while an additional 14 boreholes from three nearby sites were incorporated for model validation and to improve the reliability of the developed empirical models. According to (Khalid et al., 2021), a minimum of 50 samples is recommended for developing reliable prediction models. Table 3.1 summarises the distribution of boreholes and samples used in this study.

Table 3.1
Distribution of Boreholes and Samples by Location

| No. | Location | No. of Borehole | No. of Sample |
|---|---|---|---|
| 1 | PT 21044 Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor | 25 | 219 |
| 2 | PT 21044 Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor | 6 | 53 |
| 3 | Lot 120185, Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor | 4 | 30 |
| 4 | Lot 120188 Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor | 4 | 32 |
| | Total | 39 | 334 |

A total of 334 disturbed and undisturbed soil samples were obtained from the borehole investigation programme and extracted from the corresponding Soil Investigation Reports. The samples were collected at selected sampling depths during the SPT drilling programme and classified according to the available laboratory test records. Each sample was assigned a unique identification number and subsequently

subjected to laboratory classification tests, including Moisture Content, Atterberg Limits, Bulk Density, Specific Gravity and Particle Size Distribution (PSD), depending on the availability of the laboratory test records.

The complete dataset comprised 334 soil samples collected from 39 boreholes across three investigation sites. These consisted of 219 samples from 25 boreholes at PT 21044, which were used for empirical model development, 53 samples from six additional boreholes at PT 21044 for sensitivity analysis, 30 samples from four boreholes at Lot 120185 and 32 samples from four boreholes at Lot 120188, both of which were used for independent model validation.

Detailed information on the sampling locations, sample identification numbers and sampling depths is presented in APPENDICES 1–4, whereas the complete SPT *N*-value dataset is provided in APPENDICES 5–8. The laboratory test results are presented in APPENDICES 9–12. Representative borehole logs for PT 21044, Lot 120185 and Lot 120188 are provided in APPENDICES 14–18, while the corresponding summary of representative laboratory test results is presented in APPENDICES 19–20. The representative borehole layout plan is provided in APPENDIX 21.

Site investigation comprises borehole data that describes soil types in relation to depth. The data include soil samples that were sent to the laboratory to determine essential soil properties. Soil investigation works aim to collect essential data regarding subsurface conditions to guarantee safe, efficient and cost-effective construction practices. This research evaluates the physical and engineering characteristics of soil and rock, examines groundwater conditions, and identifies possible subsurface hazards. The subsoil engineering characteristics and physical properties are summarized for the purpose of interpretation. A simplified soil profile was developed based on the general subsoil profile and summarized subsoil properties, and design parameters will be adopted for settlement analysis purposes. The soil investigation was conducted in accordance with MS 2038:2006 – Site Investigation (Code of Practice), MS 1056:2005 – Soil for Civil Engineering Purposes (Test Method), and the JKR Specification for Site Investigation Works.

Table 3.2 summarises the field and laboratory tests conducted in this study together with the applicable testing standards and the number of samples analysed. The soil samples collected from the boreholes were subjected to laboratory testing in accordance with BS 1377: Part 2 (1990). The laboratory programme included Moisture Content, Dry Density, Specific Gravity and Particle Size Distribution (PSD), which

were used in the statistical analyses and empirical model development. Detailed laboratory test results are provided in APPENDIX 9–12. Although 334 soil samples were collected during the site investigation, not all samples were subjected to every laboratory test. The number of samples tested varied according to the availability, quality and suitability of the soil samples for each laboratory test.

Table 3.2
Summary of Field and Laboratory Tests Conducted

| No. | Test/Data | Standard | No. of Samples | Purpose |
|---|---|---|---|---|
| 1. | Boreholes | MS 2038:2006 | 39 | To establish the subsurface soil profile and obtain representative soil samples for field and laboratory investigations. |
| 2. | Standard Penetration Test (SPT) | BS EN ISO 22476-3 | 334 | To obtain SPT *N*-values for the development and validation of the empirical prediction models. |
| 3. | Moisture Content | BS 1377-2:1990 | 257 | To determine the natural moisture content for correlation and model development. |
| 4. | Bulk Density ($\rho_b$) | BS 1377-2:1990 | 226 | To determine the bulk density for statistical correlation and empirical model development. |
| 5. | Specific Gravity ($G_s$) | BS 1377-2:1990 | 221 | To determine the specific gravity of soil solids for physical soil characterisation and model development. |
| 6. | Particle Size Distribution (PSD) | BS 1377-2:1990 | 320 | To classify soils and determine the distribution of sand, silt and clay fractions used in soil characterisation. |

The SPT are carried out at 1.5 metre interval to obtain *N*-value and disturbed sample. Undisturbed sample are taken if encounter soft cohesive soils. Boreholes are terminating at depth when achieving 5 consecutive SPT N' test with 50 blows/feet and greater, maximum depth 30 metre, 10 metre continuous rock coring into limestone or 6.0 metre continuous rock coring into other types of rock. During the drilling process, the water level was monitored in relation to the original ground level. Soil samples collected from the boreholes were sent to the Civil Engineering Department at UiTM

for laboratory testing. The tests conducted included Moisture Content, particle size analysis and Atterberg limits to determine physical properties.

In accordance with (BS 1377, 1990) standards, both disturbed and undisturbed representative soil samples were carefully selected for laboratory analysis. These samples underwent basic properties testing, including PSD, Moisture Content, Dry Density, and Atterberg Limits to determine the soil's physical characteristics. In addition, Atterberg Limits tests were conducted in accordance with BS 1377-2:1990 to determine the consistency and plasticity characteristics of the soils. However, these parameters were used primarily for soil classification and characterisation and were not included in the correlation analysis or empirical model development.

### 3.2.1 Field Work Exploration

Fieldwork for exploration boreholes involves a systematic investigation of subsurface conditions. The borehole locations have been selected in accordance with site conditions, ensuring alignment with project requirements as directed by the site engineer. The rotary wash boring machine, model YWE-D90R with a maximum torque of 600 kg/m, was utilized for subsurface exploration. The borehole was cleaned through the circulation of water which was pumped into the hole utilizing a YWE Piston Pump powered by a Yanmar TS80C diesel engine. The borehole was reinforced with NW/HW casing measuring 89mm/115mm in outer diameter to avert the collapse of the borehole wall. Bentonite served as a stabilizing medium during the boring process. The sampling and in-situ analysis are conducted at 1.5-meter intervals to obtain the *N*-value and disturbed samples. Undisturbed samples are collected when soft cohesive soils are encountered.

Boreholes are concluded at a depth upon obtaining 5 consecutive SPT *N*' tests with 50 blows per foot or greater, with a maximum depth of 30 meters including 10 meters of continuous rock coring into limestone or 6.0 meters of continuous rock coring into other rock types. The groundwater level in the borehole was recorded twice daily which is once in the morning before boring operations commenced and once in the evening after boring operations ceased for the day. The readings obtained were documented in the borehole logs. Groundwater samples were collected immediately upon encountering the water-bearing stratum in the borehole. Approximately one litre has been collected in a clean glass or inert plastic bottle, with the bottle being rinsed

three times using the sampled water prior to filling. Water samples can deteriorate quickly; thus, testing should occur promptly after collection.

Soil samples were collected at each transition of soil strata or at specified intervals. The disturbed samples were extracted using a split-barrel tube that was driven into the soil. The samples obtained were subsequently stored in properly sealed, double-layered polythene bags for visual examination and further laboratory testing. Undisturbed soil samples were collected using a thin-walled sampling tube with a diameter of 6 cm and a length of 75 cm. The ends of samples were trimmed, cleaned, and subsequently sealed with non-shrinking wax to mitigate moisture loss. The resistance or stress deformation characteristics of the deposit can be inferred from laboratory tests by minimizing the disturbance of the samples. All samples were meticulously labelled and tagged prior to their dispatch to the laboratory for subsequent analysis.

#### *3.2.1.1 Fieldwork for Exploratory Borehole at PT 21044 Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor*

The sampling station locations are determined by

Figure 3.12, the areas identified as BH1 to BH31 were strategically located within PT 21044 Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor. The selection of these sampling stations was determined by site conditions and conducted under the supervision of the site engineer. The selection criteria for borehole locations included accessibility, site topography, proximity to reference points and the necessity to encompass various geological formations within the project area. Borehole locations were precisely determined using GPS technology and reference locations were established based on the site's Temporary Benchmark (TBM). The drilling depths for BH1 to BH31 were determined based on anticipated subsurface conditions, with adjustments made as required to access significant soil layers or underlying hard strata. A total of 219 soil samples were collected from BH1–BH19 and BH26–BH31 at PT 21044 Cyberjaya for the main data analysis and statistical assessment. Detailed information regarding the sampling stations and soil samples from these boreholes is presented in APPENDIX 1.

In addition, 53 soil samples were collected from the same study location to be used for sensitivity analysis. The detailed information of these samples is provided in APPENDIX 2.

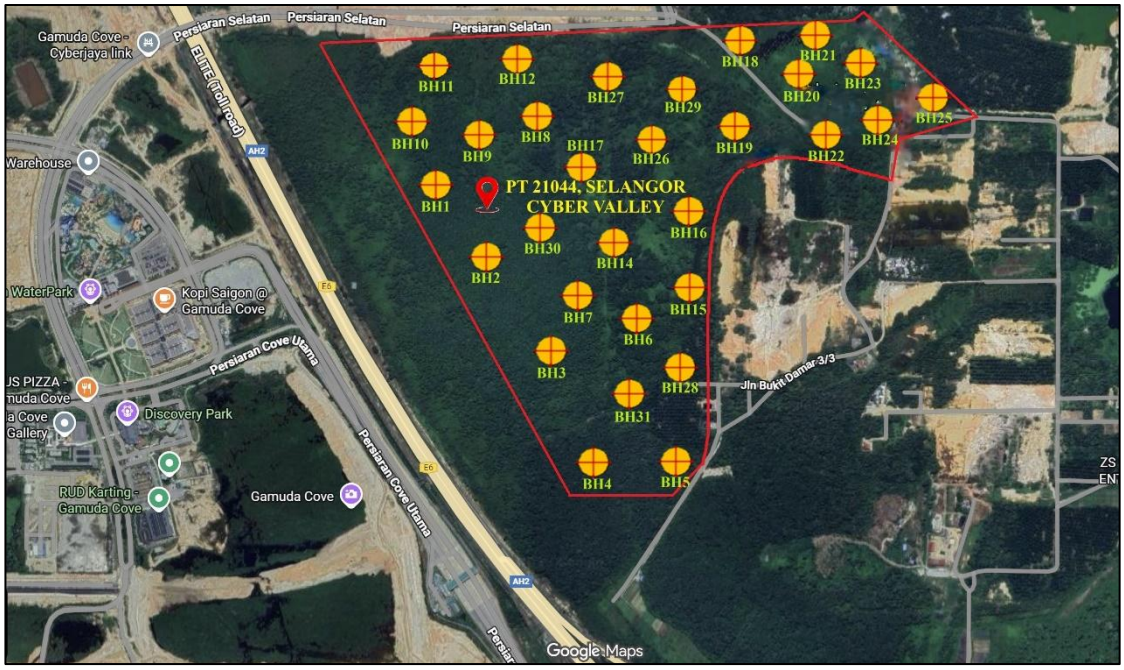



Figure 3.12 The Location of The Borehole at PT 21044 Cyberjaya

Source: Adapted from (Google Maps, 2025)

### *3.2.1.2 Fieldwork for Exploratory Borehole at Lot 120185, Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor*

Figure 3.13 indicates the positions of the sampling stations for BH1 to BH4 within Lot 120185, Selangor Cyber Valley. Locations are usually set according to the site layout and the recommendations of the site engineer. Soil samples are obtained during drilling through the use of drilling equipment to extract material from the borehole. Soil samples are typically collected at one-meter intervals or in response to notable changes in the soil strata. Boreholes were drilled by skilled drillers under the direct supervision of a technician, following the provided instructions and specifications. APPENDIX 3 presents information on 4 exploratory borehole stations, which include 32 samples from Lot 120185, located in Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor.




Figure 3.13 The Location of The Borehole at LOT 120185, Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor

Source: Adapted from (Google Maps, 2025)

### *3.2.1.3 Fieldwork for Exploratory Borehole at Lot 120188, Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor*

The borehole sampling station at Lot 120188, Selangor Cyber Valley was established in accordance with site conditions and the recommendations of the site engineer, consistent with previous study area locations. Soil sampling was performed at intervals of 1 to 1.5 meters or upon observation of a significant change in the soil strata. A total of 4 exploratory boreholes, designated BH1 to BH4, were drilled to collect in-situ soil samples as illustrated in Figure 3.14. The soil sampling details include 30 samples from Lot 120188, Selangor Cyber Valley, as presented in APPENDIX 4 for validation data analysis.




Figure 3.14 The Location of The Borehole at Lot 120188, Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor

Source: Adapted from (Google Maps, 2025)

### 3.2.2 Standard Penetration Test (SPT)

Figure 3.15 show the study outlines methodology employed for executing the Standard Penetration Test (SPT). The SPT was conducted following Test Number 19 of BS 1337: 1975 at intervals of 1 or 1.5 meters in both stiff cohesive and cohesionless soils. This test is an established approach for evaluating in-situ soil characteristics, including density and relative strength.

The procedure initiates with the insertion of an open-ended split-spoon sampler into the borehole via a drill rod. The split-spoon sampler consists of a steel cylinder divided longitudinally into two halves. These halves are secured by a cutting shoe, which facilitates the smooth collection of soil as the sampler is driven into the ground. The sampler is positioned, and a hammer with a mass of 65 kilograms is released from a height of 75 centimetres. The energy generated by the descending hammer propels the split-spoon sampler into the soil to a depth of 45 centimetres.



Figure 3.15 Standard Penetration Test (SPT)

The *N*-values denote the cumulative number of hammers blows necessary to advance the split-spoon sampler into the soil for the last 30 centimetres of penetration. Upon completion of the test and documentation of the blow counts for each segment, the split-spoon sampler is meticulously removed from the borehole. The soil obtained from the split spoon sampler can be analysed to characterize the soil profile (Look, 2021. A soil sample was collected from the spoon for subsequent analysis. The SPT was performed at 1-meter intervals to achieve precise and comprehensive soil profiling. The correlation proposed by (Look, 2021) between the SPT *N*-values and the unconfined compressive strength of cohesive soil is presented in Table 3.3.

Table 3.3
Correlations between N-value, Consistency and UCS

| **N (Blows)** | **Consistency** | **Unconfined Compressive Strength (kN/m²)** |
|---|---|---|
| <2 | Very Soft | <20 |
| 2-4 | Soft | 20-40 |
| 5-8 | Medium stiff | 40-75 |
| 9-15 | Stiff | 75-150 |
| 16-30 | Very Stiff | 150-300 |
| > 30 | Hard | >300 |

Source : (Look, 2021)

SPT is conducted at 1.5-meter intervals to obtain the *N*-value and disturbed samples as shows in

Figure 3.16. Undisturbed samples are collected when encountering soft cohesive soils. Boreholes are concluded at a depth upon obtaining 5 consecutive SPT *N*' tests with 50 blows per foot or greater, with a maximum depth of 30 meters, including 10 meters of continuous rock coring in limestone or 6.0 meters of continuous rock coring in other rock types. Site investigation reports include borehole data that describes soil types in relation to depth. The data include soil samples that were sent to the laboratory to determine essential soil properties. The engineering characteristics and physical properties of the subsoil are summarized for interpretative purposes. A simplified soil profile was developed based on the general subsoil profile and summarized subsoil properties, with design parameters adopted for settlement analysis purposes.



Figure 3.16 Borehole Drilling

### 3.2.3 SPT from Borehole

The selection of the borehole location is based on anomalies detected during geophysical surveys and the potential for subsidence. Borehole were drilled using a rotary drilling machine. If the SPT *N*-value exceeds 50 blows per 75mm, or if the borehole reaches a depth of 3 meters without encountering rock (depending on the type of rock), it is required to drill vertically through the soil to approximately 45 meters. During the routine penetration testing, disturbed soil samples were collected at intervals of 1.5 meters or whenever a change in soil stratum was identified. In order to minimize disturbance, a thin-walled sampler, conforming to industry standards for sampling tubes was used to collect the samples. The results of 39 SPT values for the study area are shown in Table 3.4.

Table 3.4
Number of SPTs Conducted at The Study Areas

| No. | Location | No. of SPT |
|---|---|---|
| 1 | PT 21044 Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor | 31 |
| 2 | LOT 120185, Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor | 4 |
| 3 | Lot 120188, Selangor Cyber Valley, Daerah Sepang, Mukim Dengkil, Selangor | 4 |
| | **Total** | **39** |

#### *3.2.3.1 SPT at PT 21044 Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor*

A total of 31 exploratory boreholes (BH1–BH31) were completed at PT 21044 using rotary wash boring equipment incorporating the SPT in accordance with BS 1377: Part 9 (1990). Of these, 25 boreholes (BH1–BH19 and BH26–BH31) were designated as the primary dataset for empirical model development, whereas the remaining six boreholes (BH20–BH25) were reserved for sensitivity analysis to evaluate the internal consistency of the developed model.

Detailed soil sampling records, including sample identification numbers, sample types and sampling depths, are presented in APPENDICES 1 and 2, while the

corresponding SPT *N*-value data are provided in APPENDICES 5 and 6. Representative borehole logs are presented in APPENDICES 14–16, whereas the representative laboratory test results are provided in APPENDIX 19.

#### *3.2.3.2 SPT at Lot 120185, Selangor Cyber Valley (SCV), Mukim Dengkil, Daerah Sepang, Selangor*

The SPT data from Lot 120185, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor, were utilised as an independent dataset for model validation. The site investigation was carried out to obtain the geotechnical information required for the proposed development of 124 units of two-storey terrace houses. A total of four exploratory boreholes (BH1–BH4) were completed using the rotary wash boring method incorporating the SPT.

Detailed soil sampling records, including sample identification numbers, sample types and sampling depths, are presented in APPENDIX 4, while the corresponding SPT *N*-value data are provided in APPENDIX 8. The representative borehole log is presented in APPENDIX 17, whereas the representative laboratory test results are included in APPENDIX 20

#### *3.2.3.3 SPT at Lot 120188, Selangor Cyber Valley (SCV), Mukim Dengkil, Daerah Sepang, Selangor*

The SPT data from Lot 120188, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor, were utilised as a second independent dataset to further evaluate the performance and reliability of the proposed empirical prediction model. The site investigation was carried out to obtain the geotechnical information required for the proposed development of 156 units of two-storey super link houses. A total of four exploratory boreholes (BH1–BH4) were completed using the rotary wash boring method incorporating the SPT.

Detailed soil sampling records, including sample identification numbers, sample types and sampling depths, are presented in APPENDIX 3, while the corresponding SPT *N*-value data are provided in APPENDIX 7. The representative

borehole log is presented in APPENDIX 18, whereas the representative laboratory test results are included in APPENDIX 20.

### 3.2.4 Soil Sampling

Representative samples of disturbed and undisturbed soil were selected for laboratory testing to assess their geotechnical properties in accordance with (BS 1377, 1990). Disturbed samples were employed to ascertain fundamental physical properties, whereas undisturbed samples were utilized for tests necessitating the soil's natural structure. The laboratory investigation assessed the fundamental physical properties of the soils, including Moisture Content, Specific Gravity, PSD, Bulk Density and Atterberg Limits. A strength test was conducted to assess the mechanical properties of the soil and its ability to endure applied loads.

#### *3.2.4.1 Disturbed Soil Samples*

BS 1377: Methods of Test for Civil Engineering Purposes (1990) specifies that disturbed samples are generally collected at regular intervals, typically ranging from 1 to 1.5 meters, or upon the observation of a significant change in soil strata. The borehole was advanced to the required depth using a drilling rig to ensure stability and clarity of obstructions. Upon reaching the target depth, a split-spoon sampler, which is a steel tube intended for soil sampling, was affixed to the drill rods and subsequently lowered into the borehole. The sampler is driven into the soil by releasing a 63.5 kg hammer from a height of 760 mm. The quantity of blows necessary to advance the sampler through three consecutive 150 mm intervals was documented, with the concluding 300 mm yielding the SPT *N*-value, which serves as a measure of soil resistance. Upon completion of the driving process, the sampler is meticulously retrieved to avoid contamination or loss of the soil sample. The split-spoon sampler is subsequently opened, and the disturbed soil sample, generally obtained along its length, is extracted. The sample is stored in moisture-proof containers or polyethylene bags to maintain its characteristics as demonstrated in

Figure 3.17. Samples are labelled accurately with information including borehole number, sampling depth and date prior to secure storage for transport to the laboratory.



Figure 3.17 Collection of The Disturbed Soil Sample

### *3.2.4.2 Undisturbed Soil Samples*

(Gui, 2003) reports the collection of undisturbed soil samples from cohesive soils ranging from moderately stiff to soft. In reference to

Figure 3.18, a thin-walled sampling tube with a diameter of 6 cm and a length of 75 cm was employed to reduce disturbance during the sampling process. The tube was precisely inserted into the soil at the designated depth utilizing static force or mechanical assistance to retrieve the sample while preserving its natural structure. After filling the tube, it was carefully removed from the borehole to minimize additional disturbance. The sample ends are subsequently trimmed and cleaned to eliminate any loose material, thereby ensuring a clean and representative specimen. The ends of the sample are sealed with non-shrinking wax to maintain the natural Moisture Content and prevent loss. Each sample was labelled with information including the sampling location, depth, and collection date to ensure accurate identification. The sealed tubes are encased in protective materials, including sponges, to mitigate damage during

transportation and are housed within a secure sample box. The samples are subsequently sent to the laboratory for additional testing to assess the geotechnical properties.



Figure 3.18 Collection of The Undisturbed Soil Sampling

## 3.3 Soil Sampling for Laboratory Testing

A total of eight types of laboratory tests were conducted to ascertain the physical characteristics and geotechnical properties of soil. The details of the laboratory testing program are presented in Table 3.5.

Table 3.5
Laboratory Testing Programme

| No. | Type of Test | Method Lab Used |
|---|---|---|
| **1** | Moisture Content | Oven Dry $100^0$c |
| **2** | Atterberg Limit | Cone Penetration |
| **3** | Bulk/Dry Density | Very useful Index Test |
| **4** | Specific Gravity | Gas Jar Test |
| **5** | Particle Size Distribution | Sieve Analysis (for coarse-grained soil) |
| **6** | Dry Sieve Analysis | Standard Sieving |

| | | |
|---|---|---|
| **7** | Wet Sieve Analysis | Wet Sieving |
| **8** | Hydrometer Testing | Hydrometer (fine-grained soil) |

### 3.3.1 Moisture Content, *w*

Soil samples from the site were enclosed in moisture-proof containers to ensure representativeness and prevent contamination during Moisture Content determination. The samples were promptly sealed in airtight, moisture-tight containers to inhibit evaporation or water absorption during transport to the laboratory, as advised by (Head, 1992). The oven drying process of the soil samples is illustrated in

Figure 3.19**.** Each soil sample was initially weighed in its natural condition before being placed in an oven set at a temperature of 105 ± 5°C for a duration of 24 hours. The drying process was conducted to guarantee the complete evaporation of free water while preventing the decomposition of the organic content. Following cooling in a desiccator to prevent moisture absorption from the atmosphere, the oven-dried mass of the soil was measured.



Figure 3.19 Drying oven used for Moisture Content testing at the Civil Engineering Laboratory, UiTM Shah Alam.

The Moisture Content analysis results were utilized to evaluate the soil's suitability for different construction activities and to establish correlations between moisture levels and other geotechnical parameters, including compaction and shear strength (Mitchell & Soga, 2005). The measured Moisture Content values were subsequently used to construct Moisture Content with depth and Moisture Content with SPT *N*-value profiles for data interpretation. These profiles were used to evaluate the variation of Moisture Content with depth and *N*-value, identify the distribution of soft soil layers and support the development of the empirical prediction models.

### 3.3.2 Atterberg Limit

The Atterberg limits are parameters that define the consistency and behaviour of fine-grained soils at varying Moisture Contents, offering insights into their plasticity and classification. The behaviour of soil is directly correlated with the quantity of water present. The Atterberg limits consist of the Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) which are determined in the laboratory using standardized procedures. This study involved the collection of soil samples from the site in accordance with BS 1377: Methods of Test for Civil Engineering Purposes (1990) to ensure the acquisition of undisturbed samples, thereby preserving the natural structure and Moisture Content. Figure 3.20 shows the PL indicates the Moisture Content at which soil transitions from a flexible plastic state to a brittle semi-solid state. The PL denotes the Moisture Content at which soil shifts from a malleable plastic condition to a brittle semi-solid condition. At this Moisture Content, the soil loses its capacity to be shaped or molded without fracturing. The PL is established empirically via laboratory testing, in which soil threads are rolled until they disintegrate at a diameter of 3 mm. PL denotes the lowest Moisture Content at which soil maintains its elastic properties.



Figure 3.20 Plastic Limit Testing on Soil Samples

The *LL* of soil is assessed through the cone penetrometer method as illustrated in Figure 3.21 adhered to the procedure outlined in BS 1337: Part 2: 1990. The *LL* is the Moisture Content at which soil transitions from a plastic state, indicating the point at which it begins to flow under minimal applied force. The soil sample underwent sieving through a 425 µm sieve to eliminate coarse particles was combined with distilled water to create a homogeneous paste and subsequently transferred to a sample container.

A metal cone weighing 80g and having a 30° apex angle is placed in contact with the soil surface. Upon release, the cone penetrates the soil under its own weight for a duration of 5 seconds. The penetration depth is measured and the test is conducted at varying Moisture Contents to attain a penetration depth ranging from 15 mm to 25 mm. The Moisture Content at a penetration depth of 20 mm is determined through interpolation as the *LL*.




Figure 3.21 Liquid Limit Testing using Cone Penetrometer

The measured *LL* and *PI* values were subsequently interpreted using the Plasticity Chart in accordance with BS 5930:2015 for the classification of fine-grained soils, as illustrated in Figure 3.22.

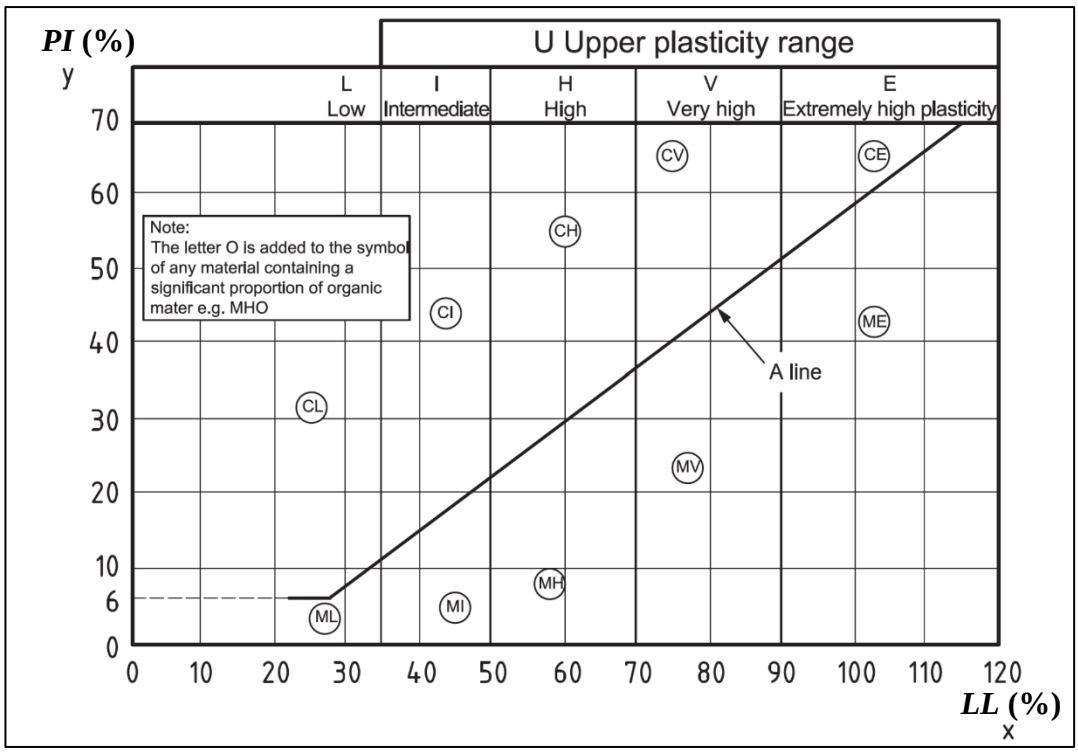



Figure 3.22 Plasticity Chart for the Classification of Fine-Grained Soils according to BS 5930:2015

Note: C = Clay; M = Silt; O = Organic soil; L = Low plasticity; I = Intermediate plasticity; H = High plasticity; V = Very high plasticity; E = Extremely high plasticity.

The behaviour of soil at varying moisture levels can be analysed through the Shrinkage Limit (*SL*) which denotes the Moisture Content at which further water loss does not result in additional volume reduction. This illustrates the transitions among the liquid, plastic, semi-solid and solid states of soils. The shrinkage and water content test indicate a decrease in volume as a result of drying. The *SL* is determined experimentally through a linear shrinkage method which detects shrinkage in a single dimension. This method involves shaping a soil sample that is at or above its *LL*, followed by drying it in an oven and measuring its average length to evaluate shrinkage. The *LL* and *PL* are crucial for determining the *PI* which reflects the Moisture Content range within which soil exhibits plastic behaviours. The calculated *PI*, together with the corresponding *LL* values, was subsequently used to classify the soil based on the Plasticity Chart in accordance with BS 5930:2015.

Soils exhibiting a *PI* ranging from 20% to 40% are notably prone to engineering issues, including settlement as demonstrated by (Asad et al., 2013). The correlation highlighted the significance of establishing the liquid limit and associated parameters for comprehending soil behaviour and addressing geotechnical issues in engineering contexts.

### 3.3.3 Bulk Density ($\rho_b$) and Determination of Dry Density ($\rho_d$)

Bulk Density ($\rho_b$) and Dry Density ($\rho_d$) indicate the mass of soil per unit volume and are directly associated with compaction and strength properties. In soft, saturated soils, a high $\rho_b$ is observed alongside a low $\rho_d$, which suggests elevated void ratios and compromised structural integrity (Das & Sobhan, 2017). The $\rho_b$ test quantifies the mass of soil per unit volume, encompassing both solid particles and pore spaces. It also offers insights into the compaction, porosity, and overall density characteristics of the soil. $\rho_b$ indicates the capacity of soil to provide structural support, facilitate water and solute movement and ensure adequate aeration.

Bulk Density serves as a means to facilitate the conversion between the weight and volume of soil. This method quantifies soil physical, chemical and biological

properties on a volumetric basis, facilitating soil quality assessment and comparisons across different management systems. This enhances the validity of comparisons by eliminating errors related to variations in soil density at the time of sampling. Figure 3.23 illustrates the $\rho_b$ conducted as part of the laboratory classification tests to assess the physical properties of the subsoil. The results obtained from these laboratory tests, together with the detailed subsoil profile descriptions, were used to classify the subsoil according to established geotechnical and soil classification standards.




Figure 3.23 Sample of Density Test

The $\rho_d$ of soil is defined as the mass of soil solids per unit total volume, assessed after the removal of all pore water, usually via oven drying. A soil mass typically comprises three phases namely solids, water and air. $\rho_d$ indicates the ratio of solid particles to the total soil volume, omitting the effects of water and air. The term is also commonly known as the dry unit weight of soil. The $\rho_d$ values were calculated using the equation presented in Chapter 2.

The measured $\rho_b$ values were subsequently plotted against depth and SPT *N*-values to evaluate the variation of soil density within the subsurface profile. The $\rho_b$ data were then incorporated into the correlation analysis and empirical prediction model development. The $\rho_b$ profiles were also used to interpret the variation of soil density

with depth and to identify the distribution of soft soil layers prior to the statistical analysis.

### 3.3.4 Specific Gravity ($G_s$) Test

The Specific Gravity ($G_s$) test was conducted in accordance with BS 1377: Part 2 (1990) using the gas jar method to determine the $G_s$ of representative soil samples collected from the boreholes. $G_s$ is defined as the ratio of the mass of soil solids to the mass of an equivalent volume of water. This is significant to the soil index property, which is closely related to mineralogy and chemical composition (Oyideran & Durojaiye, 2012). Figure 3.24 illustrates the laboratory equipment used during the $G_s$ test. The theoretical background and equation for determining $G_s$ are presented in Chapter 2.




Figure 3.24 Sample of Specific Gravity Test using Gas Jar

The test was performed by measuring the mass of the empty gas jar, followed by the mass of the gas jar containing the oven-dried soil specimen and distilled water. The required measurements were recorded in accordance with the procedures specified

in BS 1377: Part 2 (1990). Care was taken to remove entrapped air from the specimen to ensure the accuracy of the test results.

The measured $G_s$ values were used to characterise the physical properties of the soil and to support the interpretation of subsurface conditions. The $G_s$ data were subsequently plotted against depth and SPT *N*-values to evaluate the variation of soil properties with depth and were incorporated into the correlation analysis and empirical prediction model development. Table 3.6 presents the typical $G_s$ values for common soil types reported in the literature. These values were used as a reference to interpret the laboratory test results obtained in this study and to assist in the identification of the engineering characteristics of the investigated soils (Das & Sobhan, 2022).

Table 3.6
Typical Values of Specific Gravity ($G_s$)

| **Type of Soil** | **Specific Gravity** |
|---|---|
| Sand | 2.65 – 2.67 |
| Silty Sand | 2.67 – 2.70 |
| Inorganic Clay | 2.70 – 2.80 |
| Soil with Mica or Iron | 2.75 – 3.00 |
| Organic Soil | 1.00 – 2.60 |
| Sand | 2.65 – 2.67 |

Source: Adapted from (Das and Sobhan, 2022).

The measured $G_s$ values obtained in this study were compared with the typical ranges presented in Table 3.6 to support the interpretation of soil composition and engineering behaviour. The comparison assists in identifying the dominant soil composition and supports the interpretation of the engineering characteristics of the investigated tropical soft soils. The interpretation of the $G_s$ results contributed to the identification of soil characteristics and the assessment of the engineering behaviour of the tropical soft soils investigated in this study (Das & Sobhan, 2022). The $G_s$ of soil indicates its suitability as a construction material with higher values correlating to increased strength for roads and foundations. This method is utilized to assess porosity, degree of saturation, void ratio and various other soil parameters (Prakash & Jain, 2002).

### 3.3.5 Particle Size Distribution

The Particle Size Distribution (PSD) test is a critical procedure in geotechnical engineering for determining the distribution of particle sizes within a soil sample. This analysis provides information on soil gradation and supports the interpretation of soil behaviour for engineering applications. The PSD test was conducted in accordance with BS 1377: Part 2 (1990) using sieve analysis for coarse-grained soils and hydrometer analysis for fine-grained soils.

This test involved two primary methods, namely sieve analysis for coarse particles and hydrometer analysis for finer particles. Together, these methods provided a comprehensive understanding of soil gradation. The theoretical background, particle size distribution curves, the calculation of the Uniformity Coefficient (Cu) and Coefficient of Gradation (Cg) are presented in Chapter 2.

The PSD test was carried out to determine the percentage distribution of different particle sizes and to classify the soils according to their gradation characteristics. The laboratory results were subsequently used to interpret the variation of soil texture with depth and to support the correlation analysis between PSD and SPT N-values conducted in this study.

#### *3.3.5.1 Dry Sieve Analysis*

Dry sieve analysis is a critical method used to assess the particle size distribution (PSD) of coarse-grained soils, including sand and gravel. Although this study primarily focused on soft soils, the collected soil samples contained varying proportions of coarse particles, particularly sand fractions. Therefore, dry sieve analysis was carried out in accordance with BS 1377-2:1990 to separate the coarse fraction prior to subsequent wet sieve analysis and hydrometer testing, where applicable. Figure 3.25 illustrates the dry sieve analysis conducted as part of the laboratory testing programme.

To initiate the dry sieve analysis, a representative soil sample was collected and oven-dried at a temperature of 100–105 °C until a constant mass was achieved. This procedure ensured the removal of moisture that could affect particle separation during sieving. The dried soil sample was then weighed using a balance with a sensitivity of 0.01 g. Subsequently, the sample was carefully disaggregated using a rubber pestle to

break down soil lumps without crushing the individual particles before being subjected to sieve analysis.




Figure 3.25 Dry Sieve Analysis using Mechanical Sieve Shaker

The sieving process was carried out using a series of standard sieves arranged in descending order of mesh size in accordance with BS 1377-2:1990. Each sieve represented a specific particle size range, with the finest sieve positioned above the receiving pan to collect the smallest particles. The prepared soil sample was placed in the top sieve, and the complete sieve stack was secured in a mechanical sieve shaker, as shown in Figure 3.25. The shaker was operated for approximately 10 to 15 minutes to ensure adequate separation of soil particles according to size while minimising particle breakage.

Following the sieving process, the material retained on each sieve was carefully collected and weighed. The cumulative percentage retained and the percentage passing through each sieve were subsequently calculated based on the total sample mass. The test results were then tabulated, and the particle size distribution curve was

plotted on a semi-logarithmic graph to evaluate the soil gradation characteristics, as described in Chapter 2.

#### *3.3.5.2 Wet Sieve Analysis*

Wet sieve analysis is a critical procedure used to ascertain the particle size distribution of soils with fine particles, including Silt and Clay, which may adhere to coarser grains. This method ensures accurate separation of particles by washing away fines, thereby providing a more precise gradation of soil. Wet sieving is crucial when soil contains a substantial number of fines that cannot be adequately separated through dry sieving methods alone. The test commences with the preparation of a representative soil sample, which is oven-dried at a temperature of 105 – 100 °C to eliminate Moisture Content. The dried sample is subsequently weighed to ascertain its initial weight.

Figure 3.26 display the soil sample is placed in water with a dispersing agent, sodium hexametaphosphate, to inhibit flocculation. The mixture is stirred thoroughly to ensure that fine particles are adequately detached. This method is employed to disaggregate soil particles and eliminate fines that adhere to coarser particles. Following the washing process, the material collected on each sieve is carefully gathered, dried in an oven at 105 – 100 °C until a constant weight is achieved, and subsequently weighed. The weights of the retained fractions are documented, and the cumulative percentage retained is computed. The percentage passing through each sieve is calculated by deducting the cumulative retained percentage from 100%. The values are presented in a table, and a particle size distribution curve is generated using a logarithmic scale for particle size.



Figure 3.26 Wet Sieve Analysis at UiTM Laboratory, Shah Alam, Selangor

### *3.3.5.3 Hydrometer Testing*

Figure 3.27 shows the hydrometer test was performed following the guidelines of BS1377: Part 2:1990 on soil samples obtained in a bucket during a wet sieving test. The hydrometer test aimed to identify particles smaller than 63µm and to analyse the dispersion of fine particles within the soil sample.



Figure 3.27 Hydrometer Test conducted at UiTM Laboratory, Shah Alam

The soil suspension is subsequently transferred to a 1,000 ml sedimentation cylinder, which is filled with distilled water to a designated volume as indicated in Figure 3.28. The mixture is stirred thoroughly to achieve uniform distribution of soil particles and afterwards enabled to settle under the influence of gravity. A hydrometer is systematically inserted into a suspension to measure density at specific time intervals, typically ranging from 0.5 minutes to 24 hours. The readings indicate the concentration of particles suspended at various depths and times.




Figure 3.28 Sedimentation Cylinder for Hydrometer Testing

## 3.4 Data Analysis Framework

Soil characteristics were established through the collection, summarization, and interpretation of data from the subsurface investigation report. The analyses were presented in a tabular format and supplemented by a graph that compared the results. This research examined three distinct site investigations, each concentrating on Sandy or Clay soil types. The process commenced with the gathering of information from multiple consultants. Site investigations provided estimates of SPT *N*-values, which are available for nearly all locations. The test was conducted through general soil

exploration. Field and laboratory results were subsequently analysed to compare soil parameters derived from the SPT *N*-values.

The relationship between SPT *N*-values and soil properties was established through correlation and regression analyses. The analyses were conducted to identify statistically significant relationships between SPT *N*-values and the selected soil properties. Inter-relationships allow for the calculation of soil parameters, including Specific Gravity, Dry Density and PSD following the estimation of SPT *N*-values. This analysis entails the identification of correlations among the chosen soil parameters. The $R^2$ value is utilized to evaluate the existence of a significant relationship between the SPT *N*-value and the soil properties derived from the data. Thus, a correlation between the SPT *N*-value and soil properties can be determined. Empirical relationships for soil parameters will be established based on SPT *N*-values using a random number generation technique. Upon obtaining these parameters, it becomes feasible to derive the most prevalent input parameters outlined above for soil numerical modelling.

This data analysis framework delineates the systematic methodology employed in this research to examine the relationship between SPT *N*-values, depth and selected soil properties within the soft alluvial deposits of PT21044 Cyberjaya. The primary aim of this study is to develop empirical models for estimating soil behaviour based on simple field measurements. A structured analysis framework is essential to ensure that the selected predictors are statistically valid and geotechnically meaningful stress (Das & Sobhan, 2022).

The analysis was structured into several essential stages from assessing fundamental relationships via correlation, establishing statistical significance and identifying the most suitable variables for modelling. This systematic approach guarantees technical reliability while adhering to geotechnical principles, recognizing that soil behaviours is influenced by natural stratification, moisture conditions, mineral composition and depth-dependent stress (Holtz et al., 2011).

### 3.4.1 Correlation of SPT *N*-value with Depth and Soil Properties

Correlation analysis is fundamental to this research as it facilitates the identification of the influence of soil resistance, indicated by SPT *N*-value and depth on the physical behaviours of soil. In soft alluvial environments like the PT21044 site, soil properties exhibit considerable variability over short distances, necessitating a thorough understanding of these natural patterns prior to the development of any empirical model.

Depth and SPT *N*-value were selected as the primary predictors due to their significant geotechnical relevance. Depth influences the overburden pressure and degree of consolidation, which in turn affect soil density, stiffness and particle arrangement. As depth increases, soils generally exhibit greater density and higher penetration resistance owing to reduced void ratios and increased effective stress (Das & Sobhan, 2022). The *N*-value is acknowledged as an effective measure of subsurface stiffness and compactness. Increased *N*-values are typically associated with more granular or compacted soils, whereas lower *N*-values are characteristic of soft, wet or Clay-rich layers which are prevalent at the Cyberjaya site.

This study analysed the relationships between Moisture Content, Bulk Density, Specific Gravity and Clay content to determine which soil properties correlated positively with SPT resistance and which exhibited an inverse relationship. Soils characterized by elevated moisture or Clay content typically produce lower *N*-values due to their susceptibility to deformation under hammer impact. In contrast, soils exhibiting elevated Specific Gravity or Bulk Density are associated with increased *N*-values, attributable to their compact and mineral-rich characteristics.

This correlation stage guarantees that only variables demonstrating genuine, interpretable relationships both statistically and geotechnically proceed to the modelling phase.

### 3.4.2 Pearson Correlation Analysis

This study employed Pearson's Correlation Coefficient ($r$) to quantify the linear relationships between continuous variables. Pearson correlation is widely recognised as a reliable statistical method for evaluating the strength and direction of relationships between soil parameters in geotechnical engineering studies (Das & Sobhan, 2022).

Pearson correlation analysis was performed to determine the relationships among the selected variables and to identify the most significant parameters for the development of the empirical prediction models. The analysis generated the correlation coefficient ($r$), $p$-value and significance level for each pair of variables. Scatter plots were also examined to verify the linearity of the relationships and identify potential outliers. The analysis was carried out using the following variables:

a) Depth ($D$)
b) $N$-value log-transformed (Log$N$)
c) Moisture Content ($w$) refers to the amount of water present in a material, typically expressed as a percentage of the total weight of the material.
d) Specific Gravity ($G_s$) refers to the ratio of the density of a substance to the density of a reference substance, typically water at a specified temperature.
e) Bulk Density ($\rho_b$)
f) Clay content (CLAY)

The statistical analysis was performed using Minitab 21.

### 3.4.3 Significance Testing ($p$-value)

The coefficient $r$ ranges from –1 to +1, reflecting the relationship between variables: a positive correlation indicates that both variables increase, a negative correlation signifies that one variable increase while the other decreases and a value of zero denotes no relationship. Correlation coefficients with an absolute value of 0.50 or greater, together with statistically significant $p$-values ($p \leq 0.05$), were considered indicative of moderate to strong relationships and were selected for subsequent regression modelling (Schober et al., 2018). The statistical significance of each relationship was evaluated using the p-value at a 95% confidence level ($\alpha = 0.05$). Variables with $p \leq 0.05$ were considered statistically significant and were subsequently evaluated for inclusion in the regression modelling process.

### 3.4.4 Variable Selection for Modelling

Variable selection represents the final and most critical phase prior to the construction of regression models. Only variables that demonstrated both statistical significance and geotechnical relevance were selected for model development. Statistical significance alone is insufficient for inclusion; geotechnical relevance must also be established. A statistically significant relationship that contradicts established soil behaviours principles may suggest measurement error or the presence of a non-physical trend (Das & Sobhan, 2017). This study involved the selection of variables based on:

a) Statistical Power
b) Predictors needed to exhibit strong correlations ($|r| \geq 0.50$) and significant *p*-values ($\leq 0.05$). Variables exhibiting weak or noisy relationships were omitted to prevent the dilution of the predictive equations.
c) Geotechnical Logic necessitates that variables correspond with established soil behaviours patterns. Moisture Content and Clay content generally decrease soil strength, indicating a negative correlation with *N*-value.
d) The Specific Gravity and Bulk Density generally exhibit an increase alongside soil strength, indicating a positive correlation with the *N*-value.

In this study, variables including *LL* and *PL* exhibited inconsistent or weak correlations and were consequently excluded from analysis. This improves model reliability and prevents the inclusion of parameters that do not contribute to predictive performance.

The selected predictors of depth, *N*-value/log(*N*), Moisture Content, Bulk Density, Specific Gravity and Clay content were subsequently used to develop the empirical prediction models presented in Chapter 4. The predictors exhibit robust statistical significance and geotechnical validity, thereby ensuring that the resulting modelling framework is both realistic and practical for preliminary soil assessment.

## 3.5 Model Development

This study employed Minitab 21 to perform the statistical analyses and develop the empirical prediction models. The collected data were organised and screened before regression analysis was carried out to establish the relationships between SPT *N*-values and the selected soil properties. Prior to the analysis, this software was utilized to reorganize and format the data for compatibility. Regression analyses were conducted to identify the relationships between variables and to assess the significance of their correlations. This study examined site PT 21044 in Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor, where models were developed utilizing engineering and physical soil properties. The data utilized for modelling the SPT *N*-value and soil properties were analysed in relation to laboratory experiments. The models were developed utilizing resistance values and soil physical parameters, which encompass Moisture Content, Dry Density, Specific Gravity, and PSD.

Figure 3.29 depict the process flow for analysing the data and deriving the equations for soil properties related to this study.

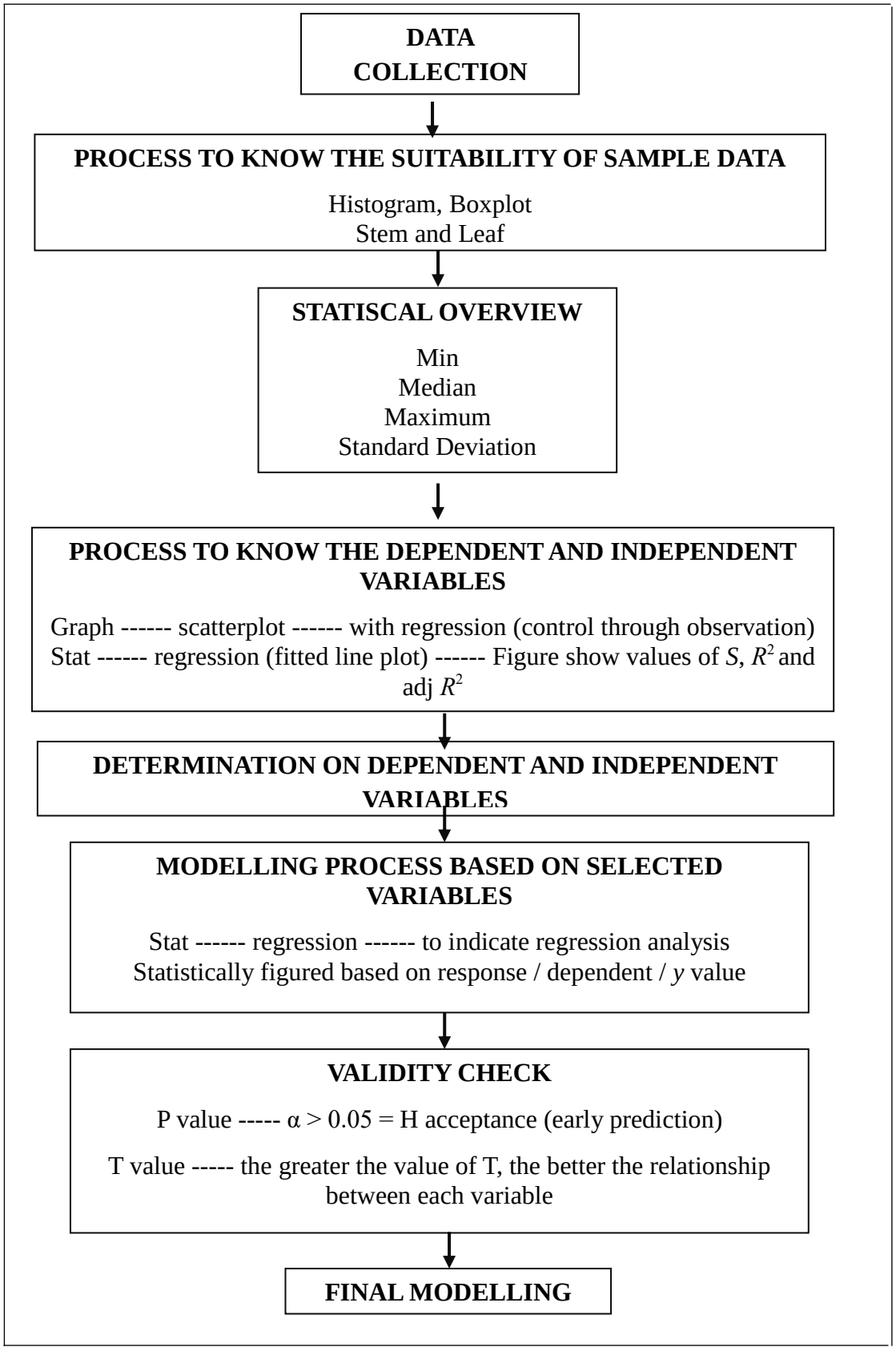



Figure 3.29 Process Flow For Analysing The Data And Deriving The Soil Properties

(Mukri, 2011)

### 3.5.1 Descriptive Statistic

Descriptive statistics provide critical insights into the characteristics of a dataset by providing a summarization of its basic features. The descriptive statistics were used to examine the distribution and variability of each variable prior to correlation and regression analyses. The metrics include the number of observations (sample size), mean (average value), standard deviation (data dispersion measure), minimum and maximum values (range), median (the centre value), skewness (data distribution asymmetry), kurtosis (distribution sharpness or flatness) and additional important measures.

This study identified and selected data with statistically significant values through rigorous sample testing procedures. The selection process relied on statistical significance to ensure the reliability and validity of the data applied for subsequent analysis. The evaluation of data distribution normality was conducted at a 95% confidence level. Datasets showing a bell-shaped curve, characteristic of a normal distribution and conforming to the empirical rule (68-95-99.7 rule) were categorized as normal.

The dataset was assessed for normality based on the characteristics of a normal distribution, where approximately 68% of the observations fall within one standard deviation of the mean, 95% within two standard deviations, and 99.7% within three standard deviations, commonly referred to as the 68–95–99.7 empirical rule (Montgomery et al., 2021).

### 3.5.2 Multiple Linear Regression Analysis

Multiple Linear Regression (MLR) analysis was employed to establish empirical relationships between SPT *N*-values and the selected soil properties. The regression analysis was conducted to develop predictive equations that describe the relationships between the dependent variables and the selected predictor variables.

Prior to regression analysis, the dataset was screened to ensure data consistency and completeness. The predictor variables were selected based on the results of the Pearson correlation analysis together with their geotechnical significance. Variables demonstrating statistically significant relationships and engineering relevance were subsequently included in the regression models. The predictor variables

considered in this study included Depth ($D$), SPT $N$-value (Log$N$), Moisture Content ($w$), Bulk Density ($\rho_b$), Specific Gravity ($G_s$) and Clay Content (CLAY), depending on the response variable being analysed.

The regression models were developed using the Regression Analysis function in Minitab 21, where all selected predictor variables were entered simultaneously into the regression model. Separate regression equations were developed for each dependent soil property to identify the contribution of each predictor variable.

The regression coefficients generated from the analysis were evaluated using the t-value and $p$-value to determine the statistical significance of each predictor variable. Variables with statistically significant regression coefficients ($p \leq 0.05$) were considered important contributors to the regression model. The Variance Inflation Factor (*VIF*) was also examined to identify potential multicollinearity among the predictor variables. Predictor variables with acceptable *VIF* values were retained in the final regression models to minimise multicollinearity effects.

The overall performance of each regression model was assessed using the coefficient of determination ($R^2$), adjusted coefficient of determination (Adjusted $R^2$) and standard error of the regression. Models with higher $R^2$ and Adjusted $R^2$ values together with lower standard errors were considered to provide better predictive performance (Montgomery et al., 2021).

Residual analysis was subsequently carried out to verify that the assumptions of linear regression were satisfied. The residual plots and normal probability plots generated in Minitab 21 were examined to ensure that the residuals were approximately normally distributed, randomly scattered and exhibited constant variance throughout the range of predicted values.

The developed empirical equations were subsequently validated using independent borehole datasets obtained from different study sites. The validation process was conducted to evaluate the predictive capability, reliability and applicability of the proposed empirical models for estimating the engineering properties of tropical soft soils.

### 3.5.3 Normality Test

Normality testing was performed after the regression models were developed to verify that the residuals satisfied the assumptions of MLR. Residuals, defined as the differences between the observed and predicted values, should be approximately normally distributed to ensure the validity and reliability of the regression model (Montgomery et al., 2021).

The normality of the residuals was assessed using the Anderson–Darling normality test available in Minitab 21. In addition, the normal probability plot and residual plots were examined to confirm that the residuals were randomly distributed without systematic patterns. These procedures were performed to verify that the assumptions of normality, independence and constant variance were satisfied prior to interpreting the regression models (Montgomery et al., 2021).

### 3.5.4 Validation Data Set

The validation of a regression model defines the concluding phase in the modelling process, confirming its reliability and predictive accuracy. The chosen model is subjected to a comprehensive validation process to verify its efficacy. The two main methods for validating a regression model involve evaluating its predictive accuracy with new data and examining its performance through holdout samples or unused calibration data. The methods include a comparison of the model's predictions with theoretical expectations and previously established empirical or simulation results to determine its consistency and accuracy.

(Khalid, 2021) highlights that a crucial indicator of successful validation is the p-value, which must exceed 0.05 to indicate that the model passed the validation process. A higher p-value indicates that the model's predictions are consistent with the observed data, thereby decreasing the probability of significant mistakes or biases in the model's design.

The validation dataset was independent of the calibration dataset and was used solely to evaluate the predictive capability and reliability of the developed empirical models. The use of an independent validation dataset reduces model bias and provides an objective assessment of model performance by comparing the predicted values with measured laboratory data (James et al., 2021).

Model validation includes statistical evaluation and empirical testing to verify its reliability. The integration of new data and holdout samples guarantees the regression model's applicability and credibility, establishing an effective basis for informed decision-making and theoretical progress.

The laboratory testing, statistical analyses, model development and validation procedures described in this chapter provided the methodological framework for evaluating the relationships between SPT *N*-values and the selected soil properties. The findings obtained from these analyses are presented and discussed in Chapter 4.

# CHAPTER 4
# RESULTS AND DISCUSSIONS

## 4.1 Surface and Subsurface Soil Profile

This chapter outlines the findings collected through field and laboratory investigations conducted at the Selangor Cyber Valley site in Mukim Dengkil, Selangor. The study area is situated in the Langat River Basin, involving low-lying, gently undulating terrain with ground elevations ranging from approximately 10 to 30 meters above mean sea level. The site is characterized by Quaternary alluvial deposits, consists mainly of soft Clay, Silty Clay, Silt, Peat, and fine Sand lenses formed in a fluvio-marine environment. These soils are generally characterized by softness, saturation and high compressibility with a shallow groundwater table frequently located less than 2 meters below the surface.

The findings presented in this chapter are organised according to the field investigation and laboratory testing results. The interpretation begins with the subsurface soil profile, followed by the SPT results and the measured soil index properties. The relationships between SPT *N*-values and soil properties are subsequently evaluated using statistical analyses to develop the proposed empirical prediction models.

### 4.1.1 Regional Geological Framework

The regional geological framework indicates that the study area is predominantly underlain by Quaternary Alluvium overlying the Kenny Hill Formation. The Quaternary deposits consist mainly of soft Clay, Silt, Peat and Sandy interbed deposited under fluvio-marine conditions, forming the upper subsurface layers encountered during the borehole investigation. These deposits are generally characterised by high Moisture Content, low shear strength and high compressibility.

The geological composition indicates a complex depositional environment characterised by the dominance of soft Clay, Silt and Peat within the upper subsurface layers. Such geological conditions strongly influence the engineering behaviour of the subsurface soils and contribute to the relatively low Standard Penetration Test (SPT) N-

values recorded within the shallow alluvial deposits. In contrast, higher penetration resistance was observed with increasing depth due to the presence of denser Sand deposits and the underlying Kenny Hill Formation.

### 4.1.2 Geological Setting of The Study Area

The geological setting observed from the borehole investigation is consistent with the regional geological framework presented in Section 3.1.1. The investigated sites are predominantly underlain by Quaternary Alluvium overlying the Kenny Hill Formation, indicating that the study area is characterised by recent unconsolidated deposits formed under fluvio-marine depositional environments.

The borehole investigation confirmed that the upper subsurface layers consist mainly of soft Clay, Silty Clay, Silt and Peat with occasional fine Sand interbeds. Variations in the thickness of these deposits were observed throughout the study area, reflecting the heterogeneous nature of the depositional environment. The predominance of these soft alluvial deposits explains the relatively low SPT *N*-values recorded within the shallow soil layers, whereas penetration resistance generally increased with depth due to the presence of denser Sand deposits and the underlying Kenny Hill Formation.

The observed geological setting provides a clear understanding of the subsurface conditions encountered across the study area and forms the basis for interpreting the borehole records, laboratory test results and the empirical relationships developed between SPT N-values and physical soil properties. A similar observation was reported by (Look, 2021), who emphasised that comprehensive borehole investigations are essential for accurately defining subsurface stratigraphy and supporting reliable geotechnical design decisions.

### 4.1.3 Geological Characteristic

The geological assessment of the study area indicates that the site is characterised by a low-lying alluvial environment with heterogeneous subsurface conditions. The borehole investigation identified alternating layers of Peat, Clay, Silty Clay, Silt and occasional fine Sand lenses, reflecting variations in the depositional environment across the study area. The presence of these materials demonstrates that

the subsurface profile is not uniform and varies both vertically and laterally between borehole locations.

The heterogeneous geological characteristics influence the engineering behaviour of the subsurface soils, particularly in terms of soil consistency, compressibility and penetration resistance. Consequently, variations in the SPT *N*-values were observed between boreholes, especially within the upper alluvial deposits where soft fine-grained soils predominate. These variations highlight the importance of detailed subsurface characterisation for accurately interpreting soil behaviour and developing reliable empirical prediction models.

The observed geological characteristics are consistent with the findings of (Almohammedi, 2024), who reported that heterogeneous soft soil deposits increase geotechnical uncertainty when subsurface conditions are not adequately characterised through comprehensive site investigation.

### 4.1.4 Local Geomorphology

Field reconnaissance and borehole investigations indicate that the Selangor Cyber Valley site is situated within an inland alluvial plain previously dominated by lowland swamp forest before land clearing and development occurred. The original vegetation has largely been replaced by oil palm plantations and secondary shrub growth, with only isolated remnants of the natural vegetation remaining. An organic and decomposing vegetation layer derived from the former swamp forest generally overlies the alluvial plain.

Local depressions and areas with insufficient drainage are frequently observed throughout the study area, resulting in a generally shallow groundwater table. The area has undergone extensive urbanisation and infrastructure development within the Cyberjaya–Putrajaya growth corridor, where residential, educational and commercial developments now dominate the surrounding land use.

The subsurface deposits comprise soft to very soft alluvial sediments consisting mainly of Clay, Silty Clay, Silt, Peat and occasional fine Sand lenses. These sediments are generally saturated and exhibit high compressibility. The thickness of the alluvial deposits varies between approximately 7.5 m and 16.5 m before reaching the more competent materials of the Kenny Hill Formation.

The Kenny Hill Formation underlying the alluvial deposits consists of interbedded quartzite, shale and occasional phyllite. The quartzite comprises angular to sub-angular quartz grains cemented within a silica matrix, whereas the shale is generally light coloured, thinly bedded and non-carbonaceous. This rock sequence has undergone low-grade metamorphism, forming a moderately weathered foundation beneath the soft alluvial deposits.

The observed local geomorphological conditions indicate a heterogeneous subsurface environment, which contributes to the variability of soil behaviour and SPT *N*-values across the study area. Similar observations were reported by (Li et al., 2025), who highlighted that irregular layering and heterogeneous soft soil deposits significantly influence subsurface behaviour and should be adequately characterised during site investigation.

### 4.1.5 Groundwater Conditions

Figure 4.1 presents the groundwater levels recorded from all boreholes within the PT 21044 site. The groundwater table is generally shallow, with most measurements ranging from 0.0 m to 1.0 m below the existing ground level (b.g.l.). This indicates that the site is predominantly waterlogged, which is a typical characteristic of soft soil environments dominated by Peat and soft Clay. The groundwater table observed in the majority of boreholes (BH1–BH31) is close to the ground surface, indicating consistently high groundwater conditions throughout the study area. This condition is commonly associated with Peat and soft compressible soils that exhibit high moisture retention capacity.

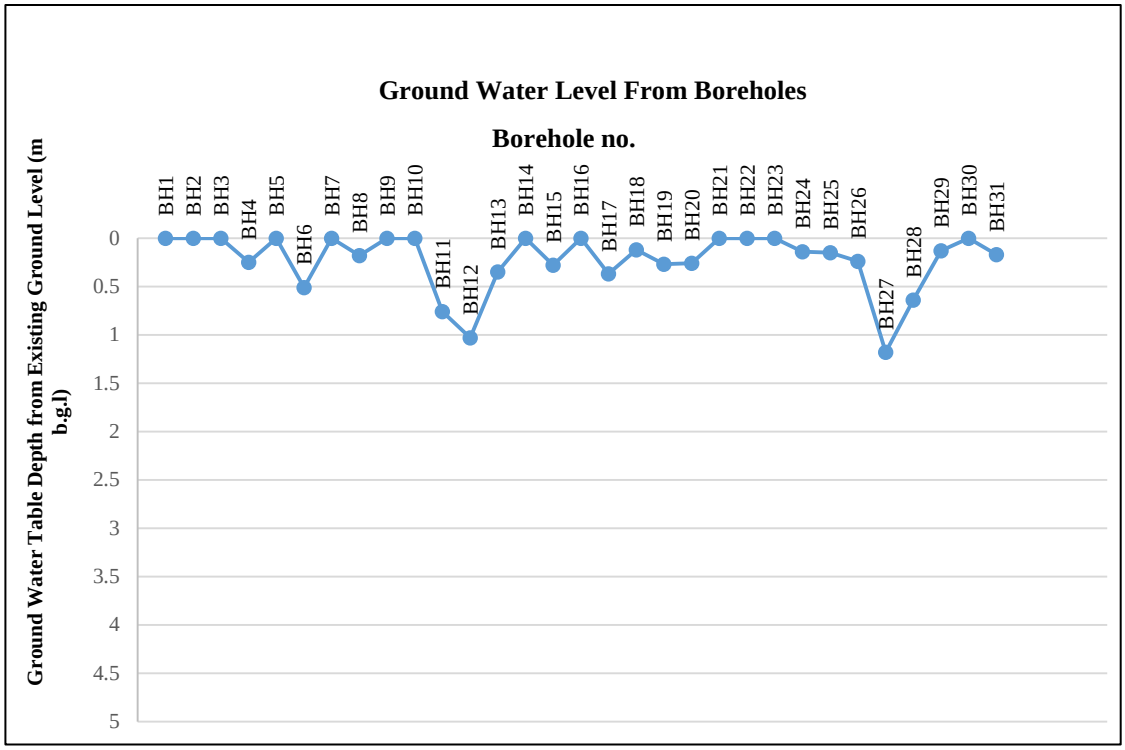



Figure 4.1 Ground Water Level (m b.g.l.) at each borehole

A high groundwater table is commonly associated with low-lying areas that exhibit poor natural drainage and highly compressible soils capable of retaining large amounts of moisture. Several boreholes, namely BH12 and BH27, demonstrate marginally deeper groundwater levels with measurements indicating water levels between 1.0 m and 1.5 m below ground level (b.g.l.). These variations are likely influenced by slight changes in ground elevation or particular soil permeability attributes. Boreholes situated on elevated terrain tend to show deeper groundwater levels while those in flatter or lower areas usually have water closer to the surface.

The consistently shallow groundwater table presents notable implications for the site. Increased groundwater levels can reduce effective stress in soil, resulting in lower SPT *N*-values in the upper layers especially in Peat and soft Clay which exhibit low strength and high compressibility. The observed groundwater conditions are consistent with the SPT results discussed in Section 4.2, where relatively low *N*-values were recorded within the upper soft soil deposits. The shallow groundwater profile at PT 21044 reflects a typical soft-soil environment characterised by high Moisture Content, which significantly influences soil behaviour, construction planning and foundation design. These observations are consistent with the findings of (Osman,

2013), who reported that prolonged waterlogging in the Cyberjaya area reduces effective stress and penetration resistance, resulting in low SPT *N*-values within shallow soft soil deposits.

### 4.1.6 Subsurface Conditions at the Study Sites

The study was conducted at three investigation sites located within the Selangor Cyber Valley area, namely PT 21044, Lot 120185 and Lot 120188. PT 21044 served as the primary study site for developing the empirical prediction model, whereas Lot 120185 and Lot 120188 were selected as independent validation sites.

Figure 4.2 illustrates the geographical locations of the three study sites within the Selangor Cyber Valley area.




Figure 4.2 Geographical Locations of PT 21044, Lot 120185 and Lot 120188 within the Selangor Cyber Valley

Source: Adapted from (Google Maps, 2025), annotated by the author.

The three investigation sites are located within the same geomorphological setting of the Langat River Basin and are underlain predominantly by Quaternary alluvial deposits. Their close geographical proximity minimises regional geological variability while providing independent datasets for validating the proposed empirical

prediction model. The use of geologically comparable validation sites enables the developed model to be evaluated under similar subsurface conditions without relying on the primary dataset.

#### *4.1.6.1 PT 21044 Cyberjaya, Mukim Dengkil, Daerah Sepang, Selangor*

PT 21044, located in Mukim Dengkil, Daerah Sepang, Selangor, served as the primary study site for developing the empirical prediction model. A total of 31 boreholes (BH1–BH31) were completed across the site to investigate the subsurface conditions. The borehole investigation revealed thick deposits of Quaternary alluvial soils consisting predominantly of Peat, Clay, Silty Clay and Silt with occasional Sand lenses. These deposits generally exhibited low SPT *N*-values within the upper soil layers, reflecting their soft and highly compressible nature.

For model development, boreholes BH1–BH19 and BH26–BH31 formed the primary dataset, whereas BH20–BH25 were reserved for sensitivity analysis to evaluate the internal consistency of the developed empirical relationships. The extensive borehole coverage across the site provided representative data for establishing empirical correlations between SPT N-values and the measured physical soil properties. Similar geological conditions within the Cyberjaya area have also been reported by (CREAM, 2023), who described the area as being dominated by heterogeneous Quaternary alluvial deposits overlying the Kenny Hill Formation.

#### *4.1.6.2 Lot 120185, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor*

Lot 120185 was selected as the first independent validation site to evaluate the applicability of the proposed empirical prediction model. The borehole investigation indicates that the site is underlain predominantly by Quaternary alluvial deposits comprising soft Clay, Silty Clay, Silt and occasional Sand layers. Although minor variations in the thickness of individual soil layers were observed, the overall subsurface profile is comparable to that of PT 21044, exhibiting characteristics typical of soft and highly compressible soils within the Selangor Cyber Valley area.

The geological and geomorphological similarities between Lot 120185 and PT 21044 provide an appropriate basis for validating the developed empirical model using an independent dataset. The use of a validation site with comparable subsurface conditions enables the reliability and applicability of the proposed prediction model to be assessed under similar geological settings. Similar characteristics of the Quaternary alluvial deposits within the Langat River Basin have also been reported by (CREAM, 2023).

#### *4.1.6.3 Lot 120188, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor*

Lot 120188 served as the second validation site to verify the performance of the proposed empirical prediction model. The borehole investigation revealed subsurface conditions comparable to those observed at PT 21044 and Lot 120185, consisting predominantly of Quaternary alluvial deposits comprising soft Clay, Silty Clay, Silt and occasional Sand layers. The subsurface profile exhibits the characteristic features of soft ground commonly encountered within the Selangor Cyber Valley area.

The geological consistency observed between Lot 120188 and the primary study site demonstrates that the validation dataset was obtained from an area with comparable subsurface conditions while remaining independent of the model development dataset. The use of independent datasets obtained from geologically comparable locations enhances the reliability, accuracy and regional applicability of the proposed empirical model for predicting physical soil properties in soft soil environments. Similar geological characteristics have also been reported by (CREAM, 2023), who described the Cyberjaya area as being predominantly underlain by heterogeneous Quaternary alluvial deposits overlying the Kenny Hill Formation.

## 4.2 Standard Penetration Test (SPT) for *N*-value

The study site was explored using rotary boring equipment designed to reach the specified depths outlined in the investigation plan. Boreholes were advanced through water flushing to eliminate loose materials and ensure stability throughout the drilling process. Soil samples exhibiting disturbance were collected at each test depth for visual inspection and classification. SPT were conducted in situ at intervals of 1.5

m depth, following the guidelines of BS 1377: Part 9: 1990. A total of 31 boreholes (BH1-BH31) were drilled at Lot PT 21044, identified as the main investigation site for this study. Out of the total, 25 boreholes (BH1-BH19 and BH26-BH31) served as the primary dataset for establishing empirical correlations between SPT *N*-values and soil index properties. Meanwhile, six boreholes (BH20-BH25) were allocated for validation analysis to assess the internal consistency of the proposed correlation model. Furthermore, 2 external validation sites were identified within Selangor Cyber Valley at Lot 120185 and Lot 120188, with four boreholes drilled at each site. The validation datasets were utilized to evaluate the reliability, performance and regional applicability of the developed predictive model in analogous soft soil conditions within the Langat River Basin.

The SPT was performed to assess the penetration resistance of soils and to categorize the subsurface strata. The test utilized a 63.5 kg hammer dropped from a height of 760 mm through a split-spoon sampler, with the number of blows needed for a final penetration of 300 mm recorded as the SPT *N*-value. The recorded *N*-values indicate the relative density and consistency of the soil at various depths, functioning as a critical measure of its engineering strength and stiffness. The findings indicate a consistent increase in *N*-values with depth, which corresponds to the densification and consolidation of soil layers resulting from overburden pressure. The upper layers, primarily composed of Peat and soft Clay, exhibited low *N*-values (ranging from 2 to 8), signifying very soft to soft soils characterized by high Moisture Content and low shear strength. At depths greater than 10 m, the *N*-values exhibited a significant increase (from 10 to 25), indicating the presence of stiff Silty Clay and fine Sand layers. The findings indicate that the site is underlain by a standard soft alluvial soil profile typical of the Langat River Basin, aligning with the previously discussed regional geological conditions.

The observed pattern of *N*-values suggests that subsurface deposits were shaped by fluvio-marine depositional processes, leading to the gradual compaction of fine-grained sediments over time. This trend indicates that shallow foundations in the upper strata may undergo significant settlement, while piled foundations extending beyond 10 m in depth can attain improved load-bearing capacity. The steady rise in *N*-values throughout the boreholes establishes a dependable foundation for the ensuing correlation analysis between SPT *N*-values and laboratory test derived soil properties, as elaborated in the subsequent section.

### 4.2.1 Dataset and Distribution of SPT *N*-Values

SPT was conducted during the site investigation at Selangor Cyber Valley to obtain representative subsurface resistance data for correlation modelling. Detailed SPT *N*-value records are provided in APPENDICES 5–8, whereas the corresponding borehole logs are presented in APPENDICES 14–18. Table 4.1 summarises the SPT *N*-values obtained from the 25 boreholes (BH1–BH19 and BH26–BH31) comprising the primary dataset used for empirical model development. The results reveal a clear variation in penetration resistance with depth, corresponding to changes in soil type and consistency within the soft alluvial deposits of the study area.

In the upper 0–6 m, the *N*-values range mostly between 2 and 8, with some locations marked as "TS", denoting Top Soil, where the material consisted mainly of loose organic matter and root fragments, and the test was therefore not performed. These very low *N*-values and skipped layers are characteristic of organic Clay and Peat, indicating very soft to soft soils with high Moisture Content and poor bearing capacity.

Between 6 m and 12 m, the *N*-values begin to increase gradually to around 10–18, reflecting a transition from soft Clay to medium-stiff Silty Clay. Beyond 15 m depth, a more consistent increase is observed, where *N*-values range between 20 and 35, representing stiff Clay and fine Sand strata that have undergone greater consolidation under overburden pressure. At depths exceeding 20 m, most boreholes record *N*-values between 35 and 50, and several layers reach the maximum count of 50 blows, indicating very stiff or dense materials typically comprising Silty Sand or weathered Sandy Clay. This trend demonstrates a progressive improvement in soil strength with depth, consistent with the depositional and consolidation characteristics of the Quaternary alluvial formations in the area.

Overall, the SPT data confirm that the PT 21044 site is underlain by soft to very soft soils at shallow depths, transitioning to stiffer and denser layers below approximately 15–20 m. This stratification pattern is typical of the fluvio-marine environment of Selangor Cyber Valley and provides the primary dataset for developing empirical correlations between SPT *N*-values and the measured physical soil properties.

Table 4.1
Summary of SPT *N*-Value for Main Model Data Set (PT 21044, Cyberjaya)

| | Depth (m) | BH 1 | BH 2 | BH 3 | BH 4 | BH 5 | BH 6 | BH 7 | BH 8 | BH 9 | BH 10 | BH 11 | BH 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | TS | TS | TS | TS | TS | TS | TS | TS | TS | TS | TS | TS |
| | 1.5 | 2 | 2 | 4 | 3 | 4 | 3 | 4 | 4 | 2 | 1 | 1 | 0 |
| | 3.0 | 2 | 3 | 3 | 4 | 6 | 4 | 5 | 5 | 2 | 1 | - | 1 |
| | 4.5 | 6 | 5 | 5 | 4 | 5 | 3 | 3 | 4 | 1 | 1 | 1 | 1 |
| | 6.0 | 3 | - | 3 | - | 3 | 2 | - | - | - | - | 1 | - |
| | 7.5 | - | 2 | - | 2 | - | - | 3 | 5 | 1 | 1 | - | 3 |
| | 9.0 | 4 | - | 4 | - | 4 | 2 | - | 10 | - | - | 0 | - |
| | 10.5 | - | 4 | - | 3 | - | - | 4 | - | 2 | 2 | 3 | 3 |
| | 12.0 | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 5 | 3 | 1 | 29 | 4 |
| | 13.5 | 5 | 5 | 4 | 6 | 9 | 5 | 3 | 11 | 2 | 3 | 24 | 4 |
| **Lot PT 21044** | 15.0 | 16 | 6 | 8 | 12 | 13 | 12 | 5 | 12 | 4 | 15 | 31 | 5 |
| | 16.5 | 23 | 12 | 11 | 17 | 16 | 16 | 9 | 16 | 19 | 19 | 35 | 8 |
| | 18.0 | 23 | 14 | 15 | 23 | 23 | 20 | 10 | 17 | 27 | 26 | 26 | 21 |
| | 19.5 | 29 | 17 | 20 | 25 | 26 | 23 | 15 | 25 | 31 | 25 | 29 | 24 |
| | 21.0 | 24 | 22 | 23 | 31 | 31 | 29 | 17 | 28 | 26 | 37 | 37 | 30 |
| | 22.5 | 34 | 32 | 29 | 30 | 22 | 35 | 25 | 36 | 30 | 33 | 33 | 34 |
| | 24.0 | 50 | 36 | 50 | 35 | 32 | 50 | 28 | 50 | 35 | 50 | 34 | 50 |
| | 25.5 | 50 | 50 | 50 | 50 | 33 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 27.0 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 28.5 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 30.0 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 31.5 | | 50 | | 50 | 50 | | 50 | | 50 | | | 50 |
| | 33.0 | | | | | 50 | | | | | | | |

| | Depth (m) | BH 13 | BH 14 | BH 15 | BH 16 | BH 17 | BH 18 | BH 19 | BH 26 | BH 27 | BH 28 | BH 29 | BH 30 | BH 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | TS | TS | TS | TS | TS | TS | TS | TS | TS | TS | TS | TS | TS |
| | 1.5 | 6 | 3 | 4 | 4 | 1 | 11 | 6 | 6 | 3 | 4 | 1 | 4 | 5 |
| | 3.0 | 7 | 4 | 6 | 6 | 1 | 13 | 8 | 6 | 3 | 2 | 3 | 5 | 4 |
| | 4.5 | 4 | 6 | 4 | 5 | 4 | 8 | 6 | 5 | 7 | 3 | 4 | 4 | 4 |
| | 6.0 | - | 4 | 2 | - | 3 | 3 | - | 2 | 4 | 3 | - | 2 | 4 |
| | 7.5 | 2 | - | - | 2 | - | - | 6 | - | - | - | 3 | - | - |
| | 9.0 | - | 4 | 3 | - | 4 | 4 | - | 3 | 3 | 5 | - | 3 | 3 |
| | 10.5 | 3 | - | - | 4 | - | - | 4 | - | - | - | 4 | - | - |
| | 12.0 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 6 | 5 | 5 | 4 | 5 |
| | 13.5 | 5 | 9 | 5 | 8 | 6 | 8 | 7 | 4 | 9 | 6 | 6 | 5 | 4 |
| **Lot PT** | 15.0 | 11 | 13 | 13 | 17 | 14 | 16 | 10 | 12 | 10 | 12 | 14 | 4 | 11 |
| **21044** | 16.5 | 19 | 18 | 19 | 24 | 18 | 22 | 11 | 17 | 16 | 22 | 20 | 13 | 13 |
| | 18.0 | 22 | 22 | 26 | 26 | 26 | 24 | 14 | 23 | 21 | 21 | 26 | 15 | 24 |
| | 19.5 | 28 | 25 | 31 | 32 | 27 | 29 | 16 | 27 | 23 | 28 | 29 | 18 | 30 |
| | 21.0 | 26 | 28 | 27 | 29 | 27 | 36 | 19 | 25 | 43 | 27 | 32 | 25 | 31 |
| | 22.5 | 31 | 34 | 31 | 36 | 30 | 31 | 20 | 30 | 50 | 31 | 35 | 28 | 36 |
| | 24.0 | 37 | 50 | 34 | 32 | 50 | 50 | 23 | 50 | 50 | 35 | 30 | 31 | 50 |
| | 25.5 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 34 | 50 |
| | 27.0 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 28.5 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 30.0 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 31.5 | | 50 | 50 | | 50 | | 50 | | | 50 | 50 | 50 | |
| | 33.0 | | | 50 | | | | | | | | | 50 | |

Representative Borehole Logs records are provided in APPENDICES 14 & 15 for BH1 & BH17

Data from 14 additional boreholes were utilised to evaluate the performance of the developed empirical model. This comprised six boreholes (BH20–BH25) at PT 21044 designated for sensitivity analysis, together with four boreholes each from Lot 120185 and Lot 120188 used as independent validation datasets. Detailed SPT *N*-value records for the sensitivity and validation datasets are presented in APPENDICES 6–8, whereas the corresponding borehole logs are provided in APPENDICES 16–18. The selected boreholes represent comparable geological and geomorphological conditions within the Quaternary alluvial deposits of the Selangor Cyber Valley area, ensuring that the model was evaluated under similar subsurface conditions.

Table 4.2 presents the SPT *N*-values obtained from the six boreholes (BH20–BH25) at PT 21044, which formed the internal sensitivity analysis dataset. The notation "TS" denotes Top Soil, representing surface organic layers that were not tested due to their loose and non-representative nature.

The *N*-values exhibit a trend comparable to that observed in the primary dataset. Within the upper 0–6 m, very low N-values ranging from 2 to 8 were recorded, corresponding to soft organic Clay and Peat with high Moisture Content and high compressibility. Between approximately 6 m and 15 m depth, the *N*-values gradually increase to between 10 and 20, indicating a transition to soft and medium-stiff Silty Clay. Below approximately 15 m depth, penetration resistance increases markedly to between 25 and 50 blows, representing stiff Clay and dense Sand layers that have undergone greater consolidation.

The similarity in the depth-dependent *N*-value trends between the primary and sensitivity datasets demonstrates the internal consistency of the field investigation data obtained at PT 21044. The comparable stratigraphic profile observed across the site further supports the suitability of the dataset for evaluating the robustness of the proposed empirical prediction model before external validation was undertaken using the independent datasets from Lot 120185 and Lot 120188.

Table 4.2
Summary of SPT *N*-Value for the Internal Sensitivity Subset (PT 21044)

| Location | Depth (m) | BH 20 | BH 21 | BH 22 | BH 23 | BH 24 | BH 25 |
|---|---|---|---|---|---|---|---|
| | 0.0 | TS | TS | TS | TS | TS | TS |
| | 1.5 | 11 | 2 | 7 | 2 | 8 | 12 |
| | 3.0 | 9 | 5 | 3 | 3 | 9 | 13 |
| | 4.5 | 7 | 2 | 2 | 4 | 3 | 2 |
| | 6.0 | 2 | - | - | - | - | - |
| | 7.5 | - | 4 | 5 | 4 | 4 | 4 |
| | 9.0 | 3 | - | - | - | - | - |
| | 10.5 | - | 9 | 6 | 6 | 5 | 6 |
| | 12.0 | 12 | 14 | 12 | 14 | 6 | 25 |
| | 13.5 | 14 | 16 | 16 | 16 | 11 | 26 |
| | 15.0 | 10 | 18 | 19 | 20 | 14 | 20 |
| | 16.5 | 15 | 18 | 20 | 17 | 21 | 25 |
| | 18.0 | 20 | 22 | 25 | 21 | 25 | 28 |
| | 19.5 | 26 | 33 | 27 | 24 | 31 | 34 |
| | 21.0 | 29 | 37 | 30 | 27 | 28 | 37 |
| | 22.5 | 39 | 50 | 34 | 29 | 30 | 39 |
| | 24.0 | 33 | 50 | 50 | 50 | 50 | 50 |
| | 25.5 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 27.0 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 28.5 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 30.0 | 50 | 50 | 50 | 50 | 50 | 50 |
| | 31.5 | 50 | | | | | |

Representative Borehole Logs records are provided in APPENDIX 16 for BH2

Table 4.3 and Table 4.4 summarise the SPT *N*-values obtained from the external validation sites, namely Lot 120185 and Lot 120188, located within the Selangor Cyber Valley area. These datasets were used to evaluate the applicability of the proposed empirical prediction model under independent field conditions. Detailed SPT *N*-value records for Lot 120185 and Lot 120188 are presented in APPENDICES 7 and 8, whereas the corresponding borehole logs and representative laboratory test summaries are provided in APPENDICES 17–20. Each validation site comprises four boreholes, and the notation "TS" denotes Top Soil, where the Standard Penetration Test was not performed because of the presence of loose organic surface materials.

The SPT *N*-values obtained from both validation sites exhibit trends comparable to those observed at PT 21044. Within the upper 0–6 m, the *N*-values are generally below 10, representing soft and highly compressible organic soils. Between approximately 10 m and 20 m depth, the *N*-values increase to between 15 and 30, indicating medium-stiff Silty Clay deposits. At depths exceeding 20 m, the *N*-values generally range between 40 and 50, representing dense Silty Sand and over-consolidated Clay layers.

The comparable depth-dependent increase in penetration resistance observed across the three investigation sites indicates consistent subsurface stratification within the Selangor Cyber Valley area. These findings demonstrate that the validation sites possess geological and geotechnical characteristics similar to those of PT 21044, thereby providing independent datasets for evaluating the performance of the proposed empirical prediction model. The agreement between the primary and validation datasets further supports the regional applicability of the developed model within the Quaternary alluvial deposits of the Langat River Basin.

Table 4.3
Summary of SPT *N*-Value for Lot 120185 (Validation Data)

| Location | Depth (m) | BH 1 | BH 2 | BH 3 | BH 4 |
|---|---|---|---|---|---|
| Lot 120185 | 0.0 | TS | TS | TS | TS |
| | 1.5 | 11 | 14 | 40 | 50 |
| | 3.0 | 4 | 17 | 37 | 12 |
| | 4.5 | - | 19 | 41 | 13 |
| | 6.0 | - | 5 | - | 3 |
| | 7.5 | 15 | 7 | 37 | 3 |
| | 9.0 | 1 | 3 | 17 | 1 |
| | 10.5 | 2 | 2 | 1 | 2 |
| | 12.0 | 2 | 3 | 20 | 3 |
| | 13.5 | 2 | 8 | 18 | 10 |
| | 15.0 | 29 | 2 | 19 | 9 |
| | 16.5 | 50 | 2 | 22 | 11 |
| | 18.0 | 34 | 26 | 11 | 17 |
| | 19.5 | 30 | 27 | 15 | 17 |
| | 21.0 | 28 | 31 | 10 | - |
| | 22.5 | 30 | 27 | 11 | - |
| | 24.0 | 50 | 13 | 50 | - |
| | 25.5 | 50 | 17 | - | - |
| | 27.0 | 50 | 50 | - | - |

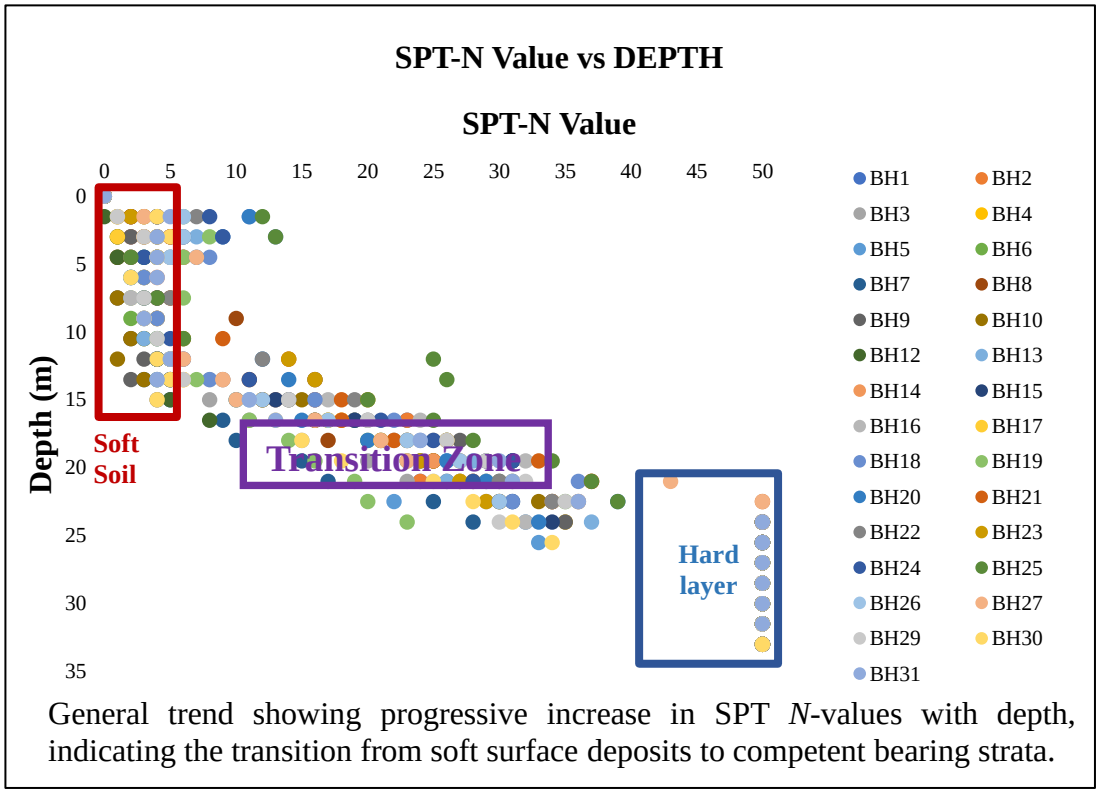
Representative Borehole Logs records are provided in APPENDIX 17 for BH4

Table 4.4
Summary of SPT *N*-Value Lot 120188 (Validation Data)

| | Depth (m) | BH 1 | BH 2 | BH 3 | BH 4 |
|---|---|---|---|---|---|
| **Lot 120188** | 1.5 | 11 | 11 | 12 | 10 |
| | 3.0 | 10 | 3 | 14 | 5 |
| | 4.5 | 7 | 10 | 6 | 7 |
| | 6.0 | 9 | 3 | 9 | 2 |
| | 7.5 | 14 | 4 | 10 | 5 |
| | 9.0 | 4 | 15 | 6 | 5 |
| | 10.5 | 4 | 11 | 6 | 14 |
| | 12.0 | 11 | 11 | 17 | 16 |
| | 13.5 | 12 | 12 | 18 | 12 |
| | 15.0 | 11 | 9 | 14 | 24 |
| | 16.5 | 11 | 8 | 11 | 21 |
| | 18.0 | 9 | 26 | 9 | 19 |
| | 19.5 | 11 | 32 | 11 | 43 |
| | 21.0 | 13 | 50 | 15 | 50 |
| | 22.5 | 18 | 50 | 18 | 50 |
| | 24.0 | 20 | 50 | 19 | 50 |
| | 25.5 | 29 | 50 | 27 | 50 |
| | 27.0 | 50 | 50 | 50 | 50 |
| | 28.5 | 50 | - | 50 | - |
| | 30.0 | 50 | - | 50 | - |
| | 31.5 | 50 | - | 50 | - |
| | 33.0 | 50 | - | 50 | - |

Representative Borehole Logs records are provided in APPENDIX 18 for BH2

Figure 4.3 illustrates the variation of SPT *N*-values with depth for all 31 boreholes at site PT 21044. A clear and consistent trend is observed, where SPT *N*-values increase with depth, reflecting the typical behaviour of soft Quaternary alluvial deposits commonly encountered in the Selangor Cyber Valley area (JMG, 2014). According to (BS 1377, 1990), increasing blow counts generally indicate an improvement in soil density and stiffness. In the upper zone, roughly from the ground surface to about 8-10 m depth, the SPT *N*-values fall between $N = 0$ to 5, which is highlighted in the graph as the soft soil zone. Such low blow counts indicate loose, weakly structured or highly weathered materials, which are characteristic of surficial deposits in humid tropical regions. This pattern is consistent with the typical lithological profile of tropical residual soils, where the upper layers are generally softer and more weathered than the deeper and denser materials (Das & Sobhan, 2017).




General trend showing progressive increase in SPT *N*-values with depth, indicating the transition from soft surface deposits to competent bearing strata.

Figure 4.3 SPT *N*-Value vs Depth (m)

Between approximately 10 m and 20 m depth, the SPT *N*-values gradually increase from about 10 to 35, forming a distinct transition zone between the soft surface deposits and the competent bearing layer. This transition zone reflects a gradual increase in soil density and stiffness as the subsurface materials change from soft Clay to medium-stiff Silty Clay and Sandy Silt deposits. The progressive increase in penetration resistance indicates increasing consolidation under overburden pressure together with a reduction in soil compressibility.

At depths exceedingly approximately 23 m, several boreholes record SPT *N*-values approaching or reaching $N = 50$, representing the competent bearing layer identified in Figure 4.3. These high blow counts indicate the presence of very stiff to dense materials, typically comprising dense Sand or weathered Sandy Clay, consistent with the upper limit of penetration resistance specified in BS 1377: Part 9 (1990).

Overall, the SPT profile demonstrates three distinct subsurface zones comprising a soft soil zone near the ground surface, a transition zone at intermediate depths and a competent bearing layer below approximately 23 m. This progressive increase in penetration resistance reflects the improvement in soil density and stiffness with depth and is consistent with the Quaternary alluvial deposits encountered throughout the Selangor Cyber Valley area.

The sub-surface soil profile for the proposed development area was interpreted using information collected from the boreholes and field observations during the soil investigation works as shows in Figure 4.4, Figure 4.5,

Figure 4.6, Figure 4.7, Figure 4.8 and Figure 4.9. These findings were reviewed together with available geotechnical data to ensure that the results are reliable, as they form the basis of the design considerations for the project.

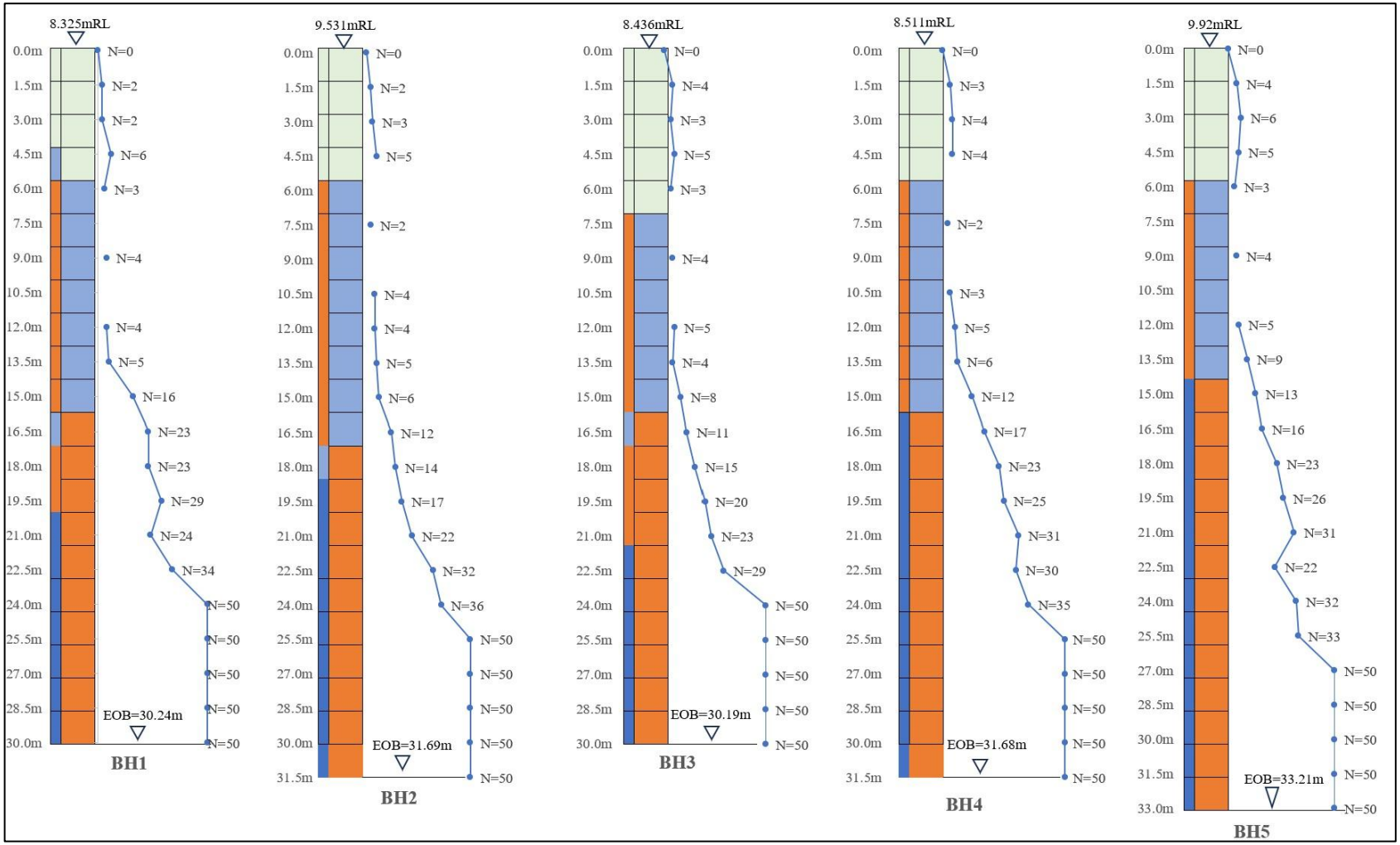



Figure 4.4 Soil Profile Based on BH1 – BH5 Result

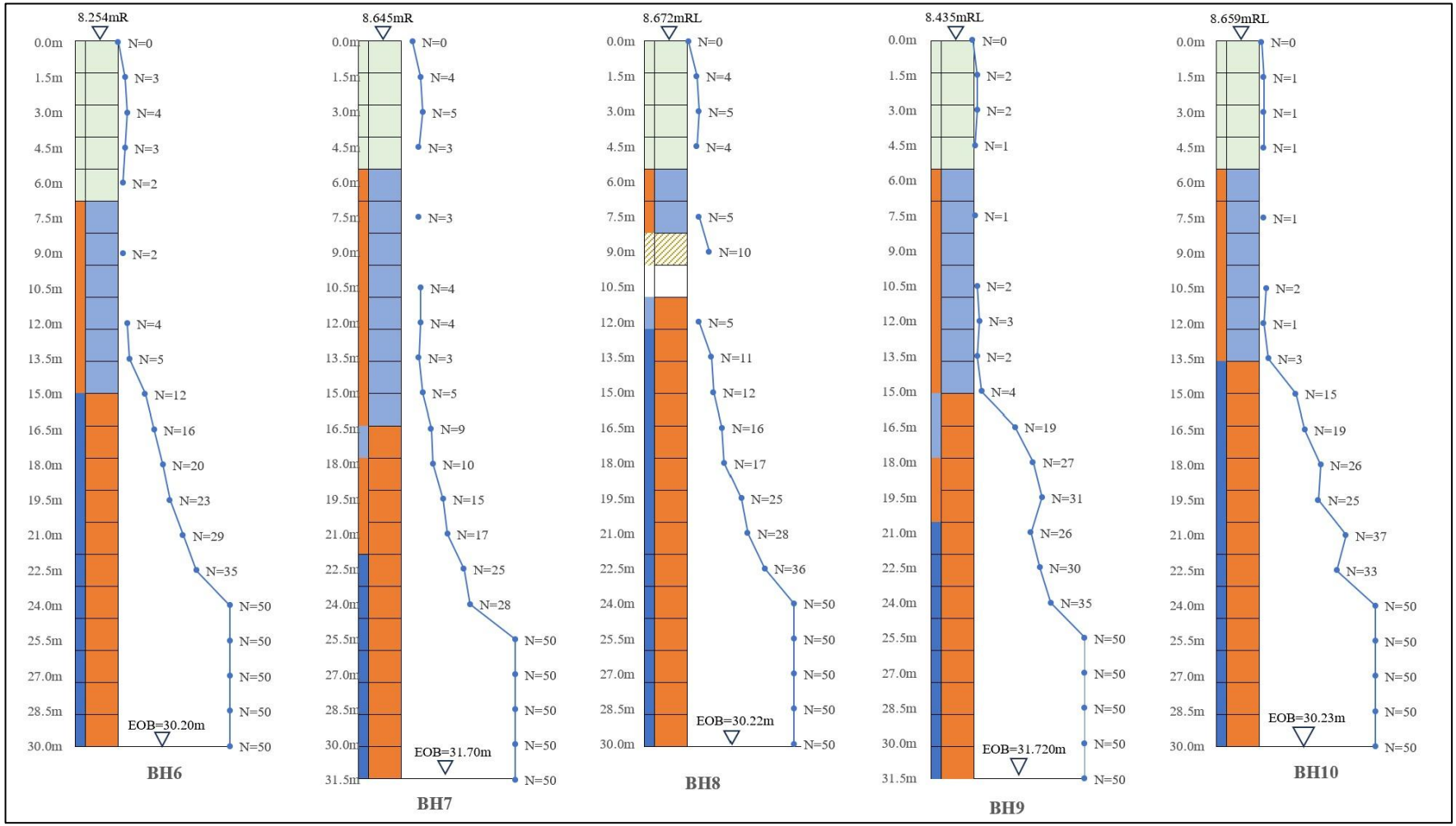



Figure 4.5 Soil Profile Based on BH6 – BH10 Result

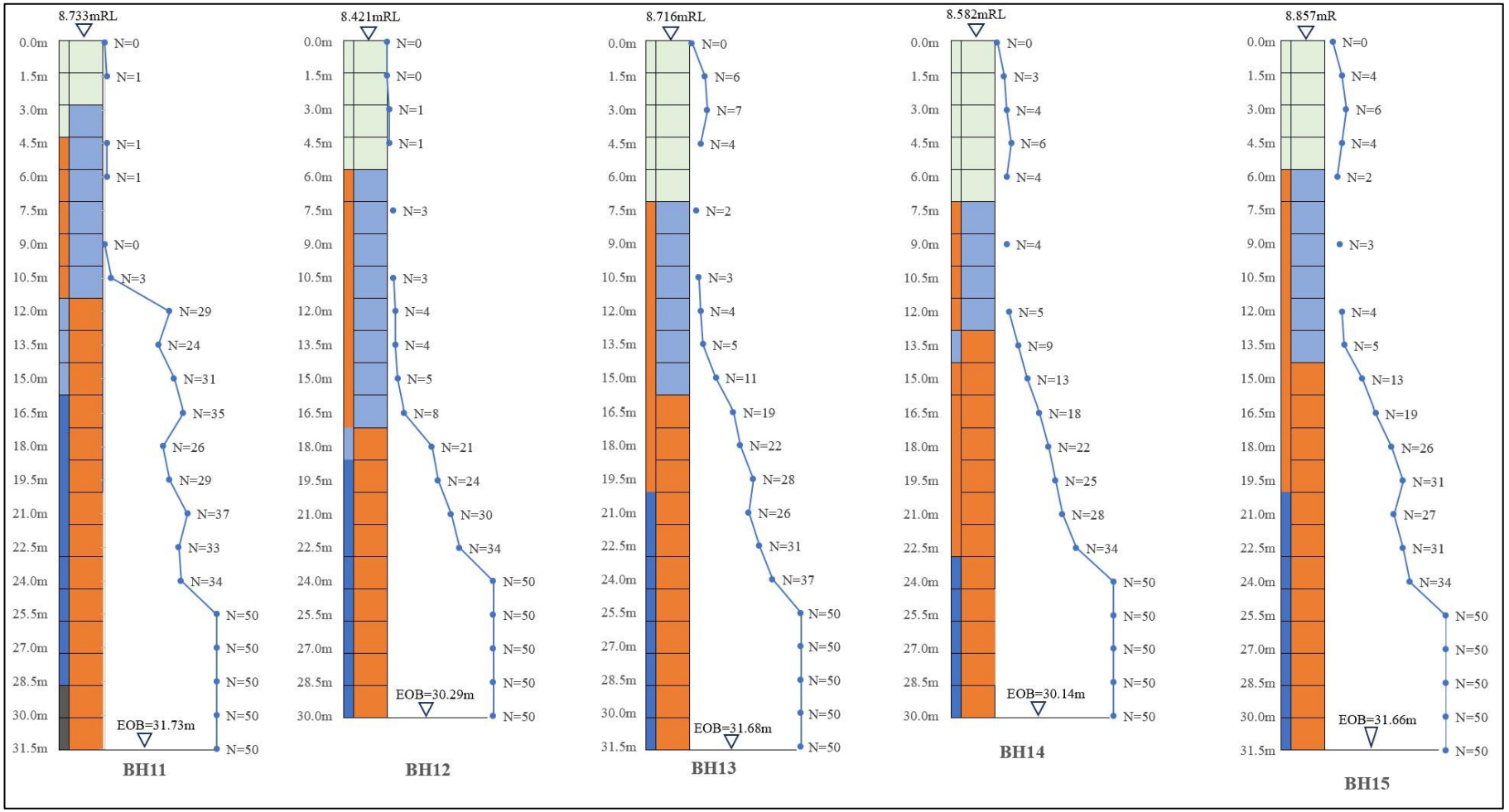



Figure 4.6 Soil Profile Based on BH11 – BH15 Result

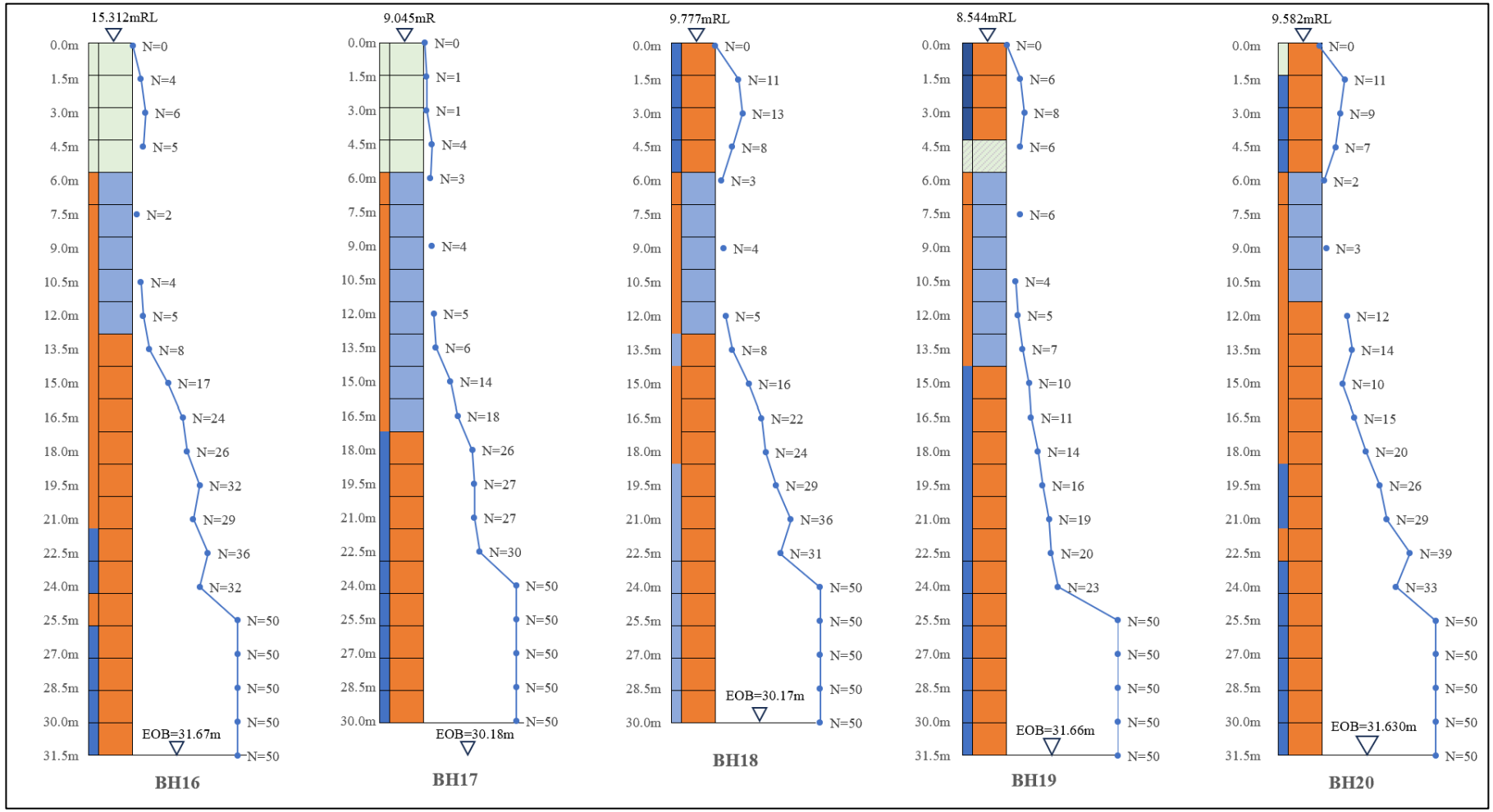



Figure 4.7 Soil Profile Based on BH16 – BH20 Result

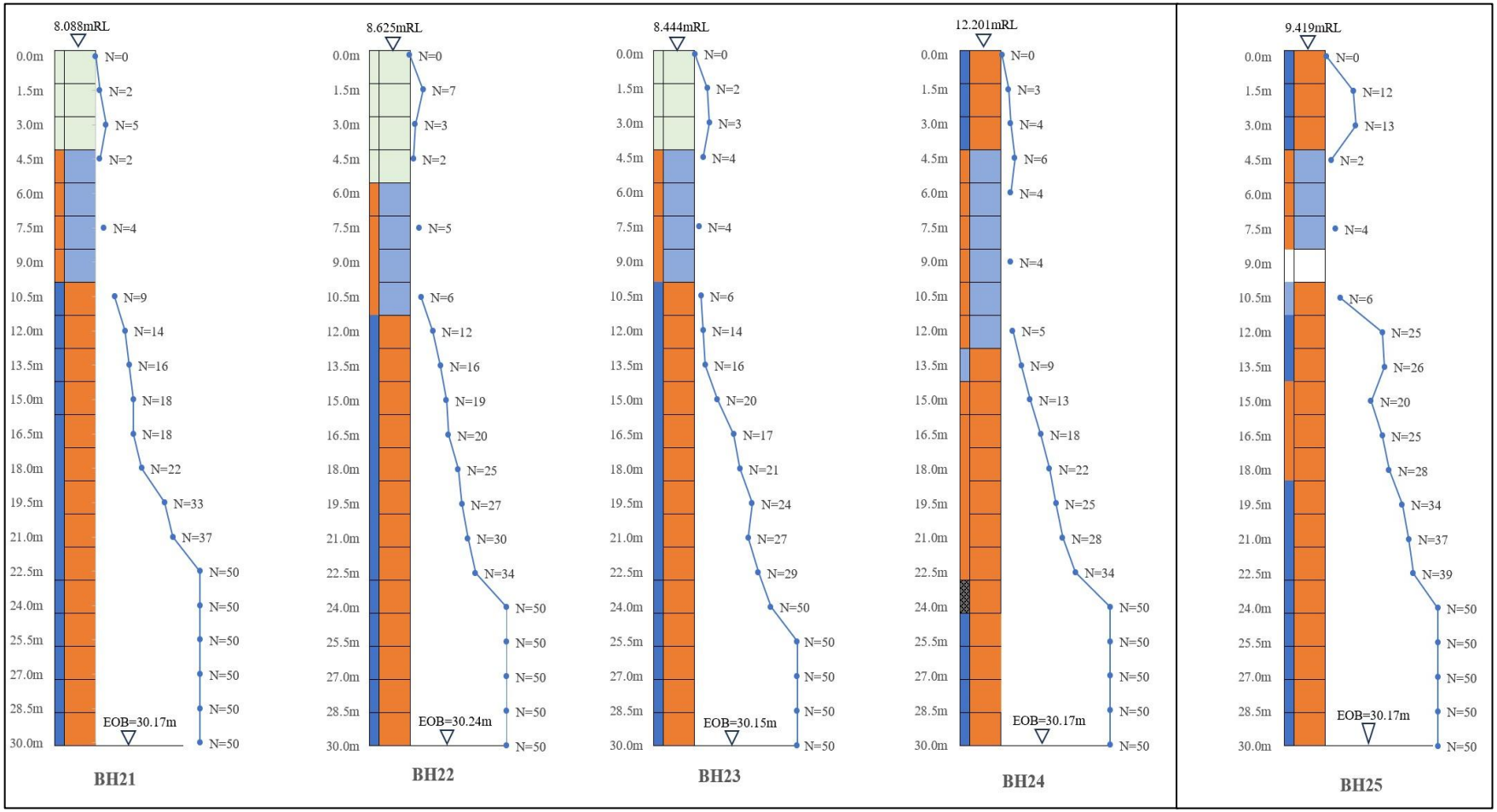



Figure 4.8 Soil Profile Based on BH21 – BH25 Result

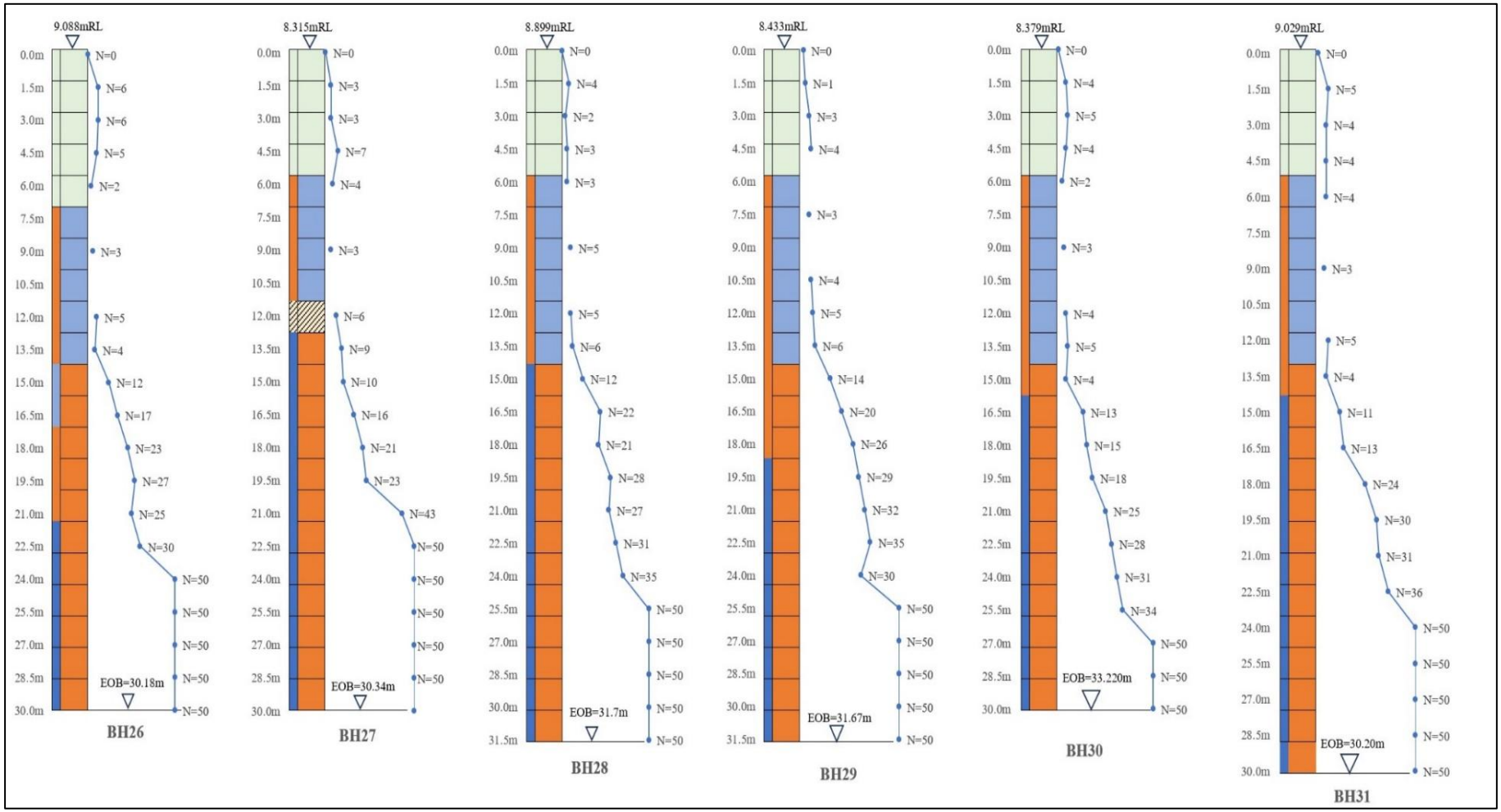



Figure 4.9 Soil Profile Based on BH26 – BH31 Result

A summary of the overall subsurface conditions at PT 21044 is presented in Table 4.5. The interpretation was established by integrating the SPT *N*-values, representative borehole logs and laboratory soil classification results. The SPT *N*-values were used to assess the relative consistency and density of the subsurface materials, whereas the soil types were identified from the borehole logs and the corresponding laboratory test results (APPENDICES 12 and 14–20).

Across the site, the subsurface profile is generally characterised by soft alluvial deposits beginning with a surface layer of Peat. The Peat layer is typically encountered between approximately 3.0 m and 7.5 m below ground level, with its thickness gradually decreasing towards the eastern part of the site where the ground elevation increases slightly. Beneath the Peat layer, soft Clay deposits (generally associated with SPT *N*-values below 4) extend to depths ranging from approximately 9.0 m to 16.5 m depending on location.

Below the soft Clay deposits, the penetration resistance increases progressively, indicating a transition to medium-dense Silty Sand and subsequently to a competent bearing stratum at depths exceedingly approximately 22.5 m. No bedrock was encountered within the investigation depth. The boreholes were terminated in accordance with the project specification after continuous penetration into materials exhibiting SPT *N*-values greater than 50 or after continuous coring into rock, whichever criterion was achieved first.

Table 4.5
Summary of Soil Stratification and SPT Interpretation at PT 21044, Cyberjaya

| Depth (m) | SPT N-Value | Soil Type | Consistency / Density | Remarks |
|---|---|---|---|---|
| 3.0 -7.5 | 0 - 2 | Peat | Very Soft | Organic surface deposit |
| 3.0 -16.5 | < 4 | Clay | Soft | Dominant soft soil zone |
| 15.0 -16.5 | > 10 | Silty Sand | Medium Dense | Transition layer |
| 22.5–25.5 | >50 | Dense Sand / Weathered Sandy Clay | Very Dense / Competent Bearing Stratum | Termination layer |

Note: The soil types were interpreted from the representative borehole logs and laboratory soil classification results (APPENDICES 12 and 14–20). The corresponding SPT *N*-values were used to indicate the relative soil consistency and density in accordance with BS 1377: Part 9 (1990).

Figure 4.10 illustrates the average variation of SPT *N*-values with increasing depth for boreholes BH1 to BH31 at PT 21044, Cyberjaya. A clear increasing trend in SPT *N*-values is observed with depth, indicating a progressive improvement in soil density and stiffness resulting from increasing overburden pressure and natural consolidation (Das & Sobhan, 2017). Based on the average SPT profile, three characteristic subsurface zones can be identified, namely the Soft Soil Zone, the Transition Zone and the Competent Bearing Layer. These zones were interpreted by integrating the SPT *N*-values with the representative borehole logs and laboratory soil classification results rather than using the SPT *N*-values alone.

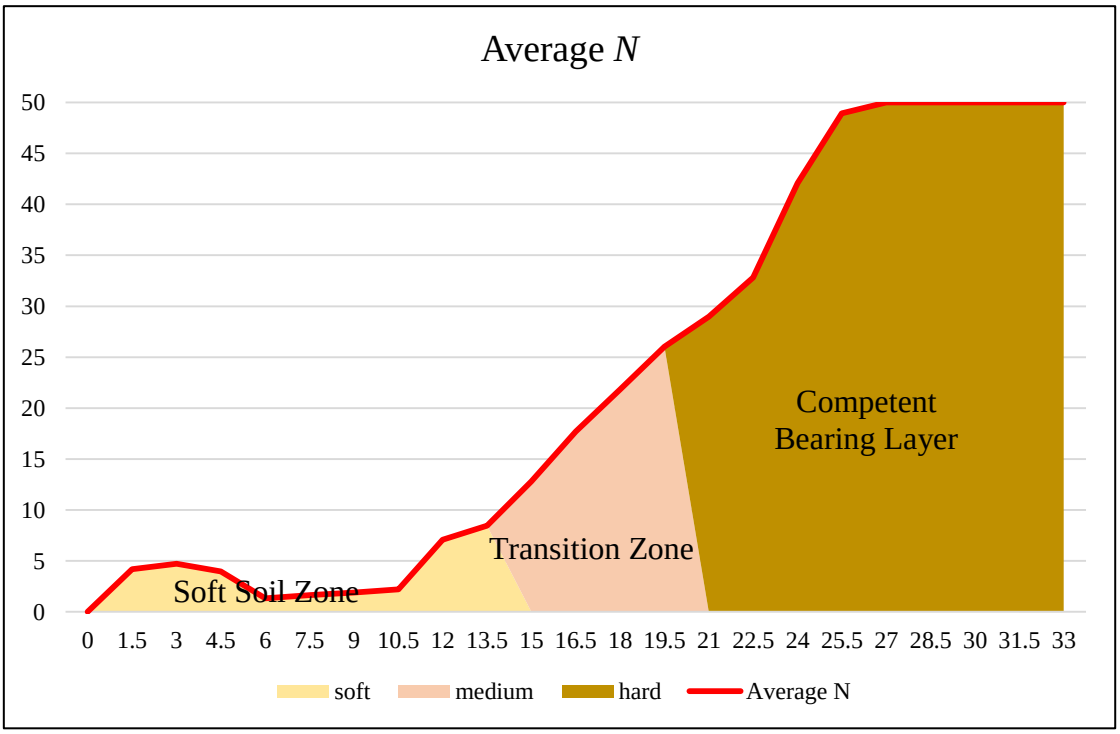



Figure 4.10 Depth Variation of SPT *N*-Values Showing Typical Increase in Resistance With Depth Due To Higher Confinement and Natural Consolidation.

In the upper 0–13.5 m, the average SPT *N*-values generally remain below 10, indicating the Soft Soil Zone. This zone corresponds predominantly to Peat and soft Clay identified from the borehole logs and laboratory soil classification results. The soils within this interval exhibit low bearing capacity, high Moisture Content and high compressibility, which are characteristic of Quaternary alluvial deposits commonly encountered within the Selangor Cyber Valley area (JMG, 2014). These soft deposits

are generally associated with low shear strength and significant settlement potential, making them critical considerations in foundation design (Asad et al., 2013).

Between approximately 13.5 m and 19.5 m, the average SPT *N*-values increase gradually from about 8 to 26, representing the Transition Zone between the soft surface deposits and the competent bearing layer. The progressive increase in penetration resistance reflects a gradual improvement in soil density and stiffness with depth as the subsurface materials transition from soft Clay to Silty Clay and Sandy Silt deposits. This behaviour is consistent with increasing overburden pressure and natural consolidation within the Quaternary alluvial sequence (Das & Sobhan, 2017).

Beyond approximately 20 m, the average SPT *N*-values exceed 30, with several boreholes approaching or reaching $N = 50$, indicating the Competent Bearing Layer. Interpretation of the representative borehole logs indicates that this zone consists predominantly of dense Sand and weathered Sandy Clay exhibiting substantially higher stiffness and penetration resistance than the overlying deposits. The high SPT N-values are consistent with the upper penetration limit specified in BS 1377: Part 9 (1990) and indicate materials capable of providing improved foundation support due to their greater density and lower compressibility (Bowles, 1997).

The interpreted Soft Soil Zone, Transition Zone and Competent Bearing Layer illustrated in Figure 4.10 were established by integrating the SPT *N*-values with the representative borehole logs and laboratory soil classification results. These interpreted zones provide a comprehensive representation of the subsurface stratification and assist in identifying changes in soil behaviour with depth across the study area.

Overall, the average SPT profile demonstrates a progressive increase in penetration resistance with depth, reflecting the gradual improvement in soil density and stiffness from the soft surface deposits to the competent bearing layer. When interpreted together with the representative borehole logs and laboratory soil classification results, the SPT *N*-values provide a reliable basis for characterising the subsurface profile and supporting preliminary foundation assessment within the PT 21044 study area.

### 4.2.2 Spatial Distribution of *N*-Values in Boreholes

Figure 4.11 demonstrates the spatial distribution of SPT N-values among the boreholes BH1 to BH31 in the study area. The contour plot demonstrates distinct horizontal and vertical variations in N-values, indicating alterations in soil stiffness and stratigraphy at various locations. Softer soils (N < 10) are primarily located at shallow depths and are concentrated in specific areas of the site especially in the northwestern and southwestern areas. This is consistent with previous research conducted in soft alluvial and organic-rich deposits in Cyberjaya and the Langat River Basin, where Silty Clay and Peat layers are frequently found at shallow depths (Baharuddin et al., 2020).

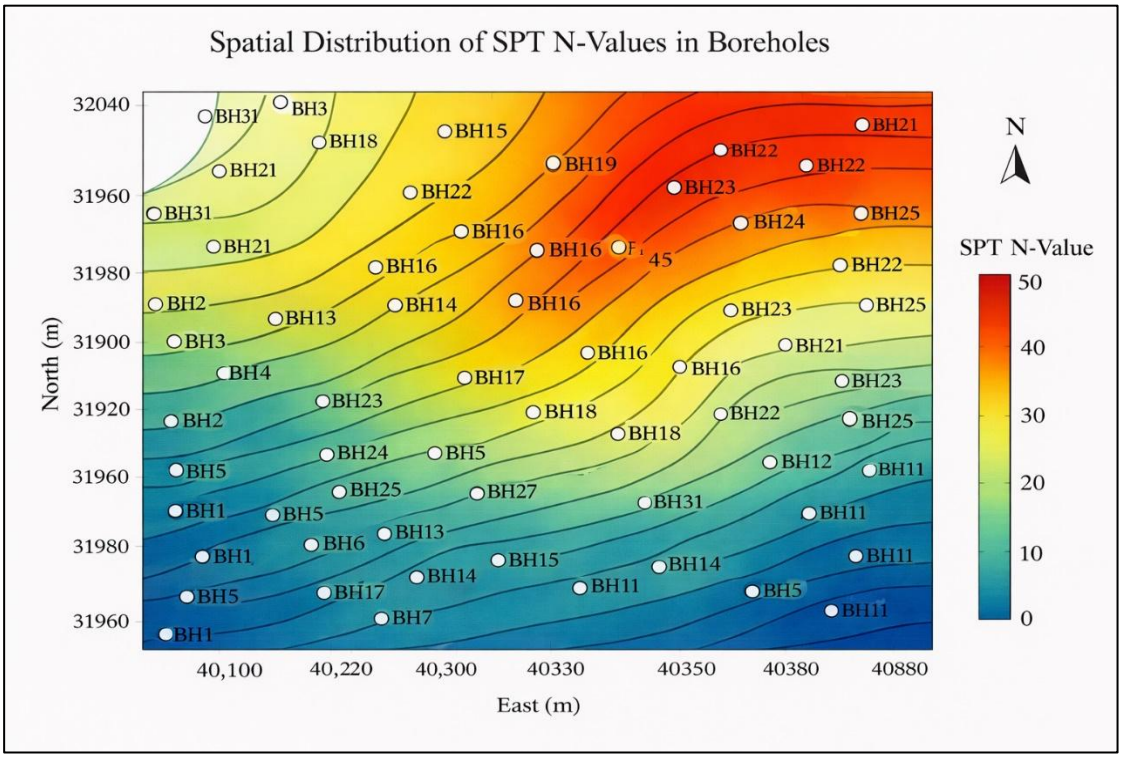



Figure 4.11 Spatial Distribution of SPT *N*-Values Across The Boreholes BH1-BH31

With increasing depth, there is a significant increase in SPT N-values, especially beyond 15 m, where moderate to dense soil layers prevail. The highest *N*-values ($N$ > 30), which indicate dense to very dense strata, are observed from approximately 20 m depth onwards in the central and southeastern zones of the site. The elevated *N*-values align with the hard layer discussed in previous sections (refer to Section 4.2.2) and are consistent with the typical depth-dependent behaviour of

increasing confinement pressure and natural consolidation observed in geotechnical studies (Kulhawy & Mayne, 1990).

The spatial variability of *N*-values offers critical observations into subsurface conditions. Regions exhibiting persistently low *N*-values may require specialized foundation treatments or preloading, whereas areas with elevated *N*-values indicate competent strata appropriate for deep foundation support. The observed variability underscores the necessity of performing borehole investigations throughout the site, rather than depending on isolated point assessments. Previous empirical correlations between *N*-values and soil properties, including Moisture Content, Atterberg Limits and Bulk Density (see Section 2.4.3), reinforce the reliability of *N*-values as indicators of subsurface strength when analysed in a spatial context (Nasiri Pishvari et al., 2024). Thus, spatial distribution mapping serves a dual purpose: it aids in the classification of soil behaviour throughout the site and enhances the optimization of foundation design strategies, thereby ensuring safety and cost-effectiveness.

### 4.2.3 Identification of Competent Bearing Layer Based on SPT N50 Termination Depth

The termination depth corresponding to an SPT N-value of 50 for each borehole across the study area is presented in

Figure 4.12. The figure illustrates the depth at which the Standard Penetration Test reaches the refusal condition of N = 50 blows, together with the final borehole depth for each location. In general, the termination of N50 occurs within a relatively consistent depth range across most boreholes, typically between approximately 24 m and 27 m below the ground surface. This pattern indicates the presence of dense to very dense soil layers or very stiff strata at these depths, which represent the transition from the upper soft soil deposits to more competent subsurface materials.

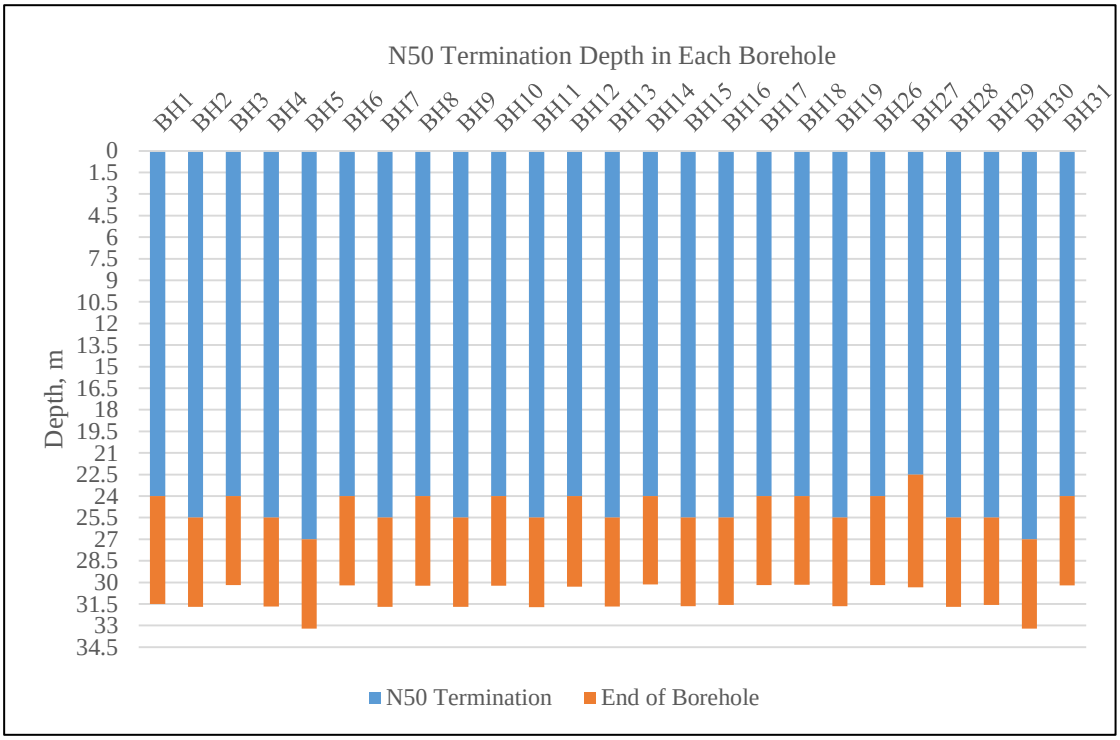



Figure 4.12 Depth of SPT *N*50 termination and Final Borehole Depth for Boreholes BH1–BH19 and BH26-BH31 in the study area

In the upper soil layers, generally within the depth range of approximately 0 m to about 10 m, the subsurface profile is characterized by soft and highly compressible soils with low SPT *N*-values, typically associated with alluvial Clay, Silt, Peat, and other fine-grained deposits commonly found in low-lying tropical environments such as the Langat River Basin. These soft deposits exhibit low penetration resistance due to their high Moisture Content, loose structure, and weak interparticle bonding. As depth increases, the gradual increase in overburden pressure and natural consolidation processes lead to progressive densification of the soil layers, which is reflected by increasing SPT *N*-values.

At greater depths, particularly beyond approximately 20 m, the soil strata exhibit significantly higher penetration resistance, eventually reaching the $N = 50$ termination condition. The occurrence of *N*50 termination at these depths suggests the presence of dense Sand layers, stiff Clay, cemented deposits or weathered geological formations that provide substantially higher resistance to penetration. Such layers are commonly interpreted as competent bearing strata in geotechnical investigations and are often considered suitable termination levels for deep foundation systems such as

driven piles or bored piles. The relatively consistent depth range of *N*50 termination observed across the majority of boreholes suggests a broadly similar subsurface stratigraphic transition throughout the study area.

Despite the overall consistency, slight variations in the termination depth are observed among different boreholes, with some locations reaching *N*50 at slightly shallower or deeper depths. These variations reflect the inherent spatial variability of subsurface conditions in soft soil environments, particularly in areas influenced by fluvial and alluvial depositional processes. Differences in sedimentation patterns, soil composition, and localized consolidation conditions can contribute to variations in soil density and stiffness at depth.

The identification of *N*50 termination depths is particularly important in geotechnical engineering practice, as it provides a practical indicator of the depth at which sufficiently dense or competent soil layers occur. These layers are commonly used as reference horizons for foundation design, especially for pile foundations where the pile toe is often extended to penetrate into or terminate within dense strata to achieve adequate load-bearing capacity. Consequently, the analysis of *N*50 termination depth provides valuable insight into the subsurface stratigraphy and supports the interpretation of soil strength progression with depth.

Overall, the results confirm that the subsurface profile within the study area consists of a thick sequence of soft and compressible soils overlying denser and more competent layers at greater depths. The relatively consistent occurrence of *N*50 termination within the depth range of approximately 24 m to 27 m indicates the presence of a regional bearing layer across the site, which has important implications for foundation design and geotechnical assessment in the Selangor Cyber Valley area.

### 4.2.4 Identification of Competent Bearing Layer

The competent bearing layer was identified based on the SPT *N*-values obtained from all boreholes at PT 21044. According to BS 1377: Part 9 (1990), increasing SPT *N*-values indicate increasing soil density and stiffness, while values approaching $N = 50$ generally represent very dense or hard strata suitable for supporting structural loads. The depth at which *N*-values reached 50 was therefore used to identify the competent bearing layer within the study area.

Table 4.6 summarises the interpretation of the SPT *N*-values observed throughout PT 21044. The upper 6 m consists predominantly of very soft soils with low penetration resistance ($N \leq 4$). Between approximately 6 m and 15 m depth, the SPT *N*-values gradually increase, indicating a transition into soft to medium stiff soils. A further increase in penetration resistance is observed between 15 m and 22.5 m, where medium stiff to stiff soils become dominant. At depths of approximately 24 m and below, most boreholes recorded SPT *N*-values of 50, indicating the presence of a competent bearing layer characterised by very dense subsurface materials.

Table 4.6
Summary of Competent Bearing Layer Based on SPT *N*-Values at PT 21044

| **SPT *N*-Value Range** | **Approximate Depth (m)** | **Interpretation** | **Engineering Significance** |
|---|---|---|---|
| 0 – 4 | 0.0 – 6.0 | Very soft soil | Very low bearing capacity and high compressibility. |
| 5 – 15 | 6.0 – 15.0 | Soft to medium stiff soil | Transitional zone with increasing soil stiffness. |
| 16 – 30 | 15.0 – 22.5 | Medium stiff to stiff soil | Improved bearing capacity due to increasing consolidation. |
| 31 – 49 | 22.5 – 24.0 | Very stiff to dense soil | High penetration resistance indicating competent subsurface material. |
| 50 (Refusal) | 24.0 m onwards (approximately) | Competent bearing layer | Indicates a very dense stratum suitable for foundation support. |

The occurrence of the competent bearing layer at depths greater than approximately 24 m is consistent across most boreholes, indicating relatively uniform subsurface conditions within the study area. Although fresh bedrock was not encountered during the site investigation, the very high penetration resistance (SPT *N*=50) indicates the presence of a dense stratum capable of providing adequate bearing support for foundation design. This competent layer forms the lower boundary of the soft alluvial deposits and represents the preferred founding level for deep foundation systems where end-bearing resistance is required.

### 4.2.5 Interpretation of Geological Strata Using Borehole Logs

Figure 4.13 presents the subsurface soil stratigraphy interpreted from the complete borehole logs obtained during the site investigation at PT 21044. The interpretation was developed by integrating the lithological descriptions recorded in the borehole logs with the corresponding SPT *N*-values at each sampling depth. The complete borehole logs used for this interpretation are provided in APPENDIX 14. The figure illustrates the vertical distribution of Peat, Clay, Silt and Sand layers across boreholes BH1–BH19 and BH26–BH31 together with the corresponding variation in penetration resistance.

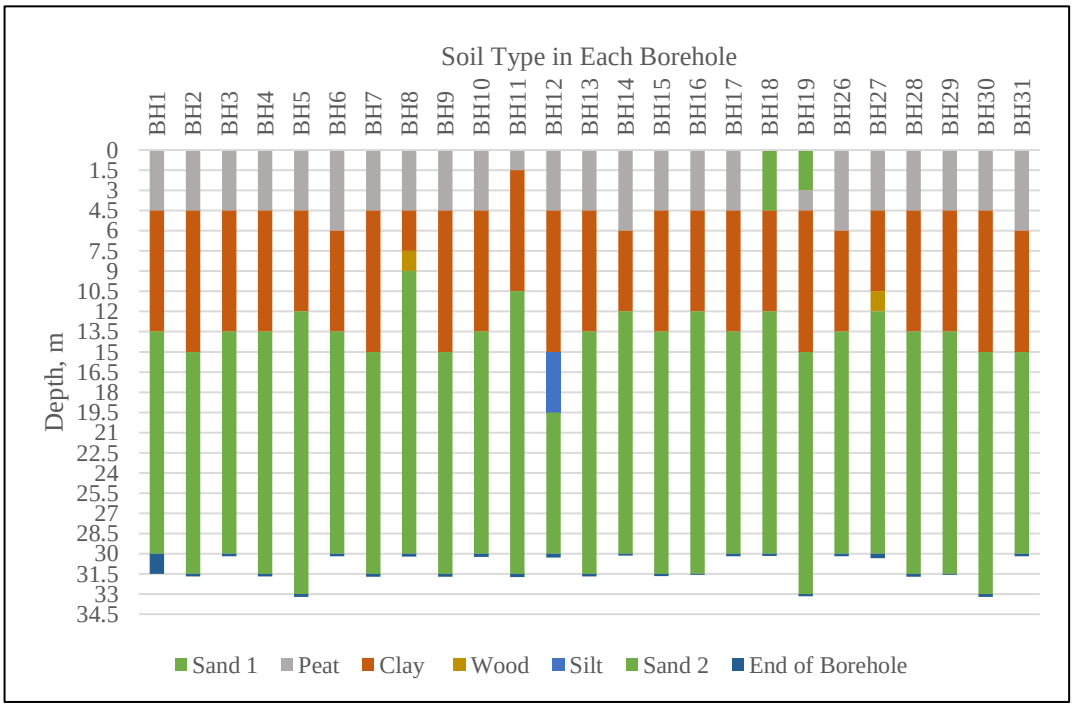



Figure 4.13 Subsurface Soil Stratigraphy Interpreted from Borehole Logs at PT 21044, Cyberjaya

The interpreted borehole logs indicate that the upper soil profile, generally within the depth range of approximately 0–10 m, is dominated by Peat and soft Clay deposits. These materials are characterised by high Moisture Content and low shear strength, which correspond to relatively low SPT *N*-values ranging from approximately 2 to 5. Such behaviour is typical of soft cohesive soils commonly associated with

alluvial and organic deposits in tropical environments. Similar observations were reported by (Baharuddin et al., 2020), who noted that soft fine-grained soils in the Cyberjaya region commonly exhibit low penetration resistance values.

With increasing depth, the borehole logs indicate a gradual transition from Peat and Clay to Silty and Sandy materials. This transition becomes more evident between approximately 12 m and 24 m, where the proportion of Silt and Sand increases significantly. Correspondingly, the recorded SPT *N*-values increase, frequently exceeding 25, indicating the presence of medium dense to dense soils that have undergone natural consolidation under increasing overburden stress. According to (Kulhawy and Mayne, 1990), increasing penetration resistance with depth generally reflects the progressive improvement in soil stiffness and strength resulting from increased effective stress.

In several boreholes, the lower sections of the borehole logs are dominated by Sand and Silty Sand layers. These layers correspond to SPT *N*-values approaching 50 blows per 300 mm penetration, indicating very dense materials. These dense layers typically mark the termination of the soft soil sequence and represent competent bearing strata that may support foundation loads. The observed depth-dependent variation in soil type and penetration resistance highlights the importance of integrating borehole stratigraphy with SPT *N*-value profiles in order to achieve reliable subsurface characterization and soil strength assessment. As emphasized by (Phoon & Kulhawy, 1999), combining geological interpretation with in-situ testing results improves the reliability of geotechnical site investigations and reduces uncertainties in subsurface evaluation.

### 4.2.6 Correlation Between *N*-Value and Groundwater Conditions

As discussed in Section 4.1.4, the Ground Water Table (GWT) across the study area was predominantly shallow with most boreholes recording water levels between 0.0 m and 1.0 m below ground level (b.g.l.), as shown in Figure 4.1. This high groundwater level is consistent with the presence of soft, saturated soils such as Peat and Clay which are prevalent in the area. The presence of a shallow water table plays a critical role in reducing effective stress in the upper soil layers, thereby contributing to low SPT *N*-values in these zones (Baharuddin et al., 2020).

This trend is particularly evident in boreholes such as BH1, BH2, BH3, BH5, BH7, BH9, BH10, BH14, BH16, BH21, BH22, BH23 and BH30, where soft soil layers with high Moisture Content are observed in conjunction with low penetration resistance. The correlation between shallow GWT and low *N*-values has also been highlighted by (Das & Sobhan, 2017), who emphasised the role of groundwater in decreasing soil shear strength and increasing compressibility. Therefore, the groundwater condition must be considered during preliminary design and soil classification as it significantly influences the *N*-value profiles and the bearing capacity of the underlying soils.

### 4.2.7 Identification of Geological Strata Using SPT *N*-Value Profiles

Table 4.7 presents the variation of SPT *N*-values with depth for boreholes BH1–BH19 and BH25-BH31 at the PT21044 study area. For ease of interpretation, the *N*-values are presented using colour shading to illustrate the progressive increase in penetration resistance with depth across the boreholes. The *N*-value profiles provide a useful indication of the subsurface stratification and the variation of soil stiffness with depth.

Table 4.7
Variation of SPT *N*-Values with Depth for Boreholes BH1–BH19 and BH25-BH31 at The PT21044 Study Area

| Depth | BH 1 | BH 2 | BH 3 | BH 4 | BH 5 | BH 6 | BH 7 | BH 8 | BH 9 | BH 10 | BH 11 | BH 12 | BH 13 | BH 14 | BH 15 | BH 16 | BH 17 | BH 18 | BH 19 | BH 26 | BH 27 | BH 28 | BH 29 | BH 30 | BH 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1.5** | 2 | 2 | 4 | 3 | 4 | 3 | 4 | 4 | 2 | 1 | 1 | 0 | 6 | 3 | 4 | 4 | 1 | 11 | 6 | 6 | 3 | 4 | 1 | 4 | 5 |
| **3.0** | 2 | 3 | 3 | 4 | 6 | 4 | 5 | 5 | 2 | 1 | - | 1 | 7 | 4 | 6 | 6 | 1 | 13 | 8 | 6 | 3 | 2 | 3 | 5 | 4 |
| **4.5** | 6 | 5 | 5 | 4 | 5 | 3 | 3 | 4 | 1 | 1 | 1 | 1 | 4 | 6 | 4 | 5 | 4 | 8 | 6 | 5 | 7 | 3 | 4 | 4 | 4 |
| **6.0** | 3 |  | 3 |  | 3 | 2 |  |  |  |  | 1 |  |  | 4 | 2 |  | 3 | 3 |  | 2 | 4 | 3 |  | 2 | 4 |
| **7.5** |  | 2 |  | 2 |  |  | 3 | 5 | 1 | 1 |  | 3 | 2 |  |  | 2 |  |  | 6 |  |  |  | 3 |  |  |
| **9.0** | 4 |  | 4 |  | 4 | 2 |  | 10 |  |  | 0 |  |  | 4 | 3 |  | 4 | 4 |  | 3 | 3 | 5 |  | 3 | 3 |
| **10.5** |  | 4 |  | 3 |  |  | 4 |  | 2 | 2 | 3 | 3 | 3 |  |  | 4 |  |  | 4 |  |  |  | 4 |  |  |
| **12.0** | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 5 | 3 | 1 | 29 | 4 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 6 | 5 | 5 | 4 | 5 |
| **13.5** | 5 | 5 | 4 | 6 | 9 | 5 | 3 | 11 | 2 | 3 | 24 | 4 | 5 | 9 | 5 | 8 | 6 | 8 | 7 | 4 | 9 | 6 | 6 | 5 | 4 |
| **15.0** | 16 | 6 | 8 | 12 | 13 | 12 | 5 | 12 | 4 | 15 | 31 | 5 | 11 | 13 | 13 | 17 | 14 | 16 | 10 | 12 | 10 | 12 | 14 | 4 | 11 |
| **16.5** | 23 | 12 | 11 | 17 | 16 | 16 | 9 | 16 | 19 | 19 | 35 | 8 | 19 | 18 | 19 | 24 | 18 | 22 | 11 | 17 | 16 | 22 | 20 | 13 | 13 |
| **18.0** | 23 | 14 | 15 | 23 | 23 | 20 | 10 | 17 | 27 | 26 | 26 | 21 | 22 | 22 | 26 | 26 | 26 | 24 | 14 | 23 | 21 | 21 | 26 | 15 | 24 |
| **19.5** | 29 | 17 | 20 | 25 | 26 | 23 | 15 | 25 | 31 | 25 | 29 | 24 | 28 | 25 | 31 | 32 | 27 | 29 | 16 | 27 | 23 | 28 | 29 | 18 | 30 |
| **21.0** | 24 | 22 | 23 | 31 | 31 | 29 | 17 | 28 | 26 | 37 | 37 | 30 | 26 | 28 | 27 | 29 | 27 | 36 | 19 | 25 | 43 | 27 | 32 | 25 | 31 |
| **22.5** | 34 | 32 | 29 | 30 | 22 | 35 | 25 | 36 | 30 | 33 | 33 | 34 | 31 | 34 | 31 | 36 | 30 | 31 | 20 | 30 | 50 | 31 | 35 | 28 | 36 |
| **24.0** | 50 | 36 | 50 | 35 | 32 | 50 | 28 | 50 | 35 | 50 | 34 | 50 | 37 | 50 | 34 | 32 | 50 | 50 | 23 | 50 | 50 | 35 | 30 | 31 | 50 |
| **25.5** | 50 | 50 | 50 | 50 | 33 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 34 | 50 |
| **27.0** | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| **28.5** | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| **30.0** | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| **31.5** | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| **33.0** | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |

At intermediate depths, generally between approximately 10 m and 20 m, the SPT *N*-values show a gradual increase, commonly ranging between 10 and 30. This trend indicates the transition from soft cohesive soils to medium stiff or stiff strata, reflecting progressive increases in soil density and effective stress with depth. The increase in penetration resistance with depth is typically associated with increasing effective stress, natural consolidation and improved soil density. Previous studies have also shown that SPT *N*-values generally increase with depth due to confinement effects and stress history within the soil mass (Phoon & Kulhawy, 1999).

At greater depths beyond approximately 20 m, the *N*-values increase significantly, in several boreholes reaching values of up to 50 blows per 300 mm penetration. Such high *N*-values indicate the presence of competent bearing strata comprising dense Sand, Silty Sand or highly weathered rock. These competent layers are often considered suitable bearing strata for deep foundation systems such as piles. According to (Kumar et al., 2016), high SPT *N*-values typically correspond to dense soil layers capable of providing greater load-bearing capacity and improved foundation performance.

The variation of *N*-value profiles among different boreholes also reflects the spatial variability of subsurface conditions within the study area. Such variability highlights the importance of multiple borehole investigations for reliable site characterization, particularly in soft ground environments. The interpretation of stratified layers using SPT *N*-value profiles therefore provides a practical and efficient approach for preliminary subsurface assessment and supports geotechnical decision-making in foundation design (Rahman et al., 2022).

Field observations at the site support the interpretation obtained from the SPT *N*-value profiles.

Figure 4.14 illustrates the occurrence of waterlogged ground conditions characterised by floating vegetation, saturated surface soils and disturbed topsoil during borehole drilling activities. These field observations are consistent with the low SPT *N*-values recorded within the upper soil layers and confirm the presence of soft, highly compressible ground conditions.

The combination of low SPT *N*-values, shallow groundwater conditions and field observations confirms that the near-surface soils possess low bearing capacity and high settlement potential. Consequently, appropriate geotechnical measures, including deep foundation systems or suitable ground improvement techniques, should be

considered during foundation design to minimise the risks of excessive settlement and bearing failure.



Figure 4.14 Field Condition During Borehole Drilling Activities

### 4.2.8 Overview of SPT Behaviour in the Study Area

This section presents an overview of the SPT *N*-values within the study area, emphasizing geotechnical variability and its implications for subsoil classification and foundation design. The SPT *N*-values obtained from the 25 boreholes exhibit notable spatial and vertical variations, indicative of the heterogeneous characteristics of the

subsurface soil strata. In the upper layers, generally within the first 5 to 10 meters, most boreholes display low *N*-values, between 0 and 5, suggesting the existence of soft compressible soils, including Peat, organic Clay or loose Silty materials. The materials exhibit low shear strength, high compressibility and inadequate load-bearing capacity which require meticulous foundation considerations.

A gradual increase in *N*-values is observed with increasing depth, particularly between 10 and 20 meters, with values ranging from 10 to 30. This indicates a transition zone characterized by medium-dense soils, commonly Clayey Sand or Silty Clay, exhibiting enhanced load-bearing properties as a result of overburden pressure and natural consolidation. These layers are typically located beneath the soft surface deposits and serve as a moderate bearing stratum.

At depths greater than 20 to 25 meters, the *N*-values in the majority of boreholes attain or surpass 50 blows per 300 mm, indicating dense to very dense soils or weathered rock formations. The layers signify the potential bearing stratum for deep foundations, including driven piles or bored piles, due to their enhanced resistance to penetration and superior structural support. The persistent presence of elevated *N*-values at these depths across various boreholes signifies a dependable layer for foundation termination. The SPT behaviour in the study area reveals a three-layer system such as:

a) Soft surface soils exhibiting low *N*-values (0–5) within the upper 10 meters.
b) Intermediate layers exhibit increasing *N*-values (10–30), signifying medium-dense soils.
c) Hard strata with *N*-values equal to or greater than 50 are typically located below depths of 24 to 27 meters, making them suitable as foundational layers.

The observations are consistent with the analysis of groundwater conditions and the soil classification profiles presented in previous sections. The relationship between *N*-values, soil type and groundwater levels underscores the necessity of combining SPT data with stratigraphic and hydrogeological information for accurate geotechnical interpretation and foundation design planning.

## 4.3 Soil Properties

This section presents the results of laboratory tests conducted on soil samples collected from the study area in Selangor Cyber Valley, Selangor. A total of 31 boreholes were drilled up to a depth of 30 meters, with SPT performed at every 1.5-meter interval. From these boreholes, disturbed and undisturbed soil samples were taken and tested in the laboratory. The laboratory testing followed BS 1377: Part 2: 1990 and focused on determining soil properties that affect strength and settlement. The tested properties include Moisture Content ($w$), Bulk Density ($\rho_b$**)** and Dry Density ($\rho_d$**)**, Particle Size Distribution (PSD) and Specific Gravity ($G_s$). These properties are especially important in soft Clay and Peat soils, which are common at the site. The results from these tests provide the basis for analysing how soil properties relate to the SPT *N*-values. They also serve as input for the development of the predictive model discussed in later sections.

### 4.3.1 Moisture Content *(w)*

Examining subsurface soil conditions is essential for understanding the engineering behaviour and properties of the ground. This study developed the Moisture Content model using data obtained from the PT 21044, Selangor Cyber Valley site, comprising 25 boreholes (BH1–BH19 and BH26–BH31) used as the primary dataset for model development. A total of 219 disturbed soil samples were included in the modelling dataset. Meanwhile, BH20–BH25 (53 samples) were reserved for internal validation to evaluate the consistency of the developed empirical relationships. In addition, Lot 120185 (30 samples) and Lot 120188 (32 samples) were utilised as independent external validation datasets. The complete laboratory Moisture Content (w) results used in this study are presented in APPENDIX 9, and these raw laboratory data form the basis for the analysis presented in this section.

Figure 4.15 was developed using the laboratory Moisture Content data presented in APPENDIX 9 and illustrates the variation of Moisture Content with depth across the boreholes at PT 21044. The Moisture Content profile clearly demonstrates the influence of lithology and groundwater conditions on the subsurface soils. Moisture Content is commonly used as an important indicator for differentiating soft soil types. Peat generally exhibits extremely high gravimetric water contents ranging from 250%

to 1000%, whereas organic Silts and Clays typically contain lower but still significant Moisture Content ranging from 47% to 76% (Azam et al., 2024).

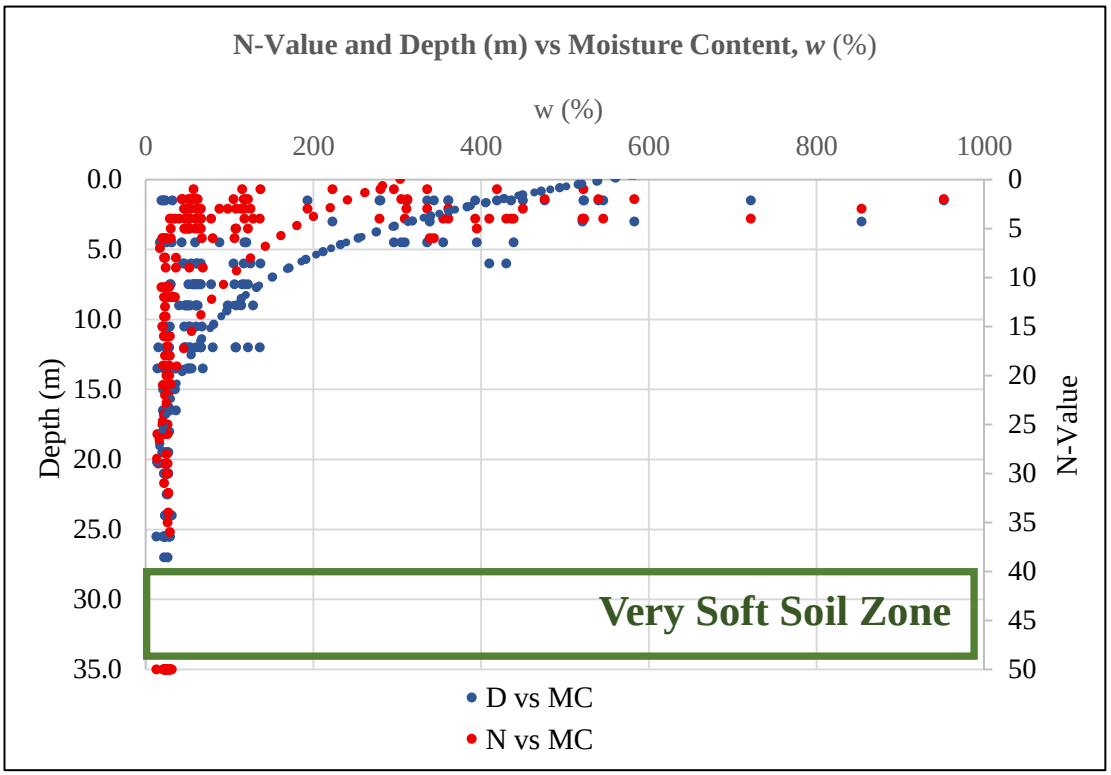



Figure 4.15 Result of Moisture Content at PT 21044, Selangor Cyber Valley

The soil samples collected from the 25 boreholes used in the primary modelling dataset indicate that the upper 10–15 m of the subsurface generally exhibits high Moisture Content, frequently exceeding 200% to 600%, particularly within the Peat, organic soil and very soft Clay layers. Fine-grained soils normally possess high compressibility and significant water-retention capacity due to their small particle size and large specific surface area. High organic matter content further increases the void ratio, allowing greater quantities of water to be retained within the soil structure. (Hazreek et al., 2015) reported that soft Clay commonly contains more than 28% Moisture Content.

The PT 21044 dataset indicates considerably higher Moisture Content than the reported reference values, confirming the presence of highly saturated soft soils. The near-surface layers therefore exhibit low strength, high compressibility and significant settlement potential. With increasing depth, Moisture Content generally decreases across most boreholes. A noticeable reduction is observed beyond approximately 15 m

depth, indicating the transition from soft Clay to stiffer Silty Clay, Sandy Silt and denser soil layers. These deeper materials generally contain less Clay and organic matter, resulting in lower plasticity and reduced water-retention capacity. Consequently, their Moisture Content commonly remains below 100%.

The variation in Moisture Content closely corresponds with the observed lithological profile and SPT *N*-values. Areas exhibiting high Moisture Content generally coincide with low SPT *N*-values ($N$ = 0–5), reflecting soils with low shear strength and high compressibility. As Moisture Content decreases with depth, the corresponding SPT *N*-values increase, indicating progressively stiffer soil layers with greater load-bearing capacity. This inverse relationship between Moisture Content and penetration resistance has been widely recognised in geotechnical engineering. High Moisture Content reduces effective stress and weakens interparticle bonding, thereby decreasing soil stiffness and increasing compressibility.

The Moisture Content profile obtained at PT 21044 therefore provides important information regarding the engineering behaviour of the subsurface soils. The high Moisture Content recorded within the upper layers confirms the requirement for appropriate ground improvement measures and careful settlement assessment prior to construction. In contrast, the lower Moisture Content observed at greater depths indicates more competent materials that are more suitable for supporting foundation loads. Overall, the observed Moisture Content distribution supports the relationship between Moisture Content, soil plasticity and SPT *N*-values, providing a reliable basis for subsequent correlation modelling.

In Clay, higher Moisture Content leads to reduced suction, subsequently decreasing soil stiffness and modulus values. High moisture levels lead to the development of positive pore water pressure, which further reduces the material's resistance to permanent deformation. (Saarenketo, 2009) reported that the undrained shear strength of Clay decreases with increasing initial Moisture Content, while both effective cohesion and internal friction angle also decrease as Moisture Content increases.

### 4.3.2 Atterberg Limit

Atterberg limit tests were carried out on soil samples collected from PT 21044, Cyberjaya in accordance with BS 1377: Part 2 (1990) to determine the consistency and plasticity characteristics of the fine-grained soils. The laboratory programme comprised the determination of Liquid Limit (*LL*), Plastic Limit (*PL*) and Plasticity Index (*PI*) for 131 soil samples obtained from boreholes BH1–BH19 and BH26–BH31, which formed the primary modelling dataset. An additional 49 soil samples from boreholes BH20–BH25 were used for internal validation, while datasets from Lot 120185 and Lot 120188 were utilised as external validation sites. The complete laboratory results of the Atterberg limit tests are presented in APPENDIX 12 and form the basis of the analysis discussed in this section.

For ease of interpretation, the SPT *N*-value classification adopted in this study is summarised in Table 4.8. Based on this classification, *N*-values less than 10 represent very soft to soft soils, *N*-values between 10 and 30 indicate medium stiff to stiff soils, while N-values greater than 30 represent dense to very dense soil layers. These classifications are used throughout the discussion to relate the Atterberg limit parameters to the observed subsurface conditions.

Table 4.8
Interpretation of SPT *N*-Value Classification Used in This Study

| SPT *N*-Value | Soil Condition | General Interpretation |
|---|---|---|
| < 10 | Very soft to soft | High compressibility and low bearing capacity |
| 10–30 | Medium stiff to stiff | Moderate compressibility with improved stiffness |
| > 30 | Dense to very dense | High stiffness and bearing capacity |

Source: Adapted from (Look, 2021).

Figure 4.16 illustrates the relationship between SPT *N*-value, depth and the Atterberg limit parameters, particularly *LL* and *PL*. The figure combines the relationships between SPT *N*-value and *LL*, SPT *N*-value and *PL*, depth and *LL*, as well as depth and *PL* to demonstrate the variation in soil consistency and plasticity with increasing depth. Three characteristic zones can be identified from the distribution of the data, namely the High Plasticity Zone, Transition Zone, and Dense Layer.

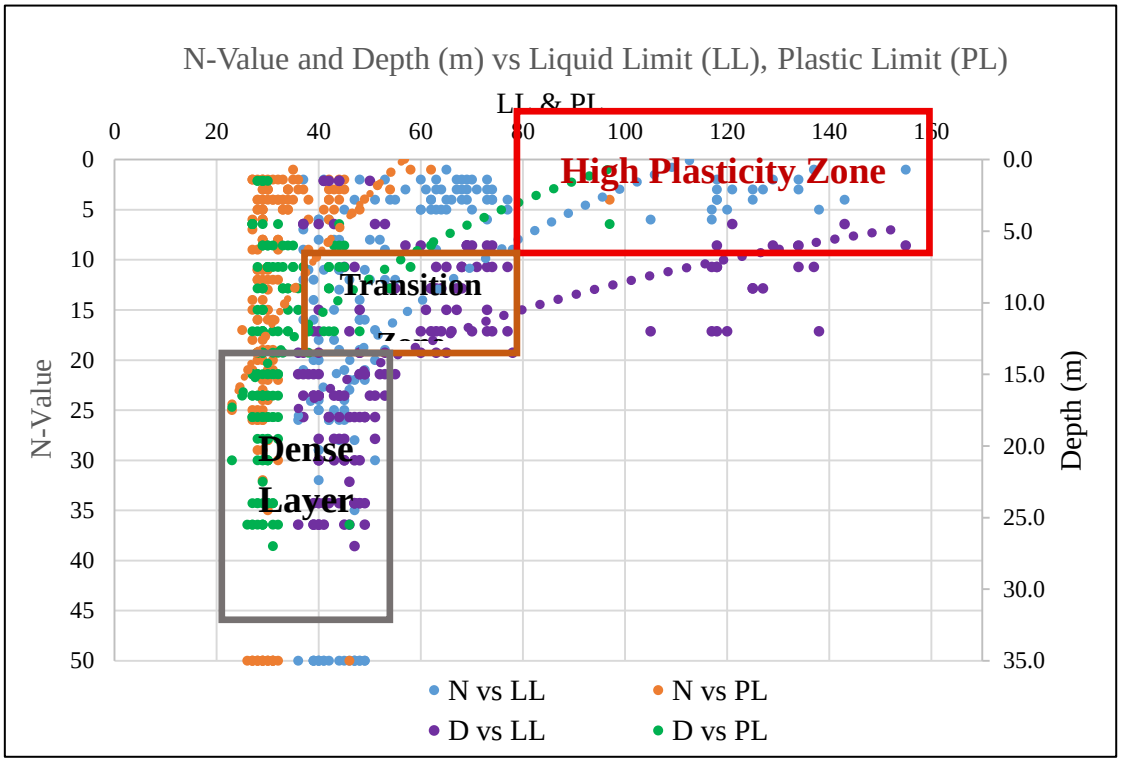



Figure 4.16 Relationship Between SPT *N*-Value, Depth and Atterberg Limits (*LL* and *PL*) at PT 21044, Cyberjaya

The High Plasticity Zone, highlighted in Figure 4.16, is concentrated within the upper approximately 10–15 m of the subsurface profile. This zone is characterised by relatively high *LL* values, generally ranging from approximately 80% to 160%, together with comparatively high *PL* values of approximately 30% to 60%. The corresponding SPT *N*-values are predominantly below 10, indicating very soft and highly compressible soils according to the classification presented in Table 4.10. These characteristics are consistent with the Peat and soft Clay deposits identified from the representative borehole logs discussed in Section 4.2. The high *LL* and *PL* values indicate greater water-holding capacity and increased soil plasticity, resulting in lower penetration resistance and reduced soil stiffness.

Below this interval, a Transition Zone is observed between approximately 15 m and 25 m depth. Within this zone, *LL* generally decreases to approximately 40%–80%, while *PL* reduces to approximately 20%–40%. At the same time, the SPT *N*-values increase to approximately 10–30, indicating the gradual transition from soft

cohesive soils to medium stiff Silty Clay and Sandy Silt deposits. The reduction in Atterberg limit values reflects decreasing soil plasticity and moisture retention as natural consolidation increases with depth.

At depths exceedingly approximately 25 m, the soil profile enters the Dense Layer, where *LL* generally ranges between approximately 30% and 50%, while *PL* remains within approximately 20%–30%. These layers are associated with SPT *N*-values generally greater than 30, indicating dense to very dense materials with higher stiffness and improved bearing capacity. The lower Atterberg limit values suggest soils containing fewer highly plastic clay minerals and lower water retention characteristics, which contribute to greater penetration resistance during SPT testing.

Overall, the relationship shown in Figure 4.16 demonstrates a clear inverse relationship between the Atterberg limit parameters and SPT *N*-value. As *LL* and *PL* decrease with increasing depth, the corresponding SPT *N*-values increase, indicating progressive improvement in soil stiffness and strength. Similar relationships between soil plasticity and penetration resistance have been reported by Asad et al. (2013) and Cavallaro et al. (2003), who observed that soils with higher *LL* and *PL* generally exhibit lower penetration resistance due to their higher compressibility and moisture retention characteristics. The comparable trends observed at the validation sites (Lot 120185 and Lot 120188) further demonstrate the consistency of soil plasticity behaviour within the Selangor Cyber Valley and support the suitability of Atterberg limit parameters for characterising soft alluvial deposits.

### 4.3.3 Bulk Density

In geotechnical engineering, Bulk Density ($\rho_b$) is an important index property that represents the mass of soil per unit volume, including both soil particles and pore water. It provides useful information on the degree of soil compaction and is influenced by soil type, Moisture Content and void ratio (Das & Sobhan, 2017). $\rho_b$ is commonly used to evaluate soil stiffness, compressibility and foundation suitability, particularly in soft ground conditions.

$\rho_b$ tests were conducted on soil samples collected from PT 21044, Selangor Cyber Valley. The primary modelling dataset consisted of samples obtained from boreholes BH1–BH19 and BH26–BH31, while boreholes BH20–BH25 together with the external validation sites at Lot 120185 and Lot 120188 were used for model

validation. The detailed Bulk Density laboratory results are presented in APPENDIX 10.

Figure 4.17 illustrates the relationship between Bulk Density (ρb), SPT *N*-value and depth for the PT 21044 study area. A soft soil layer is clearly observed within the upper 10–15 m, where $\rho_b$ generally ranges from approximately 1.30 to 1.60 Mg/m³. This zone corresponds to relatively low SPT *N*-values (generally $N < 10$), indicating soft and highly compressible soils. The low $\rho_b$ is associated with the presence of Peat, soft Clay and organic Clay, which contain high Moisture Content and large void spaces. Similar behaviour has been reported for saturated fine-grained soils, where high pore-water content contributes to lower Bulk Density values (Craig, 2004).

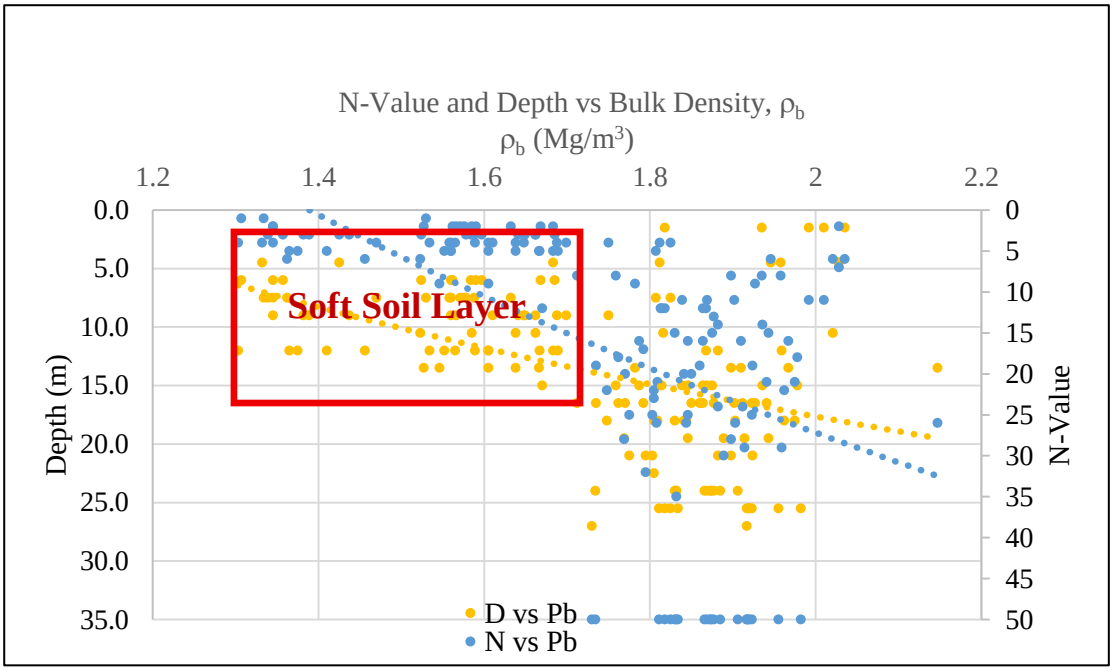



Figure 4.17 Graphical Distribution of Bulk Density Test Result at PT 21044

Below approximately 15 m, $\rho_b$ gradually increases to approximately 1.70–2.00 Mg/m³, accompanied by increasing SPT *N*-values. This trend indicates a transition from soft cohesive soils to denser Silty Clay, Sandy Silt and Sand layers. The increase in Bulk Density with depth reflects the effects of natural consolidation and increasing overburden pressure, which reduce the soil void ratio and improve particle interlocking (Mitchell & Soga, 2005). Similar depth-dependent behaviour is observed across PT

21044, Lot 120185 and Lot 120188, suggesting comparable subsurface conditions throughout the Selangor Cyber Valley area.

The relationship between $\rho_b$ and SPT *N*-value shown in

Figure 4.17 demonstrates that soils with lower $\rho_b$ generally exhibit lower penetration resistance, whereas denser soils tend to record higher SPT *N*-values. The highest $\rho_b$ values are mainly associated with SPT *N*-values exceeding 30, representing dense and competent soil layers suitable for supporting structural foundations. This observation agrees with (Wei et al., 2021), who reported that increasing $\rho_b$ is generally accompanied by higher SPT *N*-values due to improved soil stiffness and strength.Overall, the $\rho_b$ profile confirms that the upper subsurface consists predominantly of soft, low-density soils, while the deeper layers become progressively denser and stronger. The observed trend supports the development of the empirical relationship between $\rho_b$ and SPT *N*-value used in the subsequent modelling analysis.

### 4.3.4 Specific Gravity, $G_s$

The Specific Gravity ($G_s$) is an important soil index property that represents the ratio of the density of soil solids to the density of water. It provides useful information regarding the mineral composition of the soil and is commonly used in soil classification and geotechnical analysis. In this study, $G_s$ tests were carried out in accordance with BS 1377: Part 2 (1990) using soil samples collected from the PT 21044 study area. The primary modelling dataset consisted of 131 laboratory samples obtained from boreholes BH1–BH19 and BH26–BH31. Additional samples from boreholes BH20–BH25 together with the external validation sites at Lot 120185 and Lot 120188 were used to evaluate the consistency of the developed model. The detailed laboratory results are presented in APPENDIX 11.

The measured $G_s$ values for the primary modelling dataset are summarised in Table 4.9, while the complete laboratory results for all boreholes are provided in APPENDIX 11. The measured values range between 2.45 and 2.70, which are generally consistent with the mineralogical characteristics of alluvial soils commonly found within the Selangor Cyber Valley. Mineral soils typically exhibit $G_s$ values between approximately 2.60 and 2.70, whereas soils containing higher organic content generally record relatively lower values due to the lower density of organic constituents (Al-Sakkaf & Abdullah, 2020).

Table 4.9
Summary of Specific Gravity ($G_s$) Results by Borehole at PT 21044

| Borehole | No. of Tested Samples | Minimum $G_s$ | Maximum $G_s$ | Mean $G_s$ |
|---|---|---|---|---|
| BH1 | 5 | 2.55 | 2.63 | 2.594 |
| BH2 | 5 | 2.50 | 2.67 | 2.596 |
| BH3 | 6 | 2.50 | 2.63 | 2.557 |
| BH4 | 5 | 2.50 | 2.66 | 2.590 |
| BH5 | 6 | 2.50 | 2.66 | 2.587 |
| BH6 | 6 | 2.50 | 2.66 | 2.578 |
| BH7 | 5 | 2.51 | 2.68 | 2.586 |
| BH8 | 5 | 2.55 | 2.66 | 2.596 |
| BH9 | 5 | 2.55 | 2.66 | 2.592 |
| BH10 | 5 | 2.55 | 2.66 | 2.594 |
| BH11 | 5 | 2.55 | 2.65 | 2.586 |
| BH12 | 5 | 2.55 | 2.67 | 2.574 |
| BH13 | 5 | 2.51 | 2.65 | 2.586 |
| BH14 | 5 | 2.55 | 2.66 | 2.628 |
| BH15 | 6 | 2.51 | 2.67 | 2.587 |
| BH16 | 6 | 2.51 | 2.66 | 2.612 |
| BH17 | 6 | 2.50 | 2.67 | 2.578 |
| BH18 | 7 | 2.51 | 2.64 | 2.596 |
| BH19 | 7 | 2.50 | 2.64 | 2.600 |
| BH26 | 6 | 2.52 | 2.66 | 2.588 |
| BH27 | 5 | 2.55 | 2.67 | 2.614 |
| BH28 | 6 | 2.50 | 2.65 | 2.600 |
| BH29 | 6 | 2.52 | 2.67 | 2.590 |
| BH30 | 6 | 2.55 | 2.65 | 2.590 |
| BH31 | 5 | 2.55 | 2.64 | 2.598 |

Figure 4.18 illustrates the relationship between $G_s$, SPT *N*-value and depth for the PT 21044 study area. The results indicate that the variation in *Gs* is relatively small throughout the soil profile, generally ranging from 2.50 to 2.65. Within the upper soil layers (approximately 0–10 m), $G_s$ values commonly range between 2.50 and 2.60, corresponding to relatively low SPT *N*-values ($N < 10$) that represent soft and highly compressible soils. Although the mineral composition remains relatively uniform, the shallow soils exhibit lower penetration resistance due to their high Moisture Content, high void ratio and lower degree of consolidation.

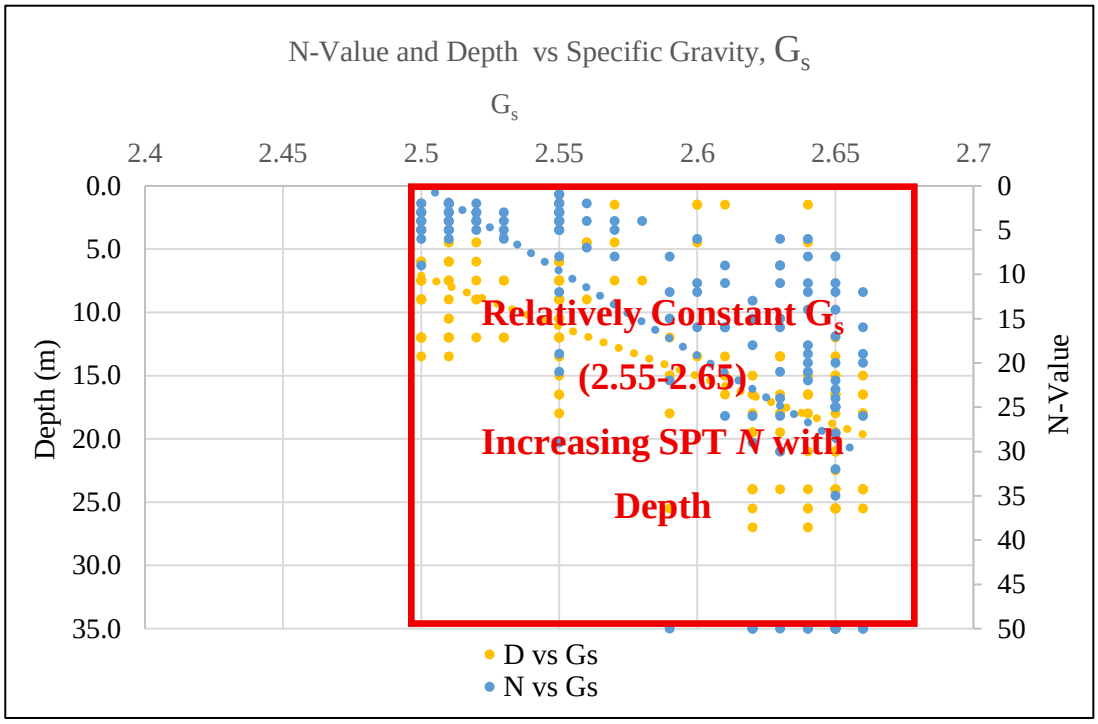



Figure 4.18 Relationship Between Specific Gravity ($G_s$), SPT *N*-Value and Depth at PT 21044, Cyberjaya

With increasing depth, SPT *N*-values progressively increase while $G_s$ values remain within a relatively narrow range of approximately 2.55–2.65. The increase in penetration resistance therefore reflects improvements in soil density, natural consolidation and effective overburden stress rather than substantial changes in mineral composition. This observation indicates that soil stiffness is influenced primarily by the physical condition of the soil mass instead of variations in $G_s$.

A generally positive relationship can be observed between $G_s$ and SPT *N*-value. Soils exhibiting relatively higher $G_s$ values are commonly associated with higher penetration resistance, particularly below approximately 15 m, where SPT *N*-values frequently exceed 20–30 blows. However, the relationship is not strongly linear because the variation in *Gs* is relatively small compared with other engineering properties such as Moisture Content and Bulk Density. Consequently, $G_s$ should be regarded as a secondary indicator of soil behaviour rather than a direct predictor of soil strength.

The validation datasets obtained from Lot 120185 and Lot 120188 exhibit similar ranges of $G_s$, indicating consistent mineralogical characteristics throughout the Selangor Cyber Valley area. This agreement supports the reliability of incorporating $G_s$ together with Moisture Content, Bulk Density and Clay content in the multivariable empirical model developed in this study.

Overall, the $G_s$ results demonstrate relatively uniform mineralogical characteristics across all investigated sites. While $G_s$ contributes to identifying soil mineral composition, the increase in SPT *N*-value with depth is more strongly controlled by changes in soil density, Moisture Content and the degree of consolidation. Therefore, *Gs* was incorporated as one of the predictor variables in the proposed empirical correlation model to improve the overall predictive capability of the developed framework.

### 4.3.5 Particle Size Distribution (PSD)

Particle Size Distribution (PSD) analysis was carried out to determine the distribution of Sand, Silt, Clay and Gravel fractions within the soil profile and to evaluate their relationship with SPT N-values. The PSD results were obtained from the primary modelling dataset comprising 131 laboratory samples collected from boreholes BH1–BH19 and BH26–BH31 at PT 21044. Detailed PSD results and soil classification are presented in APPENDIX 12, while

Figure 4.19 illustrates the relationship between particle size fractions, depth and SPT N-values.

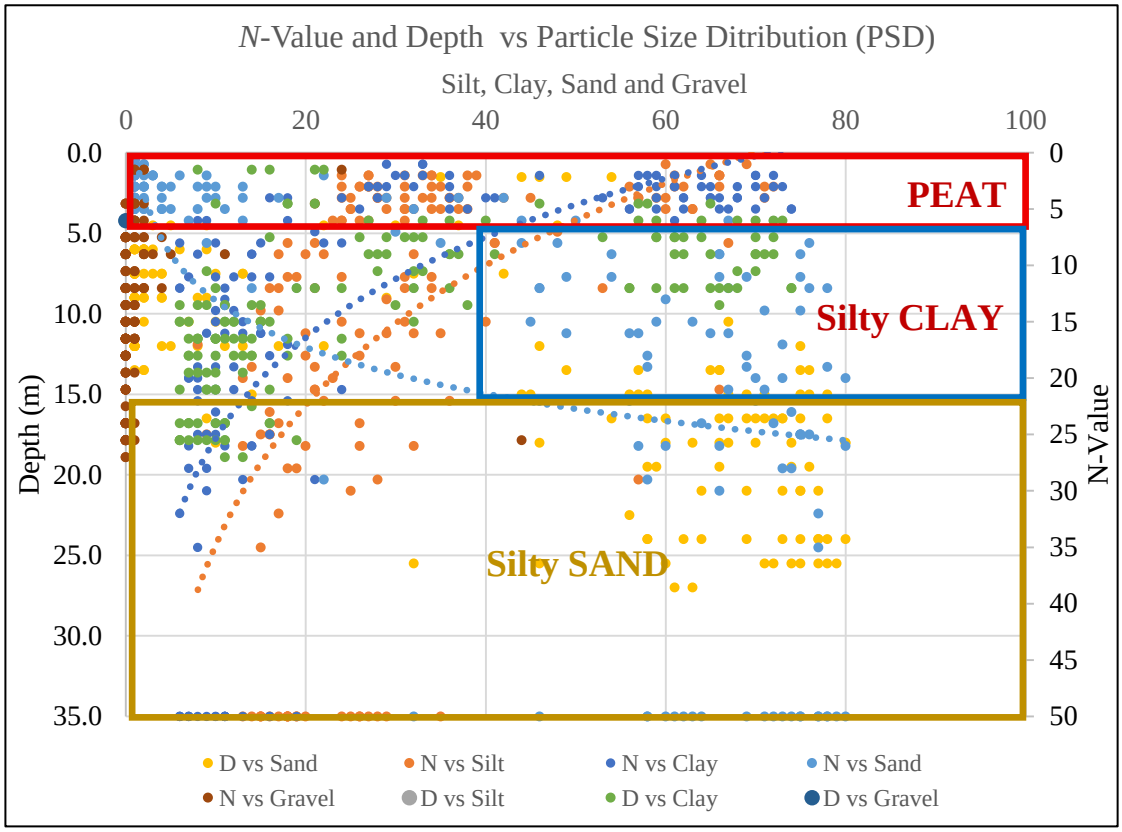



Figure 4.19 Relationship Between Particle Size Distribution (PSD), SPT *N*-Value and Depth at PT 21044, Cyberjaya

The figure shows that the soil profile can generally be divided into three distinct zones**,** namely the Peat zone**,** Silty Clay zone and Silty Sand zone based on the dominant particle size fraction together with the corresponding SPT *N*-value response.

a. Peat zone

The uppermost layer, extending from approximately 0 m to 5 m depth**,** is characterised by organic deposits (Peat), where fine particles dominate and the soil contains a high natural Moisture Content. Within this zone, the recorded SPT ***N***-values are generally less than 5, indicating extremely soft and highly compressible ground conditions. The high organic content and loose soil structure contribute to the very low penetration resistance observed in this layer.

b. Silty Clay zone

Between approximately 5 m and 15 m depth, the subsurface is predominantly composed of Silty Clay, where Clay and Silt fractions become the dominant components. Within this zone, the SPT ***N***-values generally range between 5 and 15**,** representing soft to medium stiff soil conditions. The relatively high percentage of fine particles promotes greater water retention and compressibility, resulting in lower penetration resistance compared with the deeper strata.

c. Silty Sand zone

Below approximately 15 m depth**,** the soil gradually changes into Silty Sand**,** where the Sand fraction becomes increasingly dominant while the percentage of Clay decreases. This transition is accompanied by a significant increase in SPT ***N***-values, commonly exceeding 20 and locally reaching 50 at greater depths. The higher Sand content promotes stronger particle interlocking, lower compressibility and greater penetration resistance, indicating medium dense to dense soil conditions suitable for supporting foundation loads.

Overall,

Figure 4.19 demonstrates a clear relationship between particle size distribution and soil resistance. Fine-grained soils dominated by Peat and Silty Clay correspond to low SPT ***N***-values, whereas Sand-rich layers are associated with progressively higher ***N***-values. This depth-dependent behaviour is consistent with the depositional sequence of Quaternary alluvial deposits and supports the use of PSD as one of the variables in the empirical correlation model developed in this study.

## 4.4 Correlation Analysis of SPT *N*-Value and Soil Properties

Correlation analysis was conducted to evaluate the relationships between SPT *N*-values, depth and the measured soil index properties prior to the development of the empirical prediction models. The objective of this analysis was to identify the variables that significantly influence soil behaviour and to determine the most appropriate predictor variables for regression modelling. Pearson correlation analysis was employed to quantify the strength and direction of the linear relationships between the variables, while descriptive statistical analysis was performed to examine the characteristics and distribution of the dataset. The findings from this analysis provide the statistical basis for the development of the Multiple Linear Regression (MLR) models presented in Section 4.5.

### 4.4.1 Rationale for Correlation Analysis

Correlation analysis was carried out to evaluate the relationships between SPT *N*-values, depth and the measured soil index properties prior to regression modelling. Establishing these relationships is important to identify the variables that significantly influence soil behaviour and to determine the most appropriate predictors for developing the empirical models.

Pearson correlation analysis was selected because all variables investigated were continuous numerical variables, and the objective was to evaluate the strength and direction of their linear relationships. The analysis also provided the basis for selecting independent variables for the subsequent MLR models. Previous geotechnical studies have widely applied Pearson correlation to establish empirical relationships between SPT *N*-values and laboratory-derived soil properties, particularly for soft alluvial soils where rapid preliminary assessment is required (Yusof & Zabidi, 2018).

### 4.4.2 Descriptive Statistics

Prior to correlation analysis, descriptive statistical analysis was performed to summarise the characteristics of the variables used in this study. The analysis provides information on the central tendency, variability and distribution of each variable, which is important for assessing data quality before correlation and regression analyses.

Table 4.10 presents the descriptive statistics of the SPT *N*-values obtained from the primary modelling dataset. The average SPT *N*-value is 21.05, with a standard deviation of 16.94 and a coefficient of variation (CV) of 80.46%, indicating considerable variability in penetration resistance throughout the study area. The *N*-values range from 2 to 50, reflecting the transition from very soft near-surface soils to dense or hard strata at greater depths. This wide range is consistent with the heterogeneous nature of the Quaternary alluvial deposits encountered at PT 21044, where different soil layers exhibit varying degrees of density and stiffness.

Table 4.10
Summary of Descriptive Statistics for SPT *N*-Values

| **Variable** | **Mean** | **SE Mean** | **StDev** | **Variance** | **CV (%)** | **Min** | **Med** | **Max** | **Range** |
|---|---|---|---|---|---|---|---|---|---|
| N | 21.05 | 1.92 | 16.94 | 286.88 | 80.46 | 2.00 | 16.00 | 50.00 | 48.00 |

Descriptive statistical analysis was subsequently performed for all variables used in the correlation analysis, including Depth (*D*), log-transformed SPT *N*-value (log *N*), Moisture Content (*w*), Bulk Density ($\rho_b$) Specific Gravity ($G_s$) and Clay Content. The descriptive statistics were generated using Minitab 21 to summarise the central tendency and variability of each variable. The raw laboratory and field data used in the statistical analysis are presented in APPENDICES 1, 5 and 9–12, while the corresponding descriptive statistical results in Table 4.11 summarises the descriptive statistical characteristics of the variables used in the correlation analysis. The mean values represent the average condition of each variable within the primary modelling dataset, whereas the standard deviation and variance describe the degree of data dispersion. The coefficient of variation (*CV*) provides an indication of the relative variability of each variable, with larger values representing greater spatial variability within the Quaternary alluvial deposits.

Table 4.11
Summary of Descriptive Statistics for Variables Used in the Correlation Analysis

| Variable | Mean | SE Mean | StDev | Vari-ance | CV (%) | Min | Med | Max | Range |
|---|---|---|---|---|---|---|---|---|---|
| D | 16.468 | 0.708 | 6.251 | 39.074 | 37.96 | 1.500 | 16.500 | 27.000 | 25.500 |
| log *N* | 1.1448 | 0.0493 | 0.4356 | 0.1898 | 38.05 | 0.3010 | 1.2041 | 1.6990 | 1.3979 |
| *w* | 0.3399 | 0.0171 | 0.1514 | 0.0229 | 44.56 | 0.2000 | 0.2600 | 0.6600 | 0.4600 |
| $\rho_b$ | 1.7831 | 0.0150 | 0.1324 | 0.0175 | 7.42 | 1.5239 | 1.8236 | 2.0288 | 0.5049 |
| $G_s$ | 2.6008 | 0.00685 | 0.0605 | 0.00366 | 2.33 | 2.5000 | 2.6300 | 2.6600 | 0.1600 |
| Clay | 24.49 | 2.80 | 24.72 | 610.95 | 100.94 | 6.00 | 11.00 | 74.00 | 68.00 |

Among the analysed variables, Clay Content exhibits the highest coefficient of variation (100.94%), indicating considerable variation in the distribution of fine-grained soils across the study area. In contrast, Specific Gravity ($G_s$) records the lowest coefficient of variation (2.33%), suggesting relatively uniform mineralogical characteristics throughout the investigated deposits. The remaining variables exhibit low to moderate variability, reflecting the heterogeneous nature of the alluvial soils while remaining suitable for subsequent correlation and regression analyses.

Overall, the descriptive statistical results indicate that the dataset adequately represents the range of subsurface conditions encountered at PT 21044. The observed variability is consistent with the stratified nature of the site and provides a reliable statistical basis for the correlation analysis and empirical model development presented in the subsequent sections.

### 4.4.3 Assessment of Data Distribution

Prior to the Pearson correlation analysis, the distribution of each variable was evaluated using skewness and kurtosis statistics to assess the normality characteristics of the dataset. Although perfect normality is not a strict requirement for Pearson correlation, examining the data distribution provides useful information on data symmetry and the presence of extreme values, which may influence subsequent

regression analysis. The skewness and kurtosis values for all variables are summarised in Table 4.12.

Table 4.12
Skewness and Kurtosis for Soil Index Properties

| Variable | Skewness | Kurtosis |
|---|---|---|
| D | -0.22 | -0.68 |
| *N* | 0.73 | -0.83 |
| log *N* | -0.40 | -0.94 |
| *w* | 1.06 | -0.60 |
| $\rho_b$ | -0.59 | -0.93 |
| $G_s$ | -0.83 | -1.05 |
| Clay | 1.15 | -0.56 |

Table 4.12 shows that the SPT *N*-value exhibits a positive skewness (0.73), indicating that lower *N*-values are more frequently recorded than higher *N*-values. This observation is consistent with the predominance of soft soils within the upper subsurface layers of the study area. Similarly, Clay Content also exhibits positive skewness (1.15), reflecting the considerable variability in the distribution of fine-grained soils across the site.

Most variables exhibit negative kurtosis, including $G_s$ (-1.05) and log *N* (-0.94), indicating relatively flatter distributions than a normal distribution. These results suggest that the dataset does not contain excessive peakiness and is considered suitable for subsequent statistical analyses. Furthermore, the logarithmic transformation of the SPT *N*-value reduced the skewness from 0.73 to -0.40, indicating an improvement in data symmetry and supporting the use of log *N* in the subsequent regression modelling.

Overall, the skewness and kurtosis statistics indicate that the dataset exhibits acceptable distribution characteristics for correlation and regression analyses, while the transformation of the SPT *N*-value improves the linearity and stability of the statistical models developed in this study.

### 4.4.4 Pearson Correlation Analysis

Following the assessment of data distribution, Pearson correlation analysis was performed to evaluate the strength and direction of the linear relationships between SPT *N*-values, depth (*D*) and the measured soil index properties. The analysis was carried out using the primary modelling dataset comprising 131 laboratory samples obtained from boreholes BH1–BH19 and BH26–BH31 at PT 21044. The resulting Pearson correlation coefficients were used to identify the variables that exhibit statistically significant relationships with SPT *N*-values and to determine the most appropriate predictor variables for the subsequent Multiple Linear Regression (MLR) modelling.

The Pearson correlation coefficients between the analysed variables are presented in Table 4.13**:**

Table 4.13
Pearson Correlation Matrix

| Variable Pair | Pearson r | Strength | Direction |
|---|---|---|---|
| *D* vs *N* | 0.901 | Very strong | Positive |
| w vs log *N* | -0.830 | Strong | Negative |
| $G_s$ vs *N* | 0.643 | Very strong | Positive |
| *Clay* vs *N* | -0.621 | Strong | Negative |
| $\rho_b$ vs *N* | 0.515 | Strong | Positive |

Table 4.13 indicates that Depth (*D*) exhibits a very strong positive correlation with the logarithm of the SPT *N*-value (log *N*) ($r$ = 0.919), indicating that penetration resistance generally increases with depth. This observation is consistent with the progressive increase in soil density and stiffness associated with increasing overburden pressure and natural consolidation, as discussed in Section 4.2.

Among the investigated soil properties, Moisture Content (*w*) shows a strong negative correlation with log *N* ($r$ = –0.830), indicating that soils with higher Moisture Content generally exhibit lower penetration resistance. This relationship reflects the behaviour of soft cohesive soils, where increased moisture reduces effective stress and shear strength, resulting in lower SPT *N*-values.

Specific Gravity ($G_s$) demonstrates a strong positive correlation with log *N* ($r$ = 0.643), suggesting that soils with relatively higher mineral density generally

correspond to higher penetration resistance. Although the relationship is positive, the moderate correlation indicates that Specific Gravity alone is not the dominant factor controlling soil strength.

Similarly, Clay Content demonstrates a moderate negative correlation with the SPT *N*-value ($r = -0.621$), indicating that soils containing higher percentages of Clay generally exhibit lower penetration resistance because of their greater compressibility and moisture retention characteristics.

Bulk Density ($\rho_b$) also exhibits a moderate positive correlation with the SPT *N*-value ($r = 0.515$). This finding suggests that denser soils generally possess higher penetration resistance, although the relationship is weaker than that observed for Moisture Content and Depth.

Overall, the Pearson correlation analysis demonstrates that Depth, Moisture Content, Specific Gravity, Clay Content and Bulk Density exhibit meaningful relationships with SPT *N*-values. Among these variables, Depth and Moisture Content show the strongest correlations with penetration resistance. These findings provide the statistical basis for selecting the predictor variables used in the subsequent Multiple Linear Regression (MLR) modelling presented in Section 4.5.

### 4.4.5 Significance Testing (*p*-value)

The Pearson correlation analysis presented in Section 4.4.4 established the statistical basis for selecting the predictor variables used in the regression modelling. Variables were selected based on three criteria: (i) the strength of the Pearson correlation coefficient ($r$), (ii) statistical significance ($p \leq 0.05$), and (iii) geotechnical relevance. This approach ensures that the developed empirical models are both statistically reliable and physically meaningful.

The analysis indicates that Depth ($D$) and SPT *N*-value (or log-transformed *N*-value) exhibit significant relationships with the measured soil index properties. Similarly, Moisture Content ($w$), Bulk Density ($\rho_b$), Specific Gravity ($G_s$) and Clay Content demonstrate statistically significant correlations with the predictor variables and were therefore selected for subsequent regression modelling.

Variables showing weak or inconsistent relationships, such as Silt and Gravel contents, were excluded from the regression analysis because their correlation

coefficients were relatively low and they contributed little to improving model performance.

Based on these findings, the predictor variables selected for the empirical modelling are summarised in Table 4.14.

Table 4.14
Selected Variables for Regression Modelling

| Category | Variables |
|---|---|
| Independent Variables | Depth (D), SPT *N*-value, log(*N*) |
| Dependent Variables | Moisture Content ($w$), Bulk Density ($\rho_b$), Specific Gravity ($G_s$), Clay Content |

## 4.5 Development of Empirical Regression Models

Multiple Linear Regression (MLR) was selected as the principal modelling technique because the objective of this study was to develop practical and interpretable empirical equations capable of estimating soil index properties from SPT *N*-values and depth. The Pearson correlation analysis presented in Section 4.4 demonstrated statistically significant linear relationships between the selected predictor variables and the measured soil properties, indicating that the assumptions required for linear regression modelling were reasonably satisfied.

Several alternative regression approaches were considered during the model selection stage. Polynomial regression was not adopted because preliminary analysis indicated that the relationships became sufficiently linear after applying logarithmic transformation to the SPT *N*-values. Consequently, higher-order polynomial functions were considered unnecessary and would increase model complexity without providing substantial improvement in predictive performance.

Non-linear regression techniques were also considered. However, these methods generally require more complex mathematical functions and are less suitable for routine engineering applications where simple empirical equations are preferred. Furthermore, advanced machine learning techniques such as Artificial Neural Networks (ANN), Support Vector Regression (SVR) and Random Forest algorithms typically require substantially larger datasets and often produce prediction models that are difficult to interpret from an engineering perspective.

In contrast, Multiple Linear Regression provides explicit mathematical equations that clearly describe the contribution of each predictor variable. This allows the developed models to be easily interpreted, verified and applied during preliminary geotechnical investigations. Therefore, MLR was considered the most appropriate modelling technique for this study because it offers a balance between statistical reliability, engineering interpretability and practical application.

### 4.5.1 Model Development Procedure

This section presents the development of empirical models for estimating soil index properties using SPT *N*-values and depth. The modelling framework integrates geotechnical interpretation with MLR analysis to establish statistically reliable and geotechnically meaningful relationships between penetration resistance and soil behaviour. The analyses were performed using Minitab 21 based on field and laboratory data obtained from PT 21044, Cyberjaya.

The modelling process consisted of dataset preparation, statistical screening, selection of significant predictor variables, formulation of regression equations and model evaluation. Prior to regression analysis, the datasets were screened using descriptive statistics, assessment of data distribution and Pearson correlation analysis, as presented in Section 4.4. Only variables satisfying the statistical selection criteria and demonstrating geotechnical significance were retained for model development.

The primary modelling dataset comprised paired SPT *N*-values and laboratory test results obtained at 1.5 m sampling intervals from 25 boreholes (BH1–BH19 and BH26–BH31). For model validation, six additional boreholes (BH20–BH25) from PT 21044 together with four boreholes from Lot 120185 and four boreholes from Lot 120188 were used for sensitivity analysis and external validation.

Regression analysis was performed using Minitab 21. The developed models were evaluated using the coefficient of determination ($R^2$), regression coefficients, statistical significance (*p*-values), residual analysis and paired sample *t*-tests to assess the predictive capability and reliability of the proposed empirical equations.

The empirical models were subsequently developed for four selected soil index properties, namely Moisture Content ($w$), Specific Gravity ($G_s$), Clay Content and Bulk Density ($\rho_b$).

#### *4.5.1.1 Empirical Model Development for Moisture Content*

The first empirical model developed in this study was for the prediction of Moisture Content (*w*), as moisture content is one of the most important soil index properties influencing the engineering behaviour of soft soils. Variations in moisture content significantly affect soil compressibility, shear strength and settlement characteristics. Therefore, the ability to estimate moisture content from SPT *N*-values and depth provides a practical approach for preliminary site assessment where laboratory testing is unavailable or limited.

The regression model was developed using the primary modelling dataset comprising laboratory test results and corresponding SPT data obtained from boreholes BH1–BH19 and BH26–BH31 at PT 21044. Based on the Pearson correlation analysis presented in Section 4.4, Depth (*D*) and the logarithm of the SPT *N*-value (log *N*) exhibited statistically significant relationships with Moisture Content and were therefore selected as the predictor variables for the regression model.

MLR analysis was performed using Minitab 21 to establish the empirical relationship between Moisture Content, Depth and log *N*. The regression coefficients were estimated using the least squares method to minimise the residual error between the measured and predicted values. The resulting regression equation is presented in Equation (4.1)

$$w = 0.654 + 0.118D - 0.441log(N) \quad (4.1)$$

In Equation (4.1), *w* denotes the Moisture Content expressed in decimal form, *D* is the sampling depth below ground level (m), *N* is the Standard Penetration Test (SPT) *N*-value expressed as the number of blows required for 300 mm penetration, and log *N* represents the base-10 logarithm of the measured SPT *N*-value. The statistical performance of the developed regression model is summarised in Table 4.15.

Table 4.15
Statistical Performance of the Moisture Content Regression Model

| Parameter | Value |
|---|---|
| Regression Equation | $w = 0.654 + 0.118D - 0.441\log(N)$ |
| $R^2$ (%) | 72.55 |
| Adjusted $R^2$ (%) | 71.82 |
| Standard Error | 0.0804 |
| *p*-value | 0.238 |

The developed Moisture Content model achieved a coefficient of determination ($R^2$ = 72.55%), indicating that approximately 72.55% of the variability in Moisture Content can be explained by Depth and SPT *N*-value. This result demonstrates that the selected predictor variables provide a satisfactory representation of the variation in moisture content within the investigated alluvial deposits.

The regression coefficients indicate that Moisture Content generally increases with depth but decreases as SPT *N*-value increases. The negative coefficient associated with log *N* reflects the inverse relationship between penetration resistance and soil moisture, where soils with lower penetration resistance generally contain higher moisture content and exhibit softer ground conditions. Conversely, increasing SPT *N*-values correspond to denser soils with lower moisture content.

Overall, the regression model provides a practical empirical equation for estimating Moisture Content from readily available field investigation data and serves as the first component of the sequential modelling framework developed in this study.

#### *4.5.1.2 Empirical Development Model for Specific Gravity*

The second empirical model developed in this study was for the prediction of Specific Gravity ($G_s$), which represents the mineralogical characteristics of the soil particles. Although $G_s$ generally exhibits relatively small variation compared with other soil index properties, it remains an important parameter in geotechnical engineering because it influences soil classification, density relationships and the interpretation of

engineering behaviour. Estimating $G_s$ from readily available field parameters provides a practical alternative when laboratory testing is unavailable or limited.

The regression model was developed using the primary modelling dataset comprising laboratory test results and corresponding SPT data obtained from boreholes BH1–BH19 and BH26–BH31 at PT 21044. Based on the Pearson correlation analysis presented in Section 4.4, Depth (*D*), SPT *N*-value (*N*) and Moisture Content (*w*) were selected as the predictor variables because they demonstrated statistically significant relationships with Specific Gravity.

MLR analysis was performed using Minitab 21 to establish the empirical relationship between Specific Gravity, Depth, SPT *N*-value and Moisture Content. The regression coefficients were estimated using the least squares method to minimise the difference between the measured and predicted values. The resulting regression equation is presented in Equation (4.2).

$$Gs = 2.6865 + 0.00150D + 0.000012N - 0.3257w \quad (4.2)$$

where $G_s$ denotes the Specific Gravity of the soil particles, *D* represents the sampling depth below ground level measured in metres (m), *N* is the Standard Penetration Test (SPT) *N*-value expressed as the number of blows per 300 mm penetration, and *w* represents the Moisture Content expressed in decimal form. The statistical performance of the developed regression model is summarised in Table 4.16**.**

Table 4.16
Statistical Performance of the Specific Gravity Regression Model

| **Parameter** | **Value** |
|---|---|
| Regression Equation | $Gs = 2.6865 + 0.00150D + 0.000012N - 0.3257w$ |
| $R^2$ (%) | 86.75 |
| Adjusted $R^2$ (%) | 86.21 |
| Standard Error | 0.0225 |
| *p*-value | 0.233 |

The developed regression model achieved a coefficient of determination ($R^2$ = 86.75%), indicating that approximately 86.75% of the variation in $G_s$ can be explained by the selected predictor variables. This high coefficient of determination demonstrates that the regression model provides a reliable prediction of $G_s$ for the investigated alluvial deposits.

Equation (4.2) indicates that $G_s$ generally increases with increasing depth and SPT *N*-value, while it decreases with increasing Moisture Content. The positive coefficients associated with depth and SPT *N*-value suggest that soils exhibiting greater penetration resistance and occurring at greater depths generally possess slightly higher $G_s$, reflecting denser and more consolidated soil materials. Conversely, the negative coefficient of Moisture Content indicates that soils containing higher amounts of water are generally associated with slightly lower $G_s$ values.

Overall, the regression model demonstrates that the combined influence of Depth, SPT *N*-value and Moisture Content provide a satisfactory prediction of $G_s$. The developed equation therefore forms the second component of the sequential empirical modelling framework proposed in this study.

#### *4.5.1.3 Empirical Model Development for Clay Content*

The third empirical model developed in this study was for the prediction of Clay Content, which is an important soil index property influencing the engineering behaviour of soft alluvial soils. Clay content significantly affects soil compressibility, plasticity, moisture retention and shear strength. Therefore, estimating Clay Content from SPT N-values and other readily available parameters provides a practical approach for preliminary geotechnical investigations where detailed laboratory testing is limited.

The regression model was developed using the primary modelling dataset comprising laboratory test results and corresponding SPT data obtained from boreholes BH1–BH19 and BH26–BH31 at PT 21044. Based on the Pearson correlation analysis presented in Section 4.4, Depth (*D*), SPT N-value (*N*), Moisture Content (*w*) and Specific Gravity ($G_s$) were identified as significant predictor variables and were therefore selected for the regression analysis.

MLR analysis was performed using Minitab 21 to establish the empirical relationship between Clay Content and the selected predictor variables. The regression coefficients were estimated using the least squares method to minimise the residual

error between the measured and predicted values. The resulting regression equation is presented in Equation (4.3).

$$Clay = 460 - 0.242D + 0.028N + 81.7w - 177.0Gs \quad (4.3)$$

Where Clay represents the percentage of clay content (%), *D* denotes the sampling depth below ground level measured in metres (m), *N* represents the SPT *N*-value expressed as the number of blows per 300 mm penetration, *w* denotes the Moisture Content expressed in decimal form, and $G_s$ represents the Specific Gravity of the soil particles. The statistical performance of the developed regression model is summarised in Table 4.17**.**

Table 4.17
Statistical Performance of the Clay Content Regression Model

| **Parameter** | **Value** |
|---|---|
| Regression Equation | $Clay = 460 - 0.242D + 0.028N + 81.7w - 177.0Gs$ |
| $R^2$ (%) | 89.88 |
| Adjusted $R^2$ (%) | 86.21 |
| Standard Error | 8.0769 |
| *p*-value | 0.354 |

The developed regression model achieved a coefficient of determination ($R^2$ = 89.88%), indicating that approximately 89.88% of the variation in Clay Content can be explained by the selected predictor variables. This demonstrates that the combination of Depth, SPT *N*-value, Moisture Content and Specific Gravity provide an excellent prediction of Clay Content for the Quaternary alluvial deposits investigated in this study.

Equation (4.3) indicates that Clay Content generally decreases with increasing depth, as reflected by the negative regression coefficient of *D*. This trend agrees with the subsurface stratigraphy discussed in Section 4.2, where the upper soil profile is

dominated by clay-rich deposits that gradually transition into silty sand and denser materials with increasing depth.

The regression coefficients indicate that Clay Content is controlled by the combined influence of depth, penetration resistance, moisture condition and mineral composition rather than by a single variable alone. This reflects the multivariate nature of the developed regression model. These relationships are consistent with the observed characteristics of the study area, where clay-rich soils exhibit higher moisture retention and lower mineral density than the underlying granular deposits.

Overall, the regression model demonstrates that the selected predictor variables adequately represent the variation in Clay Content and form the third component of the sequential empirical modelling framework developed in this study.

#### *4.5.1.4 Empirical Model Development for Bulk Density*

The final empirical model developed in this study was for the prediction of Bulk Density ($\rho_b$), which represents one of the important engineering index properties used to evaluate soil density, stiffness and foundation suitability. $\rho_b$ is influenced by soil composition, moisture condition and particle arrangement. Consequently, the ability to estimate $\rho_b$ from SPT *N*-values and other readily available soil parameters provides a practical alternative for preliminary geotechnical assessment when laboratory testing is limited.

The regression model was developed using the primary modelling dataset obtained from boreholes BH1–BH19 and BH26–BH31 at PT 21044. Based on the Pearson correlation analysis presented in Section 4.4, Depth (*D*), SPT *N*-value (*N*), Moisture Content (*w*), Specific Gravity ($G_s$), and Clay Content were identified as significant predictor variables and were therefore selected for MLR analysis.

MLR analysis was performed using Minitab 21 using the least squares estimation method to determine the empirical relationship between $\rho_b$ and the selected predictor variables. The resulting regression equation is presented in Equation (4.4).

$$Pb = -0.22 - 0.00511D + 0.00107N - 0.408w + 0.851Gs - 0.00051Clay \quad (4.4)$$

Where $\rho_b$ represents the Bulk Density (Mg/m³), $D$ denotes the sampling depth below ground level measured in metres (m), $N$ represents the SPT $N$-value expressed as the number of blows per 300 mm penetration, $w$ denotes the Moisture Content expressed in decimal form, $G_s$ represents the $G_s$ of the soil particles, and Clay denotes the Clay Content expressed as a percentage (%). The statistical performance of the developed regression model is summarised in Table 4.18**.**

Table 4.18
Statistical Performance of the Bulk Density Regression Model

| **Parameter** | **Value** |
|---|---|
| Regression Equation | $Pb = -0.22 - 0.00511D + 0.00107N - 0.408w + 0.851Gs - 0.00051Clay$ |
| $R^2$ (%) | 72.34 |
| Adjusted $R^2$ (%) | 70.42 |
| Standard Error | 0.0720 |
| $p$-value | 0.181 |

The developed regression model achieved a coefficient of determination ($R^2$ = 72.34%), indicating that approximately 72.34% of the variation in $\rho_b$ can be explained by the selected predictor variables. This result demonstrates that the proposed model provides a satisfactory estimation of $\rho_b$ within the Quaternary alluvial deposits investigated in this study.

Equation (4.4) shows that $\rho_b$ is influenced by the combined effects of Depth, SPT $N$-value, Moisture Content, Specific Gravity and Clay Content. The regression coefficients indicate that $\rho_b$ generally increases with increasing penetration resistance and Specific Gravity, whereas higher Moisture Content is associated with lower $\rho_b$. These relationships agree with the geotechnical characteristics discussed in Section 4.3, where soft saturated soils exhibited lower density than the deeper and denser soil layers.

Although the regression coefficient associated with Clay Content is relatively small, its inclusion improves the overall predictive capability of the model by accounting for the influence of fine-grained materials on soil density. This demonstrates that $\rho_b$ is governed by the combined interaction of soil composition, moisture condition and mineral characteristics rather than by a single predictor variable.

Overall, the regression model provides a practical empirical equation for estimating $\rho_b$ from readily obtainable field and laboratory parameters. Together with the preceding models for Moisture Content, Specific Gravity and Clay Content, this equation completes the empirical modelling framework developed in this study and forms the basis for the model validation presented in Section 4.6.

### 4.5.2 Model Validation

The predictive capability of the developed empirical regression models was evaluated using independent datasets that were not involved in the model development process. The independent validation dataset comprised 92 laboratory samples, including 49 samples obtained from boreholes BH20–BH25 within PT 21044 and 43 samples collected from two independent sites, namely Lot 120185 (23 samples) and Lot 120188 (20 samples), located within the Selangor Cyber Valley. The inclusion of both datasets enabled the developed regression models to be evaluated using independent data collected from the same geological formation while representing different borehole locations.

The predicted values generated from the developed empirical equations were compared with the corresponding laboratory measurements using paired sample t-tests together with graphical comparisons between the predicted and observed values. The paired sample t-test was employed to determine whether statistically significant differences existed between the predicted and measured datasets. The null hypothesis assumes that no significant difference exists between the predicted and observed values, whereas the alternative hypothesis assumes that a significant difference exists. A *p*-value greater than 0.05 indicates that the developed regression equation provides predictions that are statistically consistent with the laboratory measurements (Montgomery & Runger, 2021).

The validation procedure was applied to all four developed regression models, namely Moisture Content ($w$), Specific Gravity ($G_s$), Clay Content and Bulk Density ($\rho_b$). The results of the paired sample *t*-tests are summarised in in Table 4.19.

Table 4.19
Summary of Paired Sample *t*-Test Results for the Developed Regression Models

| Equation | Soil Property | p-value | Interpretation |
|---|---|---|---|
| 1 | Moisture Content | 0.238 | No significant difference |
| 2 | Specific Gravity | 0.233 | No significant difference |
| 3 | Clay Content | 0.354 | No significant difference |
| 4 | Bulk Density | 0.181 | No significant difference |

Table 4.19 shows that all developed regression models produced *p*-values greater than 0.05, indicating that there are no statistically significant differences between the predicted and observed values for all four soil properties at the 95% confidence level. Therefore, the null hypothesis cannot be rejected, confirming that the developed empirical equations provide statistically reliable predictions for Moisture Content, Specific Gravity, Clay Content and Bulk Density.

The close agreement between the predicted and measured values demonstrates that the developed regression models maintain satisfactory predictive performance when applied to independent datasets beyond the primary modelling dataset. This confirms that the proposed empirical equations are capable of estimating the selected soil index properties for soft alluvial deposits within the Selangor Cyber Valley and are suitable for preliminary geotechnical investigations.

#### *4.5.2.1 Comparison Between Predicted and Observed Moisture Content*

Following the development of the Moisture Content regression model, validation was performed by comparing the predicted values generated using Equation (4.1) with the corresponding laboratory-measured values. The objective of this validation was to determine whether the developed empirical equation is capable of providing reliable estimates of Moisture Content for the investigated alluvial soils. The regression equation used for prediction is:

$$w = 0.6540 + 0.0118D - 0.4441(\log N)$$

Figure 4.20 compares the predicted Moisture Content values with the observed laboratory measurements. Both datasets exhibit a similar decreasing trend with increasing SPT *N*-values, indicating that soils with lower penetration resistance generally possess higher Moisture Content, whereas denser soils with higher *N*-values contain less moisture. The predicted values closely follow the observed measurements throughout the investigated range, with only minor deviations at intermediate *N*-values.

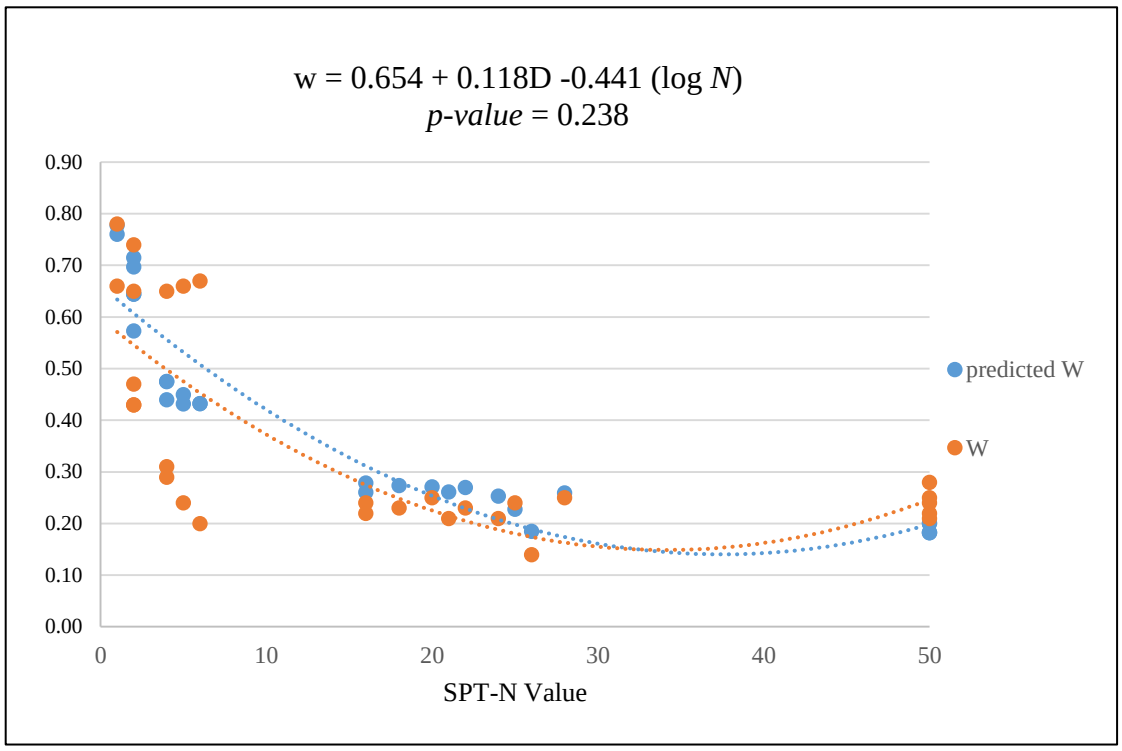



Figure 4.20 Comparison between Predicted and Observed Moisture Content Values.

The paired sample *t*-test produced a *p*-value of 0.238, which is greater than the significance level of 0.05. Therefore, no statistically significant difference exists between the predicted and observed Moisture Content values. This result confirms that the developed regression equation provides reliable predictions and is suitable for estimating Moisture Content during preliminary geotechnical investigations.

#### *4.5.2.2 Comparison Between Predicted and Observed Specific Gravity*

Validation of the Specific Gravity model was conducted using the same procedure by comparing the predicted values generated with the corresponding laboratory measurements. The regression equation is expressed as:

$$Gs = 2.6865 + 0.0015D + 0.000012N - 0.3257w$$

Figure 4.21 illustrates the comparison between the predicted and observed Specific Gravity values. The predicted results show close agreement with the laboratory data throughout the investigated range of SPT *N*-values. Although minor deviations are observed within the intermediate *N*-value range, both datasets demonstrate a consistent trend. The relatively small variation in Specific Gravity reflects the fairly uniform mineralogical composition of the investigated alluvial soils.

The paired sample *t*-test yielded a p-value of 0.233, indicating that no statistically significant difference exists between the predicted and observed Specific Gravity values. Consequently, the regression equation is considered statistically reliable for estimating Specific Gravity within the study area.

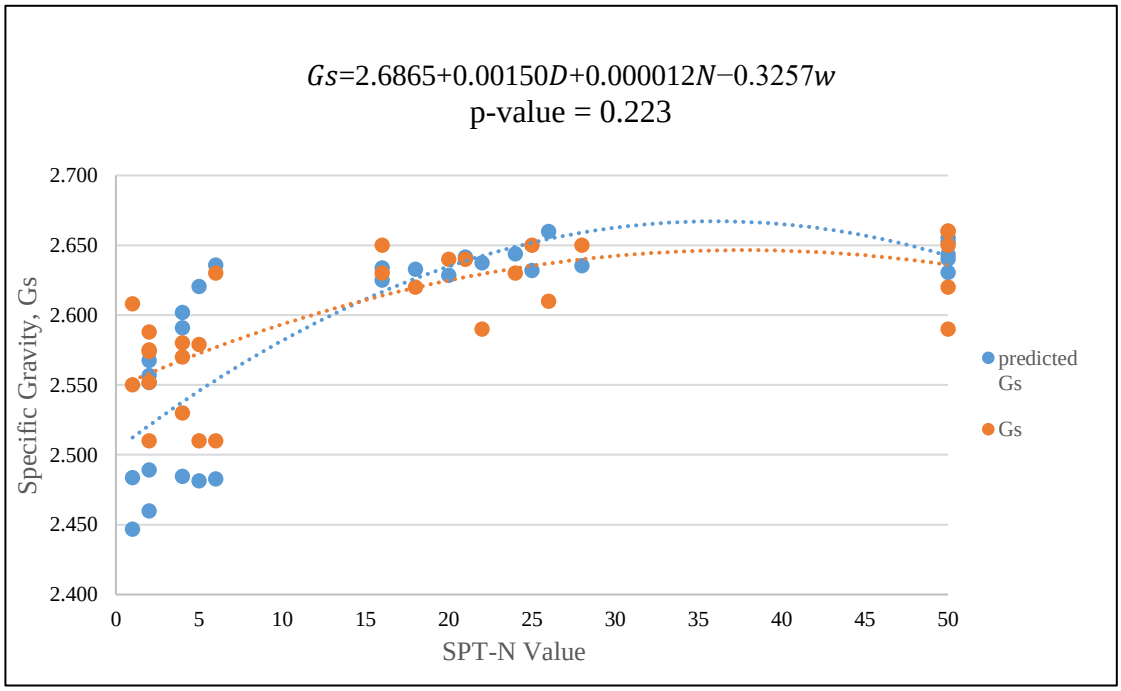



Figure 4.21 Comparison between Predicted and Observed Specific Gravity Values.

#### *4.5.2.3 Comparison Between Predicted and Observed Clay Content*

The predictive capability of the Clay Content regression model was evaluated by comparing the predicted Clay Content values with the laboratory measurements obtained from the primary modelling dataset. The developed regression equation is given by:

$$Clay = 460 - 0.242D + 0.028N + 81.7w - 177.0Gs$$

Figure 4.22 presents the comparison between the predicted and observed Clay Content values. Both datasets exhibit a similar inverse relationship with SPT *N*-values, whereby higher Clay Content is generally associated with lower penetration resistance. This behaviour is consistent with the characteristics of soft cohesive soils, where increased Clay Content contributes to higher compressibility and lower soil strength.

The paired sample *t*-test resulted in a *p*-value of 0.354**,** indicating that no statistically significant difference exists between the predicted and observed Clay Content values. Therefore, the regression equation is capable of providing satisfactory predictions of Clay Content for the investigated alluvial deposits.

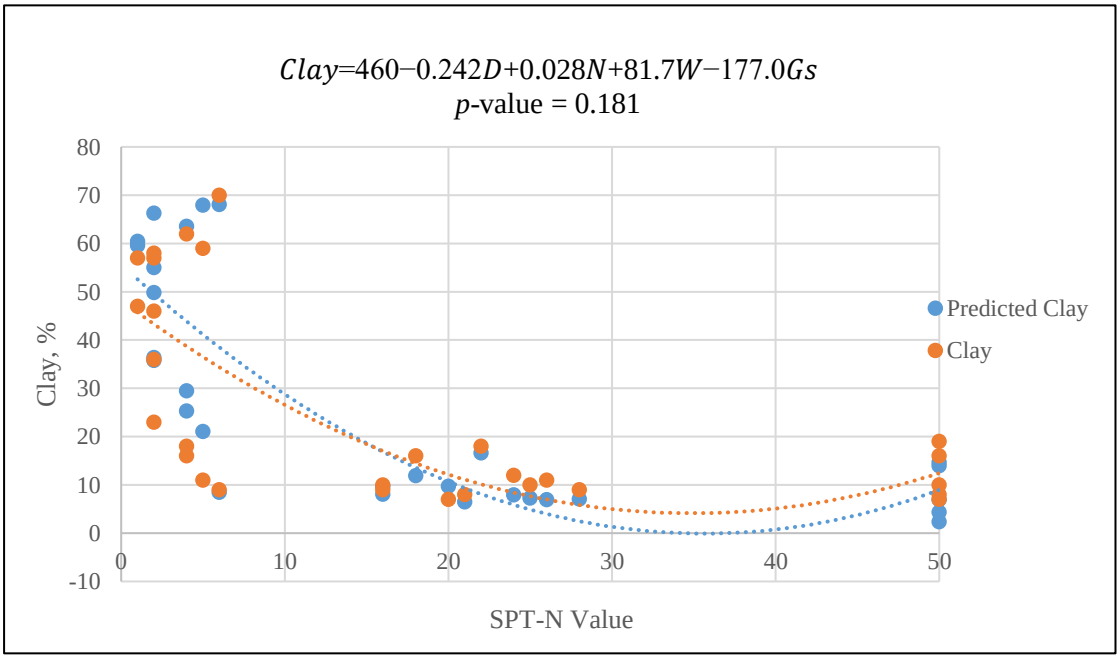



Figure 4.22 Comparison between Predicted and Observed Clay Content Values.

#### *4.5.2.4 Comparison Between Predicted and Observed Bulk Density*

The final validation was carried out for the Bulk Density regression model using the same statistical procedure. The regression equation developed in this study is:

$$\rho_b = -0.22 - 0.00511D + 0.00107N - 0.408w + 0.851Gs - 0.00051Clay$$

Figure 4.23 compares the predicted Bulk Density values with the corresponding laboratory measurements. The predicted values generally agree well with the observed data, demonstrating a similar increasing trend with increasing SPT ***N***-values. Lower Bulk Density values are associated with the shallow soft soil layers, whereas higher Bulk Density values occur within the deeper and denser strata.

The paired sample *t*-test produced a *p*-value of 0.181**,** which exceeds the significance level of 0.05. This indicates that the predicted Bulk Density values do not differ significantly from the laboratory measurements. The regression equation therefore provides reliable estimates of Bulk Density for the alluvial soils investigated in this study.

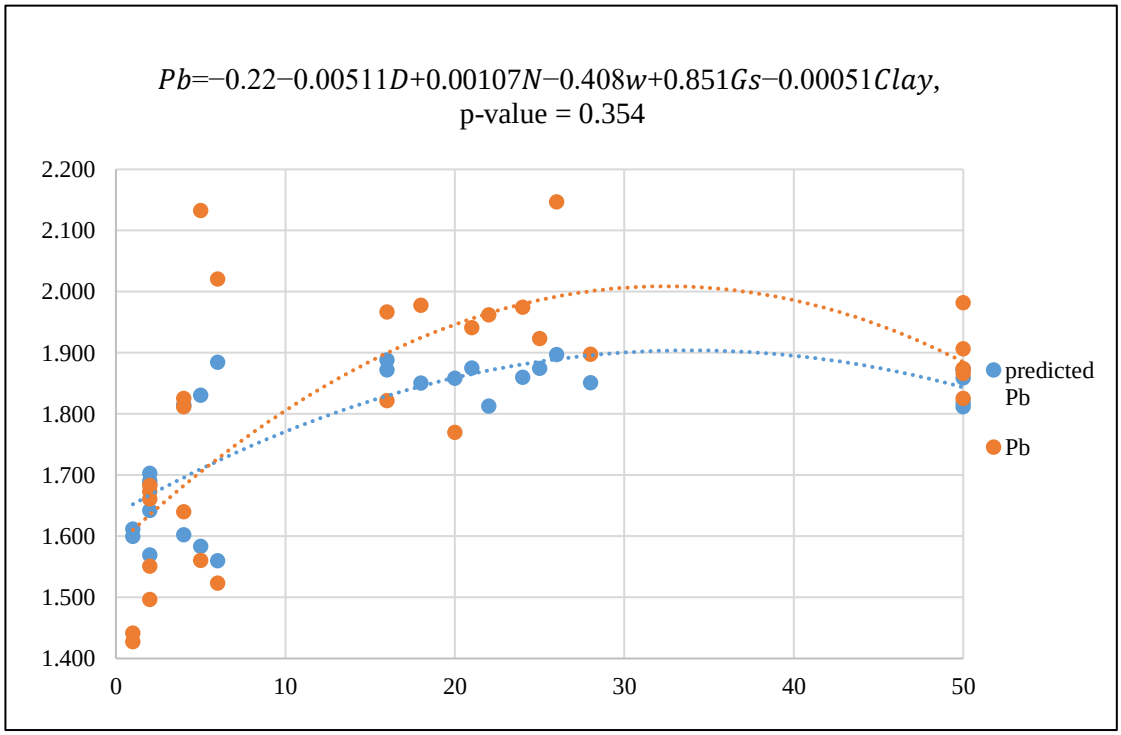



Figure 4.23 Comparison between Predicted and Observed Bulk Density Values

Overall, the validation results demonstrate that all four regression models produced *p*-values greater than 0.05, indicating no statistically significant differences between the predicted and observed values. The close agreement between the regression predictions and laboratory measurements confirms the reliability of the developed empirical equations for estimating Moisture Content, Specific Gravity, Clay Content and Bulk Density. These findings indicate that the proposed models are suitable for preliminary geotechnical investigations of soft alluvial soils and provide a sound basis for the sensitivity and external validation analyses presented in the following sections.

### 4.5.3 Development of Nomograph

The final outcome of this study is the development of a nomograph based on the validated empirical regression models. The nomograph was developed to provide a practical graphical tool for estimating selected soil index properties directly from SPT *N*-value and depth without performing repeated mathematical calculations. It integrates the four validated regression equations into a single graphical framework, allowing rapid estimation of Moisture Content ($w$), Specific Gravity ($G_s$), Clay Content and Bulk Density ($\rho_b$) during preliminary geotechnical investigations.

Figure 4.24 illustrates the developed nomograph. The horizontal axis represents the measured SPT *N*-value, whereas the vertical axis represents sampling depth. Superimposed on the graph are the contour lines corresponding to the predicted Moisture Content ($w$), Bulk Density ($\rho_b$), Specific Gravity ($G_s$) and Clay Content derived from the empirical regression models. The background stratigraphic profile is included to provide geological context and to illustrate the relationship between the estimated soil properties and the observed subsurface stratification.

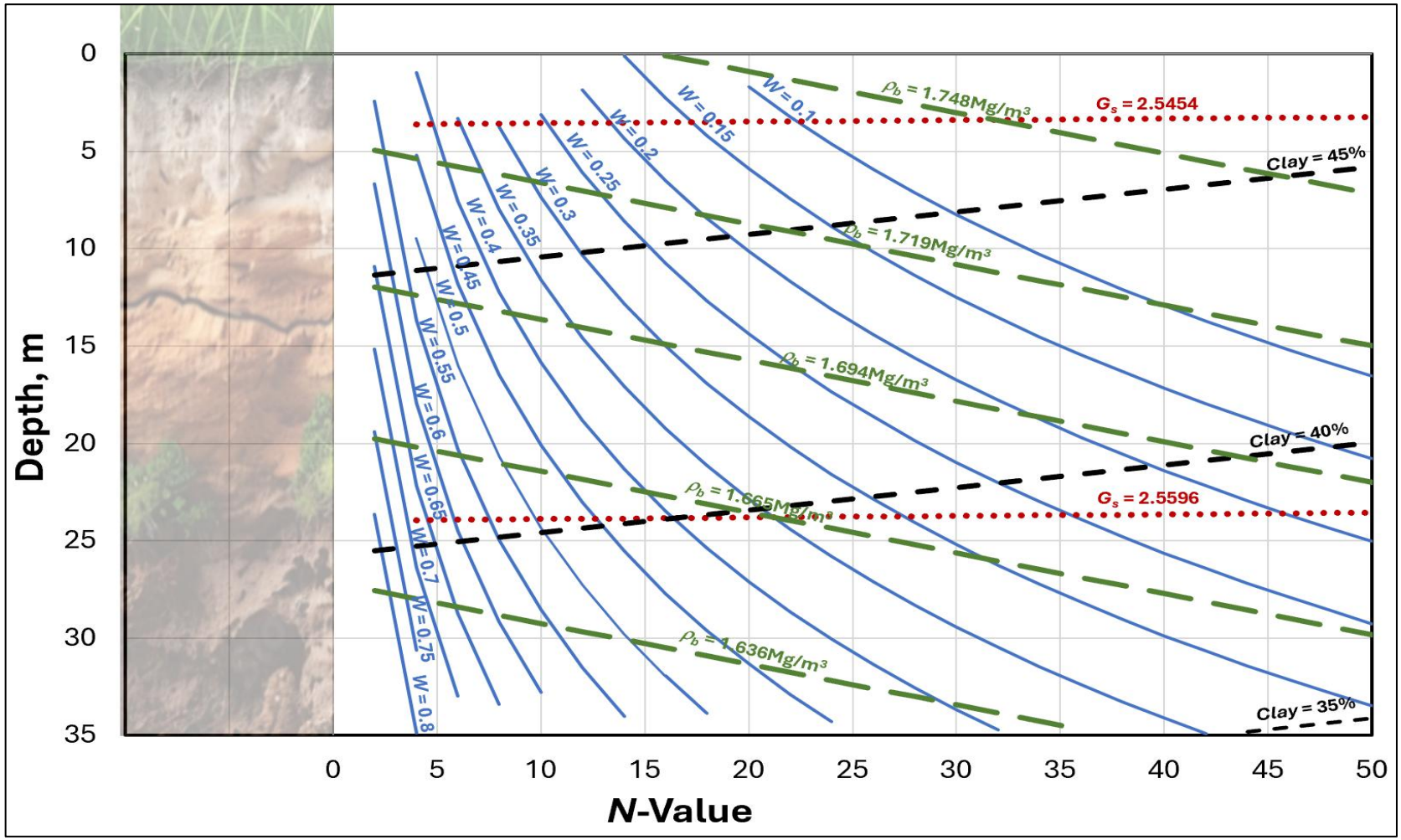



Figure 4.24 Nomograph Showing Relationship Between *N*-value and Soil Properties

The nomograph demonstrates that low SPT *N*-values recorded within the shallow soil layers are associated with relatively high Moisture Content, lower Bulk Density and higher Clay Content, representing the soft alluvial deposits identified throughout the study area. As depth and SPT *N*-values increase, the estimated Moisture Content decreases, while Bulk Density increases, indicating progressively denser and stiffer soil strata. The predicted Specific Gravity varies only slightly throughout the profile, reflecting the relatively consistent mineralogical composition of the investigated alluvial soils.

The developed nomograph enables engineers to estimate several soil index properties simultaneously using only SPT *N*-value and sampling depth. Consequently, it provides a rapid preliminary assessment tool that can support site investigations, foundation planning and preliminary geotechnical design where comprehensive laboratory testing is unavailable or limited. However, the nomograph is intended for preliminary estimation and should be applied within geological conditions similar to those represented by the PT 21044 study area and validated using appropriate laboratory testing where higher design accuracy is required.

The developed modelling framework represents a practical approach for estimating multiple soil index properties using a limited number of readily available field investigation parameters. Unlike conventional empirical correlations that independently estimate a single soil property, the proposed framework adopts a sequential prediction approach in which the estimated output from one regression model is incorporated into the subsequent model. Moisture Content ($w$) is first estimated from depth and SPT *N*-value, followed by the prediction of Specific Gravity ($G_s$). The estimated values of $w$ and $G_s$, together with depth and *N*-value, are subsequently used to estimate Clay Content, while all previously estimated parameters are finally integrated to predict Bulk Density ($\rho_b$). This sequential modelling strategy enables progressive estimation of soil properties from a limited set of field investigation data.

In addition to the development of four interconnected MLR equations, the proposed framework was transformed into a practical nomograph that enables rapid graphical estimation of soil properties without the need for direct mathematical computation. By locating the measured SPT *N*-value and sampling depth on the nomograph, engineers can estimate Moisture Content, Specific Gravity, Clay Content and Bulk Density through simple interpolation between the contour lines. This graphical

tool provides a practical alternative for users who prefer not to perform regression calculations and facilitates rapid preliminary geotechnical assessment.

Furthermore, the developed nomograph serves as a practical decision-support tool for geotechnical engineers by reducing the dependence on extensive laboratory testing during the early stages of site investigation. The estimated Bulk Density obtained from the nomograph may subsequently be used together with established geotechnical relationships to estimate additional engineering parameters, including effective stress and shear strength, which are essential for evaluating settlement behaviour, consolidation characteristics and foundation performance. Consequently, the proposed framework establishes a practical bridge between readily available SPT field data and more advanced geotechnical engineering assessments.

Overall, the developed nomograph represents the practical implementation of the empirical regression models established in this study. By integrating four sequential regression equations into a single graphical framework, the proposed approach enables efficient estimation of key soil index properties using only SPT *N*-value and depth. This contribution extends the application of conventional SPT interpretation beyond simple penetration resistance assessment and provides a practical tool for supporting preliminary site characterisation, foundation planning and geotechnical decision-making in soft alluvial deposits.

# CHAPTER 5
# CONCLUSION AND RECOMMENDATIONS

## 5.1 Overall Conclusion

The investigation of the surface and subsurface soil profiles indicated that the study area is primarily characterized by layered soft soil deposits exhibiting different geotechnical properties. The upper soil layers consist mainly of soft to very soft cohesive soils, which are defined by higher Moisture Content, lowered shear strength and relatively low stiffness indicative of weak ground conditions commonly related to alluvial deposits. As depth increases, the soil layers progressively change into stiffer and denser materials, signifying improved soil strength and density. This vertical variation illustrates the various characteristics of subsurface soils and indicates that soil behaviour significantly differs with depth as a result of depositional and geological factors. The characterization of these soil layers clarifies the subsurface stratigraphy and defines a fundamental geotechnical framework for interpreting soil behaviour within the study area. This improves the reliability of site characterization by precisely identifying the soil profile and identifying the most common soft soil conditions that influence the engineering behaviour of the site.

The examination of SPT data derived from engineering borehole logs provided significant understanding into the variability of soil resistance throughout the soil profile. The recorded *N*-values usually display low values in the shallow soil layers, indicating the presence of weak and compressible soils at the ground surface. As the depth increases, the *N*-values show a gradual increase, suggesting the existence of denser and more competent soil layers. This trend indicates a progressive improvement of soil stiffness and strength with depth, highlighting the effectiveness of the SPT as a practical in situ method for evaluating subsurface soil conditions. The dataset obtained from various boreholes offers a reliable picture of soil resistance throughout the site. This finding highlights the importance of *N*-values as an important in situ indicator to evaluate subsurface soil variability and provides an important dataset required for future correlation and modelling of soil engineering properties.

The evaluation of geotechnical engineering properties using laboratory testing provided a comprehensive characterization of the subsurface soils. Laboratory analyses of disturbed and undisturbed samples indicated variations in important soil properties, such as Moisture Content, Specific Gravity, particle size distribution and soil consistency characteristics. The findings demonstrate that the soils in the study area primarily comprise soft fine-grained deposits characterized by relatively high Moisture Content and different plasticity characteristics, which are characteristic of soft alluvial soils. The laboratory findings improve the in situ SPT results and provide quantitative parameters important to understanding the engineering behaviour of the soils. The combination of field investigation data and laboratory testing results enhances the reliability of subsurface soil characterization and establishes a comprehensive database for analysing the correlations between SPT *N*-values and soil engineering properties.

The correlation analysis of SPT *N*-values and soil engineering properties indicates that significant relationships exist between in situ penetration resistance and important soil parameters. The findings demonstrate that changes in *N*-values correlate with identifiable changes in soil engineering properties including Moisture Content, Specific Gravity, Bulk Density and Composition of *Clay*. The correlations show the significance of SPT measurements as a reliable indicator for estimating important geotechnical soil properties. The development of empirical correlations between *N*-values and soil parameters offers an effective method for analysing subsurface soil conditions especially in cases where comprehensive laboratory testing is impractical. This study improves the application of SPT data in geotechnical investigations and facilitates the development of simplified methods for estimating soil engineering properties in soft soil conditions.

A predictive modelling framework was successfully developed by integrating SPT *N*-values with selected geotechnical soil properties in order to improve the reliability of subsurface soil characterization. Based on regression analysis, four empirical equations were established to estimate soil parameters including Moisture Content ($w$), Specific Gravity ($G_s$), Clay Content and Bulk Density ($\rho_b$) using *N*-values and depth (D) as predictive variables. The developed regression equations are expressed as follows:

a) Moisture Content, $(w) = 0.6540 + 0.0118D - 0.4441 \log(N)$

b) Specific Gravity, $(G_s) = 2.6865 + 0.0015D + 0.000012N - 0.3257w$

c) Clay Content, $= 460 - 0.242D + 0.028N + 81.7w - 177.0G_s$

d) Bulk Density, $(\rho_b) = -0.22 - 0.00511D + 0.00107N - 0.408w + 0.851G_s - 0.00051\ Clay$.

The developed empirical models were validated using independent datasets from PT 21044 (BH20–BH25), Lot 120185 and Lot 120188. The validation results demonstrated good agreement between the predicted and measured values, indicating that the proposed modelling framework is applicable to similar soft alluvial soil conditions within the Selangor Cyber Valley. Nevertheless, further validation using datasets from different geological settings is recommended before wider implementation. Validation using paired sample *t*-tests produced p-values greater than 0.05 for all four developed models, indicating no statistically significant differences between the predicted and observed values. These findings confirm that the proposed empirical equations provide reliable predictions and are applicable to similar Quaternary alluvial deposits within the Selangor Cyber Valley.

In addition, a practical nomograph was successfully developed by integrating the four validated empirical equations into a single graphical framework. The nomograph enables rapid estimation of Moisture Content ($w$), Specific Gravity ($G_s$), Clay Content and Bulk Density ($\rho_b$) directly from SPT *N*-value and depth without performing repeated mathematical calculations. This practical tool enhances the application of the developed modelling framework during preliminary geotechnical investigations and provides engineers with an efficient approach for rapid site assessment and foundation planning.

## 5.2 Recommendations

Future research is recommended to apply the developed empirical modelling framework to other locations within Cyberjaya and surrounding regions with similar Quaternary alluvial deposits. Expanding the database across different geological settings would improve the general applicability and robustness of the proposed regression equations.

Artificial intelligence (AI)-based modelling techniques such as Artificial Neural Networks (ANN), Support Vector Regression (SVR), Random Forest and Gradient Boosting algorithms may be investigated and compared with the Multiple Linear Regression models developed in this study. Such comparisons would provide valuable insight into the advantages and limitations of conventional statistical models and advanced machine learning approaches for predicting soil properties.

Future studies are also encouraged to extend the proposed modelling framework to additional engineering properties, including undrained shear strength, compressibility, consolidation characteristics, permeability and shear wave velocity. Developing predictive models for these parameters would further enhance the practical application of SPT-based empirical modelling in geotechnical engineering.

Future studies are recommended to validate the proposed empirical models using datasets from different geological formations and geographical regions to further evaluate their scalability and transferability.

Additional validation using larger datasets obtained from different geological formations throughout Malaysia is recommended to further evaluate the robustness and regional applicability of the proposed empirical models. The developed regression models may also be integrated with Geographic Information Systems (GIS) and Building Information Modelling (BIM) platforms to support digital geotechnical mapping, site characterization and sustainable infrastructure planning.

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# APPENDICES

# APPENDIX 1

Detail for Soil Sampling (Data Analysis) at Site PT 21044 Cyberjaya (BH1-BH19) and (BH26-BH31).

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| BH 1 | T1D2 | D | 3.00 | 8 |
| | T1D4 | D | 6.00 | |
| | T1UD1 | UD | 7.50 | |
| | T1D5 | D | 9.00 | |
| | T1UD2 | UD | 10.50 | |
| | T1D8 | D | 15.00 | |
| | T1D12 | D | 21.00 | |
| | T1D14 | D | 24.00 | |
| BH 2 | T2D1 | D | 1.50 | 9 |
| | T2D3 | D | 4.50 | |
| | T2UD1 | UD | 6.00 | |
| | T2D4 | D | 7.50 | |
| | T2UD2 | UD | 9.00 | |
| | T2D6 | D | 12.00 | |
| | T2D9 | D | 16.50 | |
| | T2D12 | D | 21.00 | |
| | T2D15 | D | 25.00 | |
| BH 3 | T3D2 | D | 3.00 | 9 |
| | T3D4 | D | 6.00 | |
| | T3UD1 | UD | 7.50 | |
| | T3D5 | D | 9.00 | |
| | T3UD2 | UD | 10.50 | |
| | T3D6 | D | 12.00 | |
| | T3D8 | D | 15.00 | |
| | T3D10 | D | 18.00 | |
| | T3D14 | D | 24.00 | |

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| BH 4 | T4D1 | D | 1.50 | 9 |
| | T4D3 | D | 4.50 | |
| | T4UD1 | UD | 6.00 | |
| | T4D4 | D | 7.50 | |
| | T4UD2 | UD | 9.00 | |
| | T4D6 | D | 12.00 | |
| | T4D8 | D | 15.00 | |
| | T4D10 | D | 18.00 | |
| | T4D15 | D | 25.50 | |
| BH 5 | T5D1 | D | 1.50 | 9 |
| | T5D4 | D | 6.00 | |
| | T5UD1 | UD | 7.50 | |
| | T5D5 | D | 9.00 | |
| | T5UD2 | UD | 10.50 | |
| | T5D7 | D | 13.50 | |
| | T5D9 | D | 16.50 | |
| | T5D13 | D | 22.50 | |
| | T5D16 | D | 27.00 | |
| BH 6 | T6D1 | D | 1.50 | 9 |
| | T6D4 | D | 6.00 | |
| | T6UD1 | UD | 7.50 | |
| | T6D5 | D | 9.00 | |
| | T6UD2 | UD | 10.50 | |
| | T6D6 | D | 12.00 | |
| | T6D8 | D | 15.00 | |
| | T6D10 | D | 18.00 | |
| | T6D14 | D | 24.00 | |
| BH 7 | T7D1 | D | 1.50 | 9 |
| | T7D3 | D | 4.50 | |
| | T7UD1 | UD1 | 6.00 | |

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| | T7D4 | D | 7.50 | |
| | T7UD2 | UD | 9.00 | |
| | T7D6 | D | 12.00 | |
| | T7D9 | D | 16.50 | |
| | T7D11 | D | 19.50 | |
| | T7D15 | D | 25.50 | |
| BH 8 | T8D1 | D | 1.50 | 8 |
| | T8D3 | D | 4.50 | |
| | T8UD1 | UD | 6.00 | |
| | T8D4 | D | 7.50 | |
| | T8D6 | D | 11.20 | |
| | T8D8 | D | 15.00 | |
| | T8D11 | D | 19.50 | |
| | T8D14 | D | 24.00 | |
| BH 9 | T9D1 | D | 1.50 | 9 |
| | T9D3 | D | 4.50 | |
| | T9UD1 | UD | 6.00 | |
| | T9D4 | D | 7.50 | |
| | T9UD2 | UD | 9.00 | |
| | T9D7 | D | 13.50 | |
| | T9D9 | D | 16.50 | |
| | T9D12 | D | 21.00 | |
| | T9D15 | D | 25.50 | |
| BH10 | T10D2 | D | 3.00 | 8 |
| | T10UD1 | UD | 6.00 | |
| | T10D4 | D | 7.50 | |
| | T10UD2 | UD | 9.00 | |
| | T10D5 | D | 10.50 | |
| | T10D8 | D | 15.00 | |
| | T10D10 | D | 18.00 | |

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| | T10D14 | D | 24.00 | |
| BH 11 | T11D1 | D | 1.50 | 8 |
| | T11UD1 | UD | 3.00 | |
| | T11D3 | D | 6.00 | |
| | T11UD2 | UD | 7.50 | |
| | T11D5 | D | 10.50 | |
| | T11D6 | D | 12.00 | |
| | T11D10 | D | 18.00 | |
| | T11D15 | D | 25.50 | |
| BH 12 | T12D 2 | D | 3.00 | 8 |
| | T12UD1 | UD | 6.00 | |
| | T12D4 | D | 7.50 | |
| | T12UD2 | UD | 9.00 | |
| | T12D6 | D | 12.00 | |
| | T12D9 | D | 16.50 | |
| | T12D10 | D | 18.00 | |
| | T12D14 | D | 21.00 | |
| BH 13 | T13D1 | D | 1.50 | 9 |
| | T13D3 | D | 4..5 | |
| | T13UD1 | UD | 6.00 | |
| | T13D4 | D | 7.50 | |
| | T13UD2 | UD | 9.00 | |
| | T13D6 | D | 12.00 | |
| | T13D8 | D | 15.00 | |
| | T13D10 | D | 18.00 | |
| | T13D15 | D | 25.50 | |
| BH 14 | T14D1 | D | 1.50 | 9 |
| | T14D4 | D | 6.00 | |
| | T14UD1 | UD | 7.50 | |
| | T14D5 | D | 9.00 | |

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| | T14UD2 | UD | 10.50 | |
| | T14D7 | D | 13.50 | |
| | T14D9 | D | 16.50 | |
| | T14D11 | D | 19.50 | |
| | T14D14 | D | 24.00 | |
| BH 15 | T15D1 | D | 1.50 | 9 |
| | T15D4 | D | 6.00 | |
| | T15UD1 | UD | 7.50 | |
| | T15D5 | D | 9.00 | |
| | T15UD2 | UD | 10.50 | |
| | T15D7 | D | 13.50 | |
| | T15D9 | D | 16.50 | |
| | T15D11 | D | 19.50 | |
| | T15D15 | D | 25.50 | |
| BH 16 | T16D1 | D | 1.50 | 9 |
| | T16UD1 | UD | 6.00 | |
| | T16D4 | D | 7.50 | |
| | T16UD2 | UD | 9.00 | |
| | T16D5 | D | 10.50 | |
| | T16D7 | D | 13.50 | |
| | T16D9 | D | 16.50 | |
| | T16D11 | D | 19.50 | |
| | T16D15 | D | 25.50 | |
| BH 17 | T17D1 | D | 1.50 | 9 |
| | T17D4 | D | 6.00 | |
| | T17UD1 | UD | 7.50 | |
| | T17D5 | D | 9.00 | |
| | T17UD2 | UD | 10.50 | |
| | T17D6 | D | 12.00 | |
| | T17D8 | D | 15.00 | |

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| | T17D10 | D | 18.00 | |
| | T17D14 | D | 24.00 | |
| BH 18 | T18D1 | D | 1.50 | 9 |
| | T18D3 | D | 4.50 | |
| | T18UD1 | UD | 7.50 | |
| | T18D5 | D | 9.00 | |
| | T18UD2 | UD | 10.50 | |
| | T18D6 | D | 12.00 | |
| | T18D8 | D8 | 15.00 | |
| | T18D11 | D | 19.50 | |
| | T18D14 | D | 24.00 | |
| BH 19 | T19D1 | D | 1.50 | 9 |
| | T19D3 | D | 4.50 | |
| | T19UD1 | UD | 6.00 | |
| | T19D4 | D | 7.50 | |
| | T19UD2 | UD | 9.00 | |
| | T19D6 | D | 12.00 | |
| | T19D9 | D | 16.00 | |
| | T19D12 | D | 21.00 | |
| | T19D15 | D | 25.50 | |
| BH 26 | T26D2 | D | 3.00 | 9 |
| | T26D4 | D | 6.00 | |
| | T26UD1 | UD | 7.50 | |
| | T26D5 | D | 9.00 | |
| | T26UD2 | UD | 10.50 | |
| | T26D6 | D | 12.00 | |
| | T26D9 | D | 16.50 | |
| | T26D12 | D | 21.00 | |
| | T26D14 | D | 24.00 | |

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| BH 27 | T27D1 | D | 1.50 | 8 |
| | T27D4 | D | 6.00 | |
| | T27UD1 | UD | 7.50 | |
| | T27D5 | D | 9.00 | |
| | T27UD2 | UD | 10.50 | |
| | T27D7 | D | 13.50 | |
| | T27D9 | D | 16.50 | |
| | T27D13 | D | 22.50 | |
| BH 28 | T28D2 | D | 3.00 | 9 |
| | T28D4 | D | 6.00 | |
| | T28UD1 | UD | 7.50 | |
| | T28D5 | D | 9.00 | |
| | T28UD2 | UD | 10.50 | |
| | T28D8 | D | 15.00 | |
| | T28D11 | D | 19.50 | |
| | T28D14 | D | 24.00 | |
| | T28D15 | D | 25.50 | |
| BH 29 | T29D1 | D | 1.50 | 9 |
| | T29D3 | D | 4.50 | |
| | T29UD1 | UD | 6.00 | |
| | T29D4 | D | 7.50 | |
| | T29UD2 | UD | 9.00 | |
| | T29D6 | D | 12.00 | |
| | T29D9 | D | 16.50 | |
| | T29D12 | D | 21.00 | |
| | T29D15 | D | 25.50 | |
| BH 30 | T30D1 | D | 1.50 | 9 |
| | T30D4 | D | 6.00 | |
| | T30UD1 | UD | 7.50 | |
| | T30D5 | D | 9.00 | |

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| | T30UD2 | UD | 10.50 | |
| | T30D7 | D | 13.50 | |
| | T30D9 | D | 16.50 | |
| | T30D12 | D | 21.00 | |
| | T30D16 | D | 27.00 | |
| BH 31 | T31D2 | D | 3.00 | 9 |
| | T31D4 | D | 6.00 | |
| | T31UD1 | UD | 7.50 | |
| | T31D5 | D | 9.00 | |
| | T31UD2 | UD | 10.50 | |
| | T31D6 | D | 12.00 | |
| | T31D8 | D | 15.00 | |
| | T31D11 | D | 19.50 | |
| | T31D14 | D | 24.00 | |
| Total | | 219 | | |

# APPENDIX 2

Detail for Soil Sampling (Data Validation) at Site PT 21044 Cyberjaya (BH20-BH25).

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| BH 20 | T20D1 | D | 1.50 | 9 |
| | T20D3 | D | 4.50 | |
| | T20D4 | D | 6.00 | |
| | T20UD1 | UD | 7.50 | |
| | T20D5 | D | 9.00 | |
| | T20UD2 | UD | 10.50 | |
| | T20D6 | D | 12.00 | |
| | T20D12 | D | 21.00 | |
| | T20D15 | D | 25.50 | |
| BH 21 | T21D1 | D | 1.50 | 9 |
| | T21D3 | D | 4.50 | |
| | T21UD1 | UD | 6.00 | |
| | T21D4 | D | 7.50 | |
| | T21UD2 | UD | 9.00 | |
| | T21D6 | D | 12.00 | |
| | T21D8 | D | 15.00 | |
| | T21D10 | D | 18.00 | |
| | T21D15 | D | 25.50 | |
| BH 22 | T22D2 | D | 3.00 | 9 |
| | T22D3 | D | 4.50 | |
| | T22UD1 | UD | 6.00 | |
| | T22D4 | D | 7.50 | |
| | T22UD2 | UD | 9.00 | |
| | T22D5 | D | 10.50 | |
| | T22D7 | D | 13.50 | |
| | T22D9 | D | 16.50 | |
| | T22D14 | D | 24.00 | |

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| BH 23 | T23D1 | D | 1.50 | 9 |
| | T23D3 | D | 4.50 | |
| | T23UD1 | UD | 6.00 | |
| | T23D4 | D | 7.50 | |
| | T23UD2 | UD | 9.00 | |
| | T23D5 | D | 10.50 | |
| | T23D7 | D | 13.50 | |
| | T23D10 | D | 18.00 | |
| | T23D14 | D | 24.00 | |
| BH 24 | T24D1 | D | 1.50 | 9 |
| | T24D3 | D | 4.50 | |
| | T24UD1 | UD | 6.00 | |
| | T24D4 | D | 7.50 | |
| | T24UD2 | UD | 9.00 | |
| | T24D6 | D | 12.00 | |
| | T24D9 | D | 16.50 | |
| | T24D12 | D | 21.00 | |
| | T24D14 | D | 24.00 | |
| BH 25 | T25D1 | D | 1.50 | 8 |
| | T25D3 | D | 4.50 | |
| | T25UD1 | UD | 6.00 | |
| | T25D5 | D | 10.50 | |
| | T25D7 | D | 13.50 | |
| | T25D9 | D | 16.50 | |
| | T25D11 | D | 19.50 | |
| | T25D14 | D | 24.00 | |
| Total | | | | 53 |

# APPENDIX 3

Detail for Soil Sampling (Data Validation) at Site Lot 120188, Selangor Cyber Valley.

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| BH1 | SA1D3 | D | 4.50 | 8 |
| | SA1D5 | D | 7.50 | |
| | SA1UD1 | UD | 9.50 | |
| | SA1D7 | D | 10.50 | |
| | SA1D10 | D | 15.00 | |
| | SA1UD2 | UD | 15.50 | |
| | SA1D12 | D | 18.00 | |
| | SA1D17 | D | 25.50 | |
| BH2 | SA2D2 | D | 3.00 | 7 |
| | SA2UD1 | UD | 3.40 | |
| | SA2D4 | D | 6.00 | |
| | SA2D6 | D | 9.00 | |
| | SA2D9 | D | 13.50 | |
| | SA2D11 | D | 16.50 | |
| | SA2D14 | D | 21.00 | |
| BH3 | SA3D1 | D | 1.50 | 7 |
| | SA3D3 | D | 4.50 | |
| | SA3D5 | D | 7.50 | |
| | SA3UD1 | UD | 9.50 | |
| | SA3D7 | D | 10.50 | |
| | SA3D12 | D | 18.00 | |
| | SA3D14 | D | 21.00 | |
| BH4 | SA4UD1 | UD | 2.00 | 8 |
| | SA4D2 | D | 3.00 | |
| | SA4D4 | D | 7.50 | |
| | SA4D5 | D | 9 | |
| | SA4UD3 | D | 9.5 | |

| | | | |
|---|---|---|---|
| | SA4D6 | D | 10.50 |
| | SA4D10 | D | 16.50 |
| | SA4D12 | D | 19.50 |
| Total | | | 30 |

# APPENDIX 4

Detail for Soil Sampling (Data Validation) at Site Lot 120185, Selangor Cyber Valley

| Borehole | Name of Sample | Type of Sample | Depth (m) | Total of Sample |
|---|---|---|---|---|
| BH1 | SB1D1 | D | 1.50 | 8 |
| | SB1C1 | UD | 4.50 | |
| | SB1D4 | D | 9.00 | |
| | SB1D5 | D | 10.50 | |
| | SB1D6 | D | 12.00 | |
| | SB1D7 | D | 13.50 | |
| | SB1D11 | D | 21.00 | |
| | SB1C4 | UD | 29.00 | |
| BH2 | SB2D3 | D | 6.00 | 9 |
| | SB2D4 | D | 4.50 | |
| | SB2U3 | UD | 8.00 | |
| | SB2D5 | D | 9.00 | |
| | SB2D6 | D | 10.50 | |
| | SB2D9 | D | 15.00 | |
| | SB2D10 | D | 16.50 | |
| | SB2D11 | D | 18.00 | |
| | SB2C1 | UD | 29.00 | |
| BH3 | SB3D2 | D | 3.00 | 7 |
| | SB3D3 | D | 3.00 | |
| | SB3D5 | D | 9.00 | |
| | SB3D6 | D | 10.50 | |
| | SB3D8 | D | 13.50 | |
| | SB3D9 | D | 15.00 | |
| | SB3D14 | D | 24.00 | |
| BH4 | SB4D1 | D | 1.50 | 8 |
| | SB4D4 | D | 6.00 | |
| | SB4D5 | D | 7.50 | |

| | | |
|---|---|---|
| SB4D6 | D | 9.00 |
| SB4U3 | UD | 9.50 |
| SB4D7 | D | 10.50 |
| SB4D8 | D | 12.00 |
| SB4D12 | D | 18.00 |
| Total | | 32 |

# APPENDIX 5

Detail for *N*-Value at 21044 Cyberjaya (BH1-BH19) and (BH26-BH31)

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| BH 1 | T1D2 | 3.00 | 2 | 8 |
| | T1D4 | 6.00 | 3 | |
| | T1UD1 | 7.50 | | |
| | T1D5 | 9.00 | 4 | |
| | T1UD2 | 10.50 | | |
| | T1D8 | 15.00 | 16 | |
| | T1D12 | 21.00 | 24 | |
| | T1D14 | 24.00 | 50 | |
| BH 2 | T2D1 | 1.50 | 2 | 9 |
| | T2D3 | 4.50 | 5 | |
| | T2UD1 | 6.00 | | |
| | T2D4 | 7.50 | 2 | |
| | T2UD2 | 9.00 | | |
| | T2D6 | 12.00 | 4 | |
| | T2D9 | 16.50 | 12 | |
| | T2D12 | 21.00 | 22 | |
| | T2D15 | 25.00 | 50 | |
| BH 3 | T3D2 | 3.00 | 3 | 9 |
| | T3D4 | 6.00 | 3 | |
| | T3UD1 | 7.50 | | |
| | T3D5 | 9.00 | 4 | |
| | T3UD2 | 10.50 | | |
| | T3D6 | 12.00 | 5 | |
| | T3D8 | 15.00 | 8 | |
| | T3D10 | 18.00 | 15 | |
| | T3D14 | 24.00 | 50 | |
| BH 4 | T4D1 | 1.50 | 3 | 9 |

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| | T4D3 | 4.50 | 4 | |
| | T4UD1 | 6.00 | | |
| | T4D4 | 7.50 | 2 | |
| | T4UD2 | 9.00 | | |
| | T4D6 | 12.00 | 5 | |
| | T4D8 | 15.00 | 12 | |
| | T4D10 | 18.00 | 23 | |
| | T4D15 | 25.50 | 50 | |
| | T5D1 | 1.50 | 4 | |
| | T5D4 | 6.00 | 3 | |
| | T5UD1 | 7.50 | | |
| | T5D5 | 9.00 | 4 | |
| BH 5 | T5UD2 | 10.50 | | 9 |
| | T5D7 | 13.50 | 9 | |
| | T5D9 | 16.50 | 16 | |
| | T5D13 | 22.50 | 22 | |
| | T5D16 | 27.00 | 50 | |
| | T6D1 | 1.50 | 3 | |
| | T6D4 | 6.00 | 2 | |
| | T6UD1 | 7.50 | 2 | |
| | T6D5 | 9.00 | 2 | |
| BH 6 | T6UD2 | 10.50 | | 9 |
| | T6D6 | 12.00 | 4 | |
| | T6D8 | 15.00 | 12 | |
| | T6D10 | 18.00 | 20 | |
| | T6D14 | 24.00 | 50 | |
| | T7D1 | 1.50 | 4 | |
| | T7D3 | 4.50 | 3 | |
| BH 7 | T7UD1 | 6.00 | | 9 |
| | T7D4 | 7.50 | 3 | |

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| | T7UD2 | 9.00 | | |
| | T7D6 | 12.00 | | |
| | T7D9 | 16.50 | 9 | |
| | T7D11 | 19.50 | 15 | |
| | T7D15 | 25.50 | 50 | |
| BH 8 | T8D1 | 1.50 | 4 | 8 |
| | T8D3 | 4.50 | 4 | |
| | T8UD1 | 6.00 | | |
| | T8D4 | 7.50 | 5 | |
| | T8D6 | 11.20 | 5 | |
| | T8D8 | 15.00 | 12 | |
| | T8D11 | 19.50 | 25 | |
| | T8D14 | 24.00 | 50 | |
| BH 9 | T9D1 | 1.50 | 2 | 9 |
| | T9D3 | 4.50 | 2 | |
| | T9UD1 | 6.00 | | |
| | T9D4 | 7.50 | 1 | |
| | T9UD2 | 9.00 | | |
| | T9D7 | 13.50 | 2 | |
| | T9D9 | 16.50 | 19 | |
| | T9D12 | 21.00 | 26 | |
| | T9D15 | 25.50 | 50 | |
| BH10 | T10D2 | 3.00 | 1 | 8 |
| | T10UD1 | 6.00 | | |
| | T10D4 | 7.50 | 1 | |
| | T10UD2 | 9.00 | | |
| | T10D5 | 10.50 | 2 | |
| | T10D8 | 15.00 | 15 | |
| | T10D10 | 18.00 | 26 | |
| | T10D14 | 24.00 | 50 | |

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| BH 11 | T11D1 | 1.50 | 1 | 8 |
| | T11UD1 | 3.00 | | |
| | T11D3 | 6.00 | 1 | |
| | T11UD2 | 7.50 | | |
| | T11D5 | 10.50 | 3 | |
| | T11D6 | 12.00 | 29 | |
| | T11D10 | 18.00 | 29 | |
| | T11D15 | 25.50 | 50 | |
| BH 12 | T12D 2 | 3.00 | 1 | 8 |
| | T12UD1 | 6.00 | | |
| | T12D4 | 7.50 | | |
| | T12UD2 | 9.00 | | |
| | T12D6 | 12.00 | 4 | |
| | T12D9 | 16.50 | 8 | |
| | T12D10 | 18.00 | 21 | |
| | T12D14 | 21.00 | 50 | |
| BH 13 | T13D1 | 1.50 | 6 | 9 |
| | T13D3 | 4..5 | 4 | |
| | T13UD1 | 6.00 | | |
| | T13D4 | 7.50 | 2 | |
| | T13UD2 | 9.00 | | |
| | T13D6 | 12.00 | 4 | |
| | T13D8 | 15.00 | 11 | |
| | T13D10 | 18.00 | 22 | |
| | T13D15 | 25.50 | 50 | |
| BH 14 | T14D1 | 1.50 | 3 | 9 |
| | T14D4 | 6.00 | 4 | |
| | T14UD1 | 7.50 | | |
| | T14D5 | 9.00 | 4 | |
| | T14UD2 | 10.50 | | |

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| | T14D7 | 13.50 | 9 | |
| | T14D9 | 16.50 | 18 | |
| | T14D11 | 19.50 | 25 | |
| | T14D14 | 24.00 | 50 | |
| BH 15 | T15D1 | 1.50 | 4 | 9 |
| | T15D4 | 6.00 | 2 | |
| | T15UD1 | 7.50 | | |
| | T15D5 | 9.00 | 3 | |
| | T15UD2 | 10.50 | | |
| | T15D7 | 13.50 | 5 | |
| | T15D9 | 16.50 | 19 | |
| | T15D11 | 19.50 | 31 | |
| | T15D15 | 25.50 | 50 | |
| BH 16 | T16D1 | 1.50 | 4 | 9 |
| | T16UD1 | 6.00 | | |
| | T16D4 | 7.50 | 2 | |
| | T16UD2 | 9.00 | | |
| | T16D5 | 10.50 | 4 | |
| | T16D7 | 13.50 | 8 | |
| | T16D9 | 16.50 | 24 | |
| | T16D11 | 19.50 | 32 | |
| | T16D15 | 25.50 | 50 | |
| BH 17 | T17D1 | 1.50 | 1 | 9 |
| | T17D4 | 6.00 | 4 | |
| | T17UD1 | 7.50 | | |
| | T17D5 | 9.00 | 4 | |
| | T17UD2 | 10.50 | | |
| | T17D6 | 12.00 | 5 | |
| | T17D8 | 15.00 | 14 | |
| | T17D10 | 18.00 | 26 | |

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| | T17D14 | 24.00 | 50 | |
| BH 18 | T18D1 | 1.50 | 11 | 9 |
| | T18D3 | 4.50 | 8 | |
| | T18UD1 | 7.50 | | |
| | T18D5 | 9.00 | 4 | |
| | T18UD2 | 10.50 | | |
| | T18D6 | 12.00 | 5 | |
| | T18D8 | 15.00 | 16 | |
| | T18D11 | 19.50 | 29 | |
| | T18D14 | 24.00 | 50 | |
| BH 19 | T19D1 | 1.50 | 6 | 9 |
| | T19D3 | 4.50 | 6 | |
| | T19UD1 | 6.00 | | |
| | T19D4 | 7.50 | 6 | |
| | T19UD2 | 9.00 | | |
| | T19D6 | 12.00 | 5 | |
| | T19D9 | 16.00 | 11 | |
| | T19D12 | 21.00 | 19 | |
| | T19D15 | 25.50 | 50 | |
| BH 26 | T26D2 | 3.00 | | 9 |
| | T26D4 | 6.00 | 6 | |
| | T26UD1 | 7.50 | 2 | |
| | T26D5 | 9.00 | | |
| | T26UD2 | 10.50 | 3 | |
| | T26D6 | 12.00 | | |
| | T26D9 | 16.50 | 5 | |
| | T26D12 | 21.00 | 17 | |
| | T26D14 | 24.00 | 25 | |
| BH 27 | T27D1 | 1.50 | 50 | 8 |
| | T27D4 | 6.00 | 3 | |

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| | T27UD1 | 7.50 | 4 | |
| | T27D5 | 9.00 | | |
| | T27UD2 | 10.50 | 3 | |
| | T27D7 | 13.50 | | |
| | T27D9 | 16.50 | 9 | |
| | T27D13 | 22.50 | 16 | |
| | T28D2 | 3.00 | 50 | |
| | T28D4 | 6.00 | 2 | |
| | T28UD1 | 7.50 | 4 | |
| | T28D5 | 9.00 | | |
| BH 28 | T28UD2 | 10.50 | 5 | 9 |
| | T28D8 | 15.00 | | |
| | T28D11 | 19.50 | 12 | |
| | T28D14 | 24.00 | 28 | |
| | T28D15 | 25.50 | 35 | |
| | T29D1 | 1.50 | 50 | |
| | T29D3 | 4.50 | 1 | |
| | T29UD1 | 6.00 | 4 | |
| | T29D4 | 7.50 | | |
| BH 29 | T29UD2 | 9.00 | 3 | 9 |
| | T29D6 | 12.00 | | |
| | T29D9 | 16.50 | 5 | |
| | T29D12 | 21.00 | 20 | |
| | T29D15 | 25.50 | 32 | |
| | T30D1 | 1.50 | 50 | |
| | T30D4 | 6.00 | 4 | |
| | T30UD1 | 7.50 | 2 | |
| BH 30 | T30D5 | 9.00 | | 9 |
| | T30UD2 | 10.50 | 3 | |
| | T30D7 | 13.50 | | |

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| | T30D9 | 16.50 | 5 | |
| | T30D12 | 21.00 | 13 | |
| | T30D16 | 27.00 | 25 | |
| BH 31 | T31D2 | 3.00 | 50 | 9 |
| | T31D4 | 6.00 | 4 | |
| | T31UD1 | 7.50 | 4 | |
| | T31D5 | 9.00 | | |
| | T31UD2 | 10.50 | 3 | |
| | T31D6 | 12.00 | | |
| | T31D8 | 15.00 | 5 | |
| | T31D11 | 19.50 | 11 | |
| | T31D14 | 24.00 | 30 | |
| Total | | 219 | | |

# APPENDIX 6

Detail for *N*-Value at PT 21044 Cyberjaya (BH20-BH25)

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| BH 20 | T20D1 | 1.50 | 11 | 9 |
| | T20D3 | 4.50 | 2 | |
| | T20D4 | 6.00 | 2 | |
| | T20UD1 | 7.50 | | |
| | T20D5 | 9.00 | 3 | |
| | T20UD2 | 10.50 | | |
| | T20D6 | 12.00 | 12 | |
| | T20D12 | 21.00 | 29 | |
| | T20D15 | 25.50 | 50 | |
| BH 21 | T21D1 | 1.50 | 2 | 9 |
| | T21D3 | 4.50 | 2 | |
| | T21UD1 | 6.00 | | |
| | T21D4 | 7.50 | 4 | |
| | T21UD2 | 9.00 | | |
| | T21D6 | 12.00 | 16 | |
| | T21D8 | 15.00 | 18 | |
| | T21D10 | 18.00 | 22 | |
| | T21D15 | 25.50 | 50 | |
| BH 22 | T22D2 | 3.00 | 2 | 9 |
| | T22D3 | 4.50 | 2 | |
| | T22UD1 | 6.00 | | |
| | T22D4 | 7.50 | 5 | |
| | T22UD2 | 9.00 | | |
| | T22D5 | 10.50 | 6 | |
| | T22D7 | 13.50 | 16 | |
| | T22D9 | 16.50 | 20 | |
| | T22D14 | 24.00 | 50 | |

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| BH 23 | T23D1 | 1.50 | 3 | 9 |
| | T23D3 | 4.50 | 4 | |
| | T23UD1 | 6.00 | | |
| | T23D4 | 7.50 | 4 | |
| | T23UD2 | 9.00 | | |
| | T23D5 | 10.50 | 6 | |
| | T23D7 | 13.50 | 16 | |
| | T23D10 | 18.00 | 24 | |
| | T23D14 | 24.00 | 50 | |
| BH 24 | T24D1 | 1.50 | 8 | 9 |
| | T24D3 | 4.50 | 3 | |
| | T24UD1 | 6.00 | | |
| | T24D4 | 7.50 | 4 | |
| | T24UD2 | 9.00 | | |
| | T24D6 | 12.00 | 6 | |
| | T24D9 | 16.50 | 21 | |
| | T24D12 | 21.00 | 28 | |
| | T24D14 | 24.00 | 50 | |
| BH 25 | T25D1 | 1.50 | 12 | 8 |
| | T25D3 | 4.50 | 2 | |
| | T25UD1 | 6.00 | | |
| | T25D5 | 10.50 | 6 | |
| | T25D7 | 13.50 | 26 | |
| | T25D9 | 16.50 | 25 | |
| | T25D11 | 19.50 | 34 | |
| | T25D14 | 24.00 | 50 | |
| Total | | | | 53 |

# APPENDIX 7

Detail for *N*-Value (Data Validation) at Site Lot 120188, Selangor Cyber Valley.

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| BH1 | SA1D3 | 4.50 | 7 | 8 |
| | SA1D5 | 7.50 | 14 | |
| | SA1UD1 | 9.50 | | |
| | SA1D7 | 10.50 | 4 | |
| | SA1D10 | 15.00 | 11 | |
| | SA1UD2 | 15.50 | | |
| | SA1D12 | 18.00 | 9 | |
| | SA1D17 | 25.50 | 29 | |
| BH2 | SA2D2 | 3.00 | 3 | 7 |
| | SA2UD1 | 3.40 | | |
| | SA2D4 | 6.00 | 3 | |
| | SA2D6 | 9.00 | 15 | |
| | SA2D9 | 13.50 | 12 | |
| | SA2D11 | 16.50 | 8 | |
| | SA2D14 | 21.00 | 50 | |
| BH3 | SA3D1 | 1.50 | 12 | 7 |
| | SA3D3 | 4.50 | 6 | |
| | SA3D5 | 7.50 | 10 | |
| | SA3UD1 | 9.50 | | |
| | SA3D7 | 10.50 | 6 | |
| | SA3D12 | 18.00 | 9 | |
| | SA3D14 | 21.00 | 15 | |
| BH4 | SA4UD1 | 2.00 | | 8 |
| | SA4D2 | 3.00 | 12 | |
| | SA4D4 | 6.00 | 3 | |
| | SA4D5 | 7.50 | 3 | |
| | SA4UD3 | 9.00 | | |

| | | | |
|---|---|---|---|
| | SA4D6 | 10.50 | 1 |
| | SA4D10 | 15.00 | 9 |
| | SA4D12 | 18.00 | 17 |
| Total | | | 30 |

# APPENDIX 8

Detail for *N*-Value (Data Validation) at Site Lot 120185, Selangor Cyber Valley

| Borehole | Name of Sample | Depth (m) | *N*-Value | Total of Sample |
|---|---|---|---|---|
| BH1 | SB1D1 | 1.50 | 11 | 8 |
| | SB1C1 | 4.50 | | |
| | SB1D4 | 9.00 | 1 | |
| | SB1D5 | 10.50 | 2 | |
| | SB1D6 | 12.00 | 2 | |
| | SB1D7 | 13.50 | 2 | |
| | SB1D11 | 21.00 | 28 | |
| | SB1C4 | 29.00 | | |
| BH2 | SB2D3 | 6.00 | 5 | 9 |
| | SB2D4 | 4.50 | 7 | |
| | SB2U3 | 8.00 | | |
| | SB2D5 | 9.00 | 3 | |
| | SB2D6 | 10.50 | 2 | |
| | SB2D9 | 15.00 | 2 | |
| | SB2D10 | 16.50 | 2 | |
| | SB2D11 | 18.00 | 26 | |
| | SB2C1 | 29.00 | | |
| BH3 | SB3D2 | 3.00 | 37 | 7 |
| | SB3D3 | 3.00 | 41 | |
| | SB3D5 | 9.00 | 17 | |
| | SB3D6 | 10.50 | 1 | |
| | SB3D8 | 13.50 | 18 | |
| | SB3D9 | 15.00 | 19 | |
| | SB3D14 | 24.00 | 50 | |
| BH4 | SB4D1 | 1.50 | 50 | 8 |
| | SB4D4 | 6.00 | 3 | |
| | SB4D5 | 7.50 | 3 | |

| | | | |
|---|---|---|---|
| | SB4D6 | 9.00 | 2 |
| | SB4U3 | 9.50 | |
| | SB4D7 | 10.50 | 2 |
| | SB4D8 | 12.00 | 3 |
| | SB4D12 | 18.00 | 10 |
| Total | | | 32 |

# APPENDIX 9

Result of Moisture Content (*w*)

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| PT21044 | BH 1 | T1D2 | 3.00 | 398 |
| | | T1D4 | 6.00 | 46 |
| | | T1UD1 | 7.50 | |
| | | T1D5 | 9.00 | 40 |
| | | T1UD2 | 10.50 | |
| | | T1D8 | 15.00 | 26 |
| | | T1D12 | 21.00 | 22 |
| | | T1D14 | 24.00 | 25 |
| | BH 2 | T2D1 | 1.50 | 312 |
| | | T2D3 | 4.50 | 395 |
| | | T2UD1 | 6.00 | |
| | | T2D4 | 7.50 | 58 |
| | | T2UD2 | 9.00 | |
| | | T2D6 | 12.00 | 53 |
| | | T2D9 | 16.50 | 25 |
| | | T2D12 | 21.00 | 25 |
| | | T2D15 | 25.00 | 24 |
| | BH 3 | T3D2 | 3.00 | 361 |
| | | T3D4 | 6.00 | 59 |
| | | T3UD1 | 7.50 | |
| | | T3D5 | 9.00 | 56 |
| | | T3UD2 | 10.50 | |
| | | T3D6 | 12.00 | 60 |
| | | T3D8 | 15.00 | 35 |
| | | T3D10 | 18.00 | 26 |
| | | T3D14 | 24.00 | 26 |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | BH 4 | T4D1 | 1.50 | 361 |
| | | T4D3 | 4.50 | 439 |
| | | T4UD1 | 6.00 | |
| | | T4D4 | 7.50 | 60 |
| | | T4UD2 | 9.00 | |
| | | T4D6 | 12.00 | 52 |
| | | T4D8 | 15.00 | 22 |
| | | T4D10 | 18.00 | 25 |
| | | T4D15 | 25.50 | 22 |
| | BH 5 | T5D1 | 1.50 | 722 |
| | | T5D4 | 6.00 | 66 |
| | | T5UD1 | 7.50 | |
| | | T5D5 | 9.00 | 60 |
| | | T5UD2 | 10.50 | |
| | | T5D7 | 13.50 | 52 |
| | | T5D9 | 16.50 | 22 |
| | | T5D13 | 22.50 | 25 |
| | | T5D16 | 27.00 | 22 |
| | BH 6 | T6D1 | 1.50 | 311 |
| | | T6D4 | 6.00 | 60 |
| | | T6UD1 | 7.50 | |
| | | T6D5 | 9.00 | 60 |
| | | T6UD2 | 10.50 | |
| | | T6D6 | 12.00 | 66 |
| | | T6D8 | 15.00 | 33 |
| | | T6D10 | 18.00 | 28 |
| | | T6D14 | 24.00 | 24 |
| | BH 7 | T7D1 | 1.50 | 279 |
| | | T7D3 | 4.50 | 336 |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | | T7UD1 | 6.00 | |
| | | T7D4 | 7.50 | 61 |
| | | T7UD2 | 9.00 | |
| | | T7D6 | 12.00 | 66 |
| | | T7D9 | 16.50 | 24 |
| | | T7D11 | 19.50 | 20 |
| | | T7D15 | 25.50 | 23 |
| | BH 8 | T8D1 | 1.50 | 546 |
| | | T8D3 | 4.50 | 355 |
| | | T8UD1 | 6.00 | |
| | | T8D4 | 7.50 | 30 |
| | | T8D6 | 11.20 | 29 |
| | | T8D8 | 15.00 | 35 |
| | | T8D11 | 19.50 | 20 |
| | | T8D14 | 24.00 | 23 |
| | BH 9 | T9D1 | 1.50 | 540 |
| | | T9D3 | 4.50 | 296 |
| | | T9UD1 | 6.00 | |
| | | T9D4 | 7.50 | 57 |
| | | T9UD2 | 9.00 | |
| | | T9D7 | 13.50 | 55 |
| | | T9D9 | 16.50 | 28 |
| | | T9D12 | 21.00 | 24 |
| | | T9D15 | 25.50 | 24 |
| | BH10 | T10D2 | 3.00 | 419 |
| | | T10UD1 | 6.00 | |
| | | T10D4 | 7.50 | 115 |
| | | T10UD2 | 9.00 | |
| | | T10D5 | 10.50 | 53 |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | | T10D8 | 15.00 | 21 |
| | | T10D10 | 18.00 | 22 |
| | | T10D14 | 24.00 | 23 |
| | BH 11 | T11D1 | 1.50 | 336 |
| | | T11UD1 | 3.00 | |
| | | T11D3 | 6.00 | 137 |
| | | T11UD2 | 7.50 | |
| | | T11D5 | 10.50 | 46 |
| | | T11D6 | 12.00 | 15 |
| | | T11D10 | 18.00 | 26 |
| | | T11D15 | 25.50 | 13 |
| | BH 12 | T12D 2 | 3.00 | 223 |
| | | T12UD1 | 6.00 | |
| | | T12D4 | 7.50 | 62 |
| | | T12UD2 | 9.00 | |
| | | T12D6 | 12.00 | 60 |
| | | T12D9 | 16.50 | 36 |
| | | T12D10 | 18.00 | 25 |
| | | T12D14 | 21.00 | 25 |
| | BH 13 | T13D1 | 1.50 | 344 |
| | | T13D3 | 4..5 | 309 |
| | | T13UD1 | 6.00 | |
| | | T13D4 | 7.50 | 122 |
| | | T13UD2 | 9.00 | 398 |
| | | T13D6 | 12.00 | 46 |
| | | T13D8 | 15.00 | |
| | | T13D10 | 18.00 | 40 |
| | | T13D15 | 25.50 | |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | BH 14 | T14D1 | 1.50 | 26 |
| | | T14D4 | 6.00 | 22 |
| | | T14UD1 | 7.50 | 25 |
| | | T14D5 | 9.00 | 312 |
| | | T14UD2 | 10.50 | 395 |
| | | T14D7 | 13.50 | |
| | | T14D9 | 16.50 | 58 |
| | | T14D11 | 19.50 | |
| | | T14D14 | 24.00 | 53 |
| | BH 15 | T15D1 | 1.50 | 25 |
| | | T15D4 | 6.00 | 25 |
| | | T15UD1 | 7.50 | 24 |
| | | T15D5 | 9.00 | 361 |
| | | T15UD2 | 10.50 | 59 |
| | | T15D7 | 13.50 | |
| | | T15D9 | 16.50 | 56 |
| | | T15D11 | 19.50 | |
| | | T15D15 | 25.50 | 60 |
| | BH 16 | T16D1 | 1.50 | 35 |
| | | T16UD1 | 6.00 | 26 |
| | | T16D4 | 7.50 | 26 |
| | | T16UD2 | 9.00 | 361 |
| | | T16D5 | 10.50 | 439 |
| | | T16D7 | 13.50 | |
| | | T16D9 | 16.50 | 60 |
| | | T16D11 | 19.50 | |
| | | T16D15 | 25.50 | 52 |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | BH 17 | T17D1 | 1.50 | 22 |
| | | T17D4 | 6.00 | 25 |
| | | T17UD1 | 7.50 | 22 |
| | | T17D5 | 9.00 | 722 |
| | | T17UD2 | 10.50 | 66 |
| | | T17D6 | 12.00 | |
| | | T17D8 | 15.00 | 60 |
| | | T17D10 | 18.00 | |
| | | T17D14 | 24.00 | 52 |
| | BH 18 | T18D1 | 1.50 | 22 |
| | | T18D3 | 4.50 | 25 |
| | | T18UD1 | 7.50 | 22 |
| | | T18D5 | 9.00 | 311 |
| | | T18UD2 | 10.50 | 60 |
| | | T18D6 | 12.00 | |
| | | T18D8 | 15.00 | 60 |
| | | T18D11 | 19.50 | |
| | | T18D14 | 24.00 | 66 |
| | BH 19 | T19D1 | 1.50 | 33 |
| | | T19D3 | 4.50 | 28 |
| | | T19UD1 | 6.00 | 24 |
| | | T19D4 | 7.50 | 279 |
| | | T19UD2 | 9.00 | 336 |
| | | T19D6 | 12.00 | |
| | | T19D9 | 16.00 | 61 |
| | | T19D12 | 21.00 | |
| | | T19D15 | 25.50 | 66 |
| | BH 26 | T26D2 | 3.00 | 339 |
| | | T26D4 | 6.00 | 117 |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | | T26UD1 | 7.50 | |
| | | T26D5 | 9.00 | 108 |
| | | T26UD2 | 10.50 | |
| | | T26D6 | 12.00 | 107 |
| | | T26D9 | 16.50 | 26 |
| | | T26D12 | 21.00 | 26 |
| | | T26D14 | 24.00 | 25 |
| | BH 27 | T27D1 | 1.50 | 193 |
| | | T27D4 | 6.00 | 61 |
| | | T27UD1 | 7.50 | |
| | | T27D5 | 9.00 | 98 |
| | | T27UD2 | 10.50 | |
| | | T27D7 | 13.50 | 68 |
| | | T27D9 | 16.50 | 25 |
| | | T27D13 | 22.50 | 26 |
| | BH 28 | T28D2 | 3.00 | 583 |
| | | T28D4 | 6.00 | 54 |
| | | T28UD1 | 7.50 | |
| | | T28D5 | 9.00 | 62 |
| | | T28UD2 | 10.50 | |
| | | T28D8 | 15.00 | 24 |
| | | T28D11 | 19.50 | 25 |
| | | T28D14 | 24.00 | 26 |
| | | T28D15 | 25.50 | 22 |
| | BH 29 | T29D1 | 1.50 | 522 |
| | | T29D3 | 4.50 | 118 |
| | | T29UD1 | 6.00 | |
| | | T29D4 | 7.50 | 118 |
| | | T29UD2 | 9.00 | |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | | T29D6 | 12.00 | 108 |
| | | T29D9 | 16.50 | 25 |
| | | T29D12 | 21.00 | 27 |
| | | T29D15 | 25.50 | 29 |
| | BH 30 | T30D1 | 1.50 | 436 |
| | | T30D4 | 6.00 | 44 |
| | | T30UD1 | 7.50 | |
| | | T30D5 | 9.00 | 48 |
| | | T30UD2 | 10.50 | |
| | | T30D7 | 13.50 | 52 |
| | | T30D9 | 16.50 | 23 |
| | | T30D12 | 21.00 | 24 |
| | | T30D16 | 27.00 | 26 |
| | BH 31 | T31D2 | 3.00 | 521 |
| | | T31D4 | 6.00 | 410 |
| | | T31UD1 | 7.50 | |
| | | T31D5 | 9.00 | 50 |
| | | T31UD2 | 10.50 | |
| | | T31D6 | 12.00 | 47 |
| | | T31D8 | 15.00 | 28 |
| | | T31D11 | 19.50 | 26 |
| | | T31D14 | 24.00 | 29 |
| Lot PT 21044 | BH 20 | T20D1 | 1.50 | 339 |
| | | T20D3 | 4.50 | 117 |
| | | T20D4 | 6.00 | |
| | | T20UD1 | 7.50 | 108 |
| | | T20D5 | 9.00 | |
| | | T20UD2 | 10.50 | 107 |
| | | T20D6 | 12.00 | 26 |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | | T20D12 | 21.00 | 26 |
| | | T20D15 | 25.50 | 25 |
| | BH 21 | T21D1 | 1.50 | 193 |
| | | T21D3 | 4.50 | 61 |
| | | T21UD1 | 6.00 | |
| | | T21D4 | 7.50 | 98 |
| | | T21UD2 | 9.00 | |
| | | T21D6 | 12.00 | 68 |
| | | T21D8 | 15.00 | 25 |
| | | T21D10 | 18.00 | 26 |
| | | T21D15 | 25.50 | 583 |
| | BH 22 | T22D2 | 3.00 | 54 |
| | | T22D3 | 4.50 | |
| | | T22UD1 | 6.00 | 62 |
| | | T22D4 | 7.50 | |
| | | T22UD2 | 9.00 | 24 |
| | | T22D5 | 10.50 | 25 |
| | | T22D7 | 13.50 | 26 |
| | | T22D9 | 16.50 | 22 |
| | | T22D14 | 24.00 | 522 |
| | BH 23 | T23D1 | 1.50 | 118 |
| | | T23D3 | 4.50 | |
| | | T23UD1 | 6.00 | 118 |
| | | T23D4 | 7.50 | |
| | | T23UD2 | 9.00 | 108 |
| | | T23D5 | 10.50 | 25 |
| | | T23D7 | 13.50 | 27 |
| | | T23D10 | 18.00 | 29 |
| | | T23D14 | 24.00 | 436 |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | BH 24 | T24D1 | 1.50 | 44 |
| | | T24D3 | 4.50 | |
| | | T24UD1 | 6.00 | 48 |
| | | T24D4 | 7.50 | |
| | | T24UD2 | 9.00 | 52 |
| | | T24D6 | 12.00 | 23 |
| | | T24D9 | 16.50 | 24 |
| | | T24D12 | 21.00 | 26 |
| | | T24D14 | 24.00 | 521 |
| | BH 25 | T25D1 | 1.50 | 410 |
| | | T25D3 | 4.50 | |
| | | T25UD1 | 6.00 | 50 |
| | | T25D5 | 10.50 | |
| | | T25D7 | 13.50 | 47 |
| | | T25D9 | 16.50 | 28 |
| | | T25D11 | 19.50 | 26 |
| | | T25D14 | 24.00 | 29 |
| Lot PT 120188 | BH1 | SA1D3 | 4.50 | 19 |
| | | SA1D5 | 7.50 | 23 |
| | | SA1UD1 | 9.50 | |
| | | SA1D7 | 10.50 | 96 |
| | | SA1D10 | 15.00 | 13 |
| | | SA1UD2 | 15.50 | |
| | | SA1D12 | 18.00 | 45 |
| | | SA1D17 | 25.50 | 21 |
| | BH2 | SA2D2 | 3.00 | 26 |
| | | SA2UD1 | 3.40 | |
| | | SA2D4 | 6.00 | 63 |
| | | SA2D6 | 9.00 | 16 |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | | SA2D9 | 13.50 | 24 |
| | | SA2D11 | 16.50 | 25 |
| | | SA2D14 | 21.00 | 16 |
| | BH3 | SA3D1 | 1.50 | 20 |
| | | SA3D3 | 4.50 | 39 |
| | | SA3D5 | 7.50 | 28 |
| | | SA3UD1 | 9.50 | |
| | | SA3D7 | 10.50 | 22 |
| | | SA3D12 | 18.00 | 25 |
| | | SA3D14 | 21.00 | 21 |
| | BH4 | SA4UD1 | 2.00 | |
| | | SA4D2 | 3.00 | 26 |
| | | SA4D4 | 7.50 | 108 |
| | | SA4D5 | 9 | 24 |
| | | SA4UD3 | 9.5 | |
| | | SA4D6 | 10.50 | 18 |
| | | SA4D10 | 16.50 | 19 |
| | | SA4D12 | 19.50 | 20 |
| Lot PT 120185 | BH1 | SB1D1 | 1.50 | 20 |
| | | SB1C1 | 4.50 | |
| | | SB1D4 | 9.00 | 66 |
| | | SB1D5 | 10.50 | 74 |
| | | SB1D6 | 12.00 | 27 |
| | | SB1D7 | 13.50 | 24 |
| | | SB1D11 | 21.00 | 19 |
| | | SB1C4 | 29.00 | |
| | BH2 | SB2D3 | 6.00 | 23 |
| | | SB2D4 | 4.50 | |
| | | SB2U3 | 8.00 | |

| Location | Borehole | Name of Sample | Depth (m) | Moisture Content % |
|---|---|---|---|---|
| | | SB2D5 | 9.00 | 67 |
| | | SB2D6 | 10.50 | |
| | | SB2D9 | 15.00 | 43 |
| | | SB2D10 | 16.50 | 47 |
| | | SB2D11 | 18.00 | 6 |
| | | SB2C1 | 29.00 | |
| | BH3 | SB3D2 | 3.00 | 18 |
| | | SB3D3 | 3.00 | |
| | | SB3D5 | 9.00 | 26 |
| | | SB3D6 | 10.50 | 78 |
| | | SB3D8 | 13.50 | 21 |
| | | SB3D9 | 15.00 | 38 |
| | | SB3D14 | 24.00 | 15 |
| | BH4 | SB4D1 | 1.50 | |
| | | SB4D4 | 6.00 | 30 |
| | | SB4D5 | 7.50 | 26 |
| | | SB4D6 | 9.00 | 62 |
| | | SB4U3 | 9.50 | |
| | | SB4D7 | 10.50 | 65 |
| | | SB4D8 | 12.00 | 73 |
| | | SB4D12 | 18.00 | 27 |

# APPENDIX 10

Result for Bulk Density ($\rho_b$)

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| Lot PT21044 | BH 1 | T1D2 | 3.00 | @ |
| | | T1D4 | 6.00 | 1.685 |
| | | T1UD1 | 7.50 | |
| | | T1D5 | 9.00 | 1.688 |
| | | T1UD2 | 10.50 | |
| | | T1D8 | 15.00 | 1.787 |
| | | T1D12 | 21.00 | 1.882 |
| | | T1D14 | 24.00 | 1.734 |
| | BH 2 | T2D1 | 1.50 | @ |
| | | T2D3 | 4.50 | @ |
| | | T2UD1 | 6.00 | |
| | | T2D4 | 7.50 | 1.571 |
| | | T2UD2 | 9.00 | |
| | | T2D6 | 12.00 | 1.605 |
| | | T2D9 | 16.50 | 1.799 |
| | | T2D12 | 21.00 | 1.784 |
| | | T2D15 | 25.00 | 1.923 |
| | BH 3 | T3D2 | 3.00 | @ |
| | | T3D4 | 6.00 | 1.584 |
| | | T3UD1 | 7.50 | |
| | | T3D5 | 9.00 | 1.61 |
| | | T3UD2 | 10.50 | |
| | | T3D6 | 12.00 | 1.552 |
| | | T3D8 | 15.00 | 1.759 |
| | | T3D10 | 18.00 | 1.83 |
| | | T3D14 | 24.00 | 1.877 |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | BH 4 | T4D1 | 1.50 | @ |
| | | T4D3 | 4.50 | @ |
| | | T4UD1 | 6.00 | |
| | | T4D4 | 7.50 | 1.576 |
| | | T4UD2 | 9.00 | |
| | | T4D6 | 12.00 | 1.605 |
| | | T4D8 | 15.00 | 1.864 |
| | | T4D10 | 18.00 | 1.805 |
| | | T4D15 | 25.50 | 1.917 |
| | BH 5 | T5D1 | 1.50 | @ |
| | | T5D4 | 6.00 | 1.524 |
| | | T5UD1 | 7.50 | |
| | | T5D5 | 9.00 | 1.75 |
| | | T5UD2 | 10.50 | |
| | | T5D7 | 13.50 | 1.605 |
| | | T5D9 | 16.50 | 1.864 |
| | | T5D13 | 22.50 | 1.805 |
| | | T5D16 | 27.00 | 1.917 |
| | BH 6 | T6D1 | 1.50 | @ |
| | | T6D4 | 6.00 | 1.59 |
| | | T6UD1 | 7.50 | |
| | | T6D5 | 9.00 | 1.566 |
| | | T6UD2 | 10.50 | |
| | | T6D6 | 12.00 | 1.534 |
| | | T6D8 | 15.00 | 1.813 |
| | | T6D10 | 18.00 | 1.841 |
| | | T6D14 | 24.00 | 1.830 |
| | BH 7 | T7D1 | 1.50 | @ |
| | | T7D3 | 4.50 | @ |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | T7UD1 | 6.00 | |
| | | T7D4 | 7.50 | 1.578 |
| | | T7UD2 | 9.00 | |
| | | T7D6 | 12.00 | 1.565 |
| | | T7D9 | 16.50 | 1.927 |
| | | T7D11 | 19.50 | 1.943 |
| | | T7D15 | 25.50 | 1.813 |
| | BH 8 | T8D1 | 1.50 | @ |
| | | T8D3 | 4.50 | @ |
| | | T8UD1 | 6.00 | |
| | | T8D4 | 7.50 | 1.807 |
| | | T8D6 | 11.20 | 1.816 |
| | | T8D8 | 15.00 | 1.67 |
| | | T8D11 | 19.50 | 1.846 |
| | | T8D14 | 24.00 | 1.767 |
| | BH 9 | T9D1 | 1.50 | @ |
| | | T9D3 | 4.50 | @ |
| | | T9UD1 | 6.00 | |
| | | T9D4 | 7.50 | 1.53 |
| | | T9UD2 | 9.00 | |
| | | T9D7 | 13.50 | 1.527 |
| | | T9D9 | 16.50 | 1.735 |
| | | T9D12 | 21.00 | 1.749 |
| | | T9D15 | 25.50 | 1.719 |
| | BH10 | T10D2 | 3.00 | @ |
| | | T10UD1 | 6.00 | |
| | | T10D4 | 7.50 | 1.334 |
| | | T10UD2 | 9.00 | |
| | | T10D5 | 10.50 | 1.585 |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | T10D8 | 15.00 | 1.875 |
| | | T10D10 | 18.00 | 1.903 |
| | | T10D14 | 24.00 | 1.832 |
| | BH 11 | T11D1 | 1.50 | @ |
| | | T11UD1 | 3.00 | |
| | | T11D3 | 6.00 | 1.307 |
| | | T11UD2 | 7.50 | |
| | | T11D5 | 10.50 | 1.662 |
| | | T11D6 | 12.00 | 1.959 |
| | | T11D10 | 18.00 | 1.844 |
| | | T11D15 | 25.50 | 1.919 |
| | BH 12 | T12D 2 | 3.00 | @ |
| | | T12UD1 | 6.00 | |
| | | T12D4 | 7.50 | 1.588 |
| | | T12UD2 | 9.00 | |
| | | T12D6 | 12.00 | 1.589 |
| | | T12D9 | 16.50 | 1.712 |
| | | T12D10 | 18.00 | 1.809 |
| | | T12D14 | 21.00 | 1.725 |
| | BH 13 | T13D1 | 1.50 | @ |
| | | T13D3 | 4..5 | @ |
| | | T13UD1 | 6.00 | |
| | | T13D4 | 7.50 | 1.345 |
| | | T13UD2 | 9.00 | |
| | | T13D6 | 12.00 | 1.303 |
| | | T13D8 | 15.00 | 1.839 |
| | | T13D10 | 18.00 | 1.748 |
| | | T13D15 | 25.50 | 1.955 |
| | BH 14 | T14D1 | 1.50 | @ |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | T14D4 | 6.00 | @ |
| | | T14UD1 | 7.50 | |
| | | T14D5 | 9.00 | 1.648 |
| | | T14UD2 | 10.50 | |
| | | T14D7 | 13.50 | 1.782 |
| | | T14D9 | 16.50 | 1.762 |
| | | T14D11 | 19.50 | 1.923 |
| | | T14D14 | 24.00 | 1.885 |
| | BH 15 | T15D1 | 1.50 | @ |
| | | T15D4 | 6.00 | 1.562 |
| | | T15UD1 | 7.50 | |
| | | T15D5 | 9.00 | 1.649 |
| | | T15UD2 | 10.50 | |
| | | T15D7 | 13.50 | 1.638 |
| | | T15D9 | 16.50 | 1.86 |
| | | T15D11 | 19.50 | 1.821 |
| | | T15D15 | 25.50 | 1.811 |
| | BH 16 | T16D1 | 1.50 | @ |
| | | T16UD1 | 6.00 | |
| | | T16D4 | 7.50 | 1.632 |
| | | T16UD2 | 9.00 | |
| | | T16D5 | 10.50 | 1.638 |
| | | T16D7 | 13.50 | 1.898 |
| | | T16D9 | 16.50 | 1.912 |
| | | T16D11 | 19.50 | 1.847 |
| | | T16D15 | 25.50 | 1.818 |
| | BH 17 | T17D1 | 1.50 | @ |
| | | T17D4 | 6.00 | 1.357 |
| | | T17UD1 | 7.50 | |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | T17D5 | 9.00 | 1.345 |
| | | T17UD2 | 10.50 | |
| | | T17D6 | 12.00 | 1.365 |
| | | T17D8 | 15.00 | 1.936 |
| | | T17D10 | 18.00 | 1.808 |
| | | T17D14 | 24.00 | 1.819 |
| | | T18D1 | 1.50 | 1.992 |
| | | T18D3 | 4.50 | 1.958 |
| | | T18UD1 | 7.50 | |
| | | T18D5 | 9.00 | 1.699 |
| | BH 18 | T18UD2 | 10.50 | |
| | | T18D6 | 12.00 | 1.683 |
| | | T18D8 | 15.00 | 1.846 |
| | | T18D11 | 19.50 | 1.914 |
| | | T18D14 | 24.00 | 1.869 |
| | | T19D1 | 1.50 | 2.035 |
| | | T19D3 | 4.50 | 1.946 |
| | | T19UD1 | 6.00 | |
| | | T19D4 | 7.50 | 1.362 |
| | BH 19 | T19UD2 | 9.00 | |
| | | T19D6 | 12.00 | 1.689 |
| | | T19D9 | 16.00 | 1.902 |
| | | T19D12 | 21.00 | 1.924 |
| | | T19D15 | 25.50 | 1.834 |
| | | T26D2 | 3.00 | |
| | | T26D4 | 6.00 | 1.41 |
| | BH 26 | T26UD1 | 7.50 | 1.792 |
| | | T26D5 | 9.00 | 1.803 |
| | | T26UD2 | 10.50 | 1.883 |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | T26D6 | 12.00 | @ |
| | | T26D9 | 16.50 | 1.560 |
| | | T26D12 | 21.00 | |
| | | T26D14 | 24.00 | 1.437 |
| | BH 27 | T27D1 | 1.50 | |
| | | T27D4 | 6.00 | 1.546 |
| | | T27UD1 | 7.50 | 1.745 |
| | | T27D5 | 9.00 | 1.722 |
| | | T27UD2 | 10.50 | @ |
| | | T27D7 | 13.50 | 1.597 |
| | | T27D9 | 16.50 | |
| | | T27D13 | 22.50 | 1.560 |
| | BH 28 | T28D2 | 3.00 | |
| | | T28D4 | 6.00 | 1.814 |
| | | T28UD1 | 7.50 | 1.769 |
| | | T28D5 | 9.00 | 1.832 |
| | | T28UD2 | 10.50 | 1.920 |
| | | T28D8 | 15.00 | @ |
| | | T28D11 | 19.50 | 1.332 |
| | | T28D14 | 24.00 | |
| | | T28D15 | 25.50 | 1.339 |
| | BH 29 | T29D1 | 1.50 | |
| | | T29D3 | 4.50 | 1.375 |
| | | T29UD1 | 6.00 | 1.850 |
| | | T29D4 | 7.50 | 1.795 |
| | | T29UD2 | 9.00 | 1.712 |
| | | T29D6 | 12.00 | @ |
| | | T29D9 | 16.50 | 1.668 |
| | | T29D12 | 21.00 | |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | T29D15 | 25.50 | 1.662 |
| | BH 30 | T30D1 | 1.50 | |
| | | T30D4 | 6.00 | 1.666 |
| | | T30UD1 | 7.50 | 1.877 |
| | | T30D5 | 9.00 | 1.775 |
| | | T30UD2 | 10.50 | 1.730 |
| | | T30D7 | 13.50 | @ |
| | | T30D9 | 16.50 | @ |
| | | T30D12 | 21.00 | |
| | | T30D16 | 27.00 | 1.641 |
| | BH 31 | T31D2 | 3.00 | |
| | | T31D4 | 6.00 | 1.667 |
| | | T31UD1 | 7.50 | 1.869 |
| | | T31D5 | 9.00 | 1.889 |
| | | T31UD2 | 10.50 | 1.873 |
| | | T31D6 | 12.00 | 2.010 |
| | | T31D8 | 15.00 | 2.028 |
| | | T31D11 | 19.50 | 1.382 |
| | | T31D14 | 24.00 | |
| Lot PT 21044 | BH 20 | T20D1 | 1.50 | 1.378 |
| | | T20D3 | 4.50 | |
| | | T20D4 | 6.00 | 1.868 |
| | | T20UD1 | 7.50 | 1.856 |
| | | T20D5 | 9.00 | 1.825 |
| | | T20UD2 | 10.50 | 2.010 |
| | | T20D6 | 12.00 | 2.028 |
| | | T20D12 | 21.00 | |
| | | T20D15 | 25.50 | 1.558 |
| | BH 21 | T21D1 | 1.50 | |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | T21D3 | 4.50 | 1.882 |
| | | T21UD1 | 6.00 | 1.978 |
| | | T21D4 | 7.50 | 1.962 |
| | | T21UD2 | 9.00 | 1.982 |
| | | T21D6 | 12.00 | @ |
| | | T21D8 | 15.00 | @ |
| | | T21D10 | 18.00 | |
| | | T21D15 | 25.50 | 1.560 |
| | | T22D2 | 3.00 | |
| | | T22D3 | 4.50 | 1.523 |
| | | T22UD1 | 6.00 | 1.910 |
| | | T22D4 | 7.50 | 1.770 |
| | BH 22 | T22UD2 | 9.00 | 1.874 |
| | | T22D5 | 10.50 | @ |
| | | T22D7 | 13.50 | 1.812 |
| | | T22D9 | 16.50 | |
| | | T22D14 | 24.00 | 1.825 |
| | | T23D1 | 1.50 | |
| | | T23D3 | 4.50 | 2.021 |
| | | T23UD1 | 6.00 | 1.967 |
| | | T23D4 | 7.50 | 1.975 |
| | BH 23 | T23UD2 | 9.00 | 1.866 |
| | | T23D5 | 10.50 | 1.935 |
| | | T23D7 | 13.50 | 1.425 |
| | | T23D10 | 18.00 | |
| | | T23D14 | 24.00 | 1.470 |
| | | T24D1 | 1.50 | |
| | BH 24 | T24D3 | 4.50 | 1.456 |
| | | T24UD1 | 6.00 | 1.941 |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | T24D4 | 7.50 | 1.898 |
| | | T24UD2 | 9.00 | 1.829 |
| | | T24D6 | 12.00 | 1.818 |
| | | T24D9 | 16.50 | 1.683 |
| | | T24D12 | 21.00 | |
| | | T24D14 | 24.00 | 1.901 |
| | BH 25 | T25D1 | 1.50 | 2.147 |
| | | T25D3 | 4.50 | 1.923 |
| | | T25UD1 | 6.00 | 1.784 |
| | | T25D5 | 10.50 | 1.906 |
| | | T25D7 | 13.50 | 2.03 |
| | | T25D9 | 16.50 | 1.87 |
| | | T25D11 | 19.50 | |
| | | T25D14 | 24.00 | 1.45 |
| Lot PT 120188 | BH1 | SA1D3 | 4.50 | 2.18 |
| | | SA1D5 | 7.50 | |
| | | SA1UD1 | 9.50 | 1.92 |
| | | SA1D7 | 10.50 | 2.01 |
| | | SA1D10 | 15.00 | 1.95 |
| | | SA1UD2 | 15.50 | |
| | | SA1D12 | 18.00 | 1.68 |
| | | SA1D17 | 25.50 | 2.04 |
| | BH2 | SA2D2 | 3.00 | 1.98 |
| | | SA2UD1 | 3.40 | 2 |
| | | SA2D4 | 6.00 | 1.71 |
| | | SA2D6 | 9.00 | 1.76 |
| | | SA2D9 | 13.50 | 1.73 |
| | | SA2D11 | 16.50 | 1.75 |
| | | SA2D14 | 21.00 | |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | BH3 | SA3D1 | 1.50 | 2.08 |
| | | SA3D3 | 4.50 | 1.87 |
| | | SA3D5 | 7.50 | 2.04 |
| | | SA3UD1 | 9.50 | |
| | | SA3D7 | 10.50 | 1.93 |
| | | SA3D12 | 18.00 | 1.39 |
| | | SA3D14 | 21.00 | 2.13 |
| | BH4 | SA4UD1 | 2.00 | |
| | | SA4D2 | 3.00 | 2.13 |
| | | SA4D4 | 7.50 | 1.88 |
| | | SA4D5 | 9 | 2.16 |
| | | SA4UD3 | 9.5 | 1.98 |
| | | SA4D6 | 10.50 | |
| | | SA4D10 | 16.50 | 1.43 |
| | | SA4D12 | 19.50 | 1.49 |
| Lot PT 120185 | BH1 | SB1D1 | 1.50 | 1.93 |
| | | SB1C1 | 4.50 | 1.96 |
| | | SB1D4 | 9.00 | 2.04 |
| | | SB1D5 | 10.50 | |
| | | SB1D6 | 12.00 | 1.9 |
| | | SB1D7 | 13.50 | |
| | | SB1D11 | 21.00 | |
| | | SB1C4 | 29.00 | 1.61 |
| | BH2 | SB2D3 | 6.00 | |
| | | SB2D4 | 4.50 | 1.68 |
| | | SB2U3 | 8.00 | 1.66 |
| | | SB2D5 | 9.00 | 1.730 |
| | | SB2D6 | 10.50 | |
| | | SB2D9 | 15.00 | 1.76 |

| Location | Borehole | Name of Sample | Depth (m) | Bulk Density, $Mg/m^3$ |
|---|---|---|---|---|
| | | SB2D10 | 16.50 | |
| | | SB2D11 | 18.00 | 1.86 |
| | | SB2C1 | 29.00 | 1.44 |
| | BH3 | SB3D2 | 3.00 | 1.94 |
| | | SB3D3 | 3.00 | 1.61 |
| | | SB3D5 | 9.00 | 1.77 |
| | | SB3D6 | 10.50 | |
| | | SB3D8 | 13.50 | 1.91 |
| | | SB3D9 | 15.00 | 1.93 |
| | | SB3D14 | 24.00 | 1.55 |
| | BH4 | SB4D1 | 1.50 | |
| | | SB4D4 | 6.00 | 1.91 |
| | | SB4D5 | 7.50 | 1.93 |
| | | SB4D6 | 9.00 | 1.55 |
| | | SB4U3 | 9.50 | |
| | | SB4D7 | 10.50 | 1.55 |
| | | SB4D8 | 12.00 | 1.48 |
| | | SB4D12 | 18.00 | 2.00 |

# APPENDIX 11

Result for Specific Gravity ($G_s$)

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| Lot PT21044 | BH 1 | T1D2 | 3.00 | @ |
| | | T1D4 | 6.00 | 2.55 |
| | | T1UD1 | 7.50 | |
| | | T1D5 | 9.00 | 2.55 |
| | | T1UD2 | 10.50 | |
| | | T1D8 | 15.00 | 2.61 |
| | | T1D12 | 21.00 | 2.63 |
| | | T1D14 | 24.00 | 2.63 |
| | BH 2 | T2D1 | 1.50 | @ |
| | | T2D3 | 4.50 | @ |
| | | T2UD1 | 6.00 | |
| | | T2D4 | 7.50 | 2.5 |
| | | T2UD2 | 9.00 | |
| | | T2D6 | 12.00 | 2.5 |
| | | T2D9 | 16.50 | 2.66 |
| | | T2D12 | 21.00 | 2.67 |
| | | T2D15 | 25.00 | 2.65 |
| | BH 3 | T3D2 | 3.00 | @ |
| | | T3D4 | 6.00 | 2.5 |
| | | T3UD1 | 7.50 | |
| | | T3D5 | 9.00 | 2.5 |
| | | T3UD2 | 10.50 | |
| | | T3D6 | 12.00 | 2.5 |
| | | T3D8 | 15.00 | 2.59 |
| | | T3D10 | 18.00 | 2.63 |
| | | T3D14 | 24.00 | 2.62 |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | BH 4 | T4D1 | 1.50 | @ |
| | | T4D3 | 4.50 | @ |
| | | T4UD1 | 6.00 | |
| | | T4D4 | 7.50 | 2.5 |
| | | T4UD2 | 9.00 | |
| | | T4D6 | 12.00 | 2.5 |
| | | T4D8 | 15.00 | 2.66 |
| | | T4D10 | 18.00 | 2.65 |
| | | T4D15 | 25.50 | 2.64 |
| | BH 5 | T5D1 | 1.50 | @ |
| | | T5D4 | 6.00 | 2.51 |
| | | T5UD1 | 7.50 | |
| | | T5D5 | 9.00 | 2.56 |
| | | T5UD2 | 10.50 | |
| | | T5D7 | 13.50 | 2.5 |
| | | T5D9 | 16.50 | 2.66 |
| | | T5D13 | 22.50 | 2.65 |
| | | T5D16 | 27.00 | 2.64 |
| | BH 6 | T6D1 | 1.50 | @ |
| | | T6D4 | 6.00 | 2.51 |
| | | T6UD1 | 7.50 | |
| | | T6D5 | 9.00 | 2.51 |
| | | T6UD2 | 10.50 | |
| | | T6D6 | 12.00 | 2.5 |
| | | T6D8 | 15.00 | 2.64 |
| | | T6D10 | 18.00 | 2.66 |
| | | T6D14 | 24.00 | 2.65 |
| | BH 7 | T7D1 | 1.50 | @ |
| | | T7D3 | 4.50 | @ |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | T7UD1 | 6.00 | |
| | | T7D4 | 7.50 | 2.51 |
| | | T7UD2 | 9.00 | |
| | | T7D6 | 12.00 | 2.51 |
| | | T7D9 | 16.50 | 2.61 |
| | | T7D11 | 19.50 | 2.62 |
| | | T7D15 | 25.50 | 2.68 |
| | BH 8 | T8D1 | 1.50 | @ |
| | | T8D3 | 4.50 | @ |
| | | T8UD1 | 6.00 | |
| | | T8D4 | 7.50 | 2.57 |
| | | T8D6 | 11.20 | 2.55 |
| | | T8D8 | 15.00 | 2.55 |
| | | T8D11 | 19.50 | 2.65 |
| | | T8D14 | 24.00 | 2.66 |
| | BH 9 | T9D1 | 1.50 | @ |
| | | T9D3 | 4.50 | @ |
| | | T9UD1 | 6.00 | |
| | | T9D4 | 7.50 | 2.55 |
| | | T9UD2 | 9.00 | |
| | | T9D7 | 13.50 | 2.55 |
| | | T9D9 | 16.50 | 2.55 |
| | | T9D12 | 21.00 | 2.65 |
| | | T9D15 | 25.50 | 2.66 |
| | BH10 | T10D2 | 3.00 | @ |
| | | T10UD1 | 6.00 | |
| | | T10D4 | 7.50 | 2.55 |
| | | T10UD2 | 9.00 | |
| | | T10D5 | 10.50 | 2.55 |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | T10D8 | 15.00 | 2.59 |
| | | T10D10 | 18.00 | 2.62 |
| | | T10D14 | 24.00 | 2.66 |
| | BH 11 | T11D1 | 1.50 | @ |
| | | T11UD1 | 3.00 | |
| | | T11D3 | 6.00 | 2.55 |
| | | T11UD2 | 7.50 | |
| | | T11D5 | 10.50 | 2.55 |
| | | T11D6 | 12.00 | 2.55 |
| | | T11D10 | 18.00 | 2.63 |
| | | T11D15 | 25.50 | 2.65 |
| | BH 12 | T12D 2 | 3.00 | @ |
| | | T12UD1 | 6.00 | |
| | | T12D4 | 7.50 | 2.55 |
| | | T12UD2 | 9.00 | |
| | | T12D6 | 12.00 | 2.55 |
| | | T12D9 | 16.50 | 2.55 |
| | | T12D10 | 18.00 | 2.55 |
| | | T12D14 | 21.00 | 2.67 |
| | BH 13 | T13D1 | 1.50 | @ |
| | | T13D3 | 4..5 | @ |
| | | T13UD1 | 6.00 | |
| | | T13D4 | 7.50 | 2.51 |
| | | T13UD2 | 9.00 | |
| | | T13D6 | 12.00 | 2.51 |
| | | T13D8 | 15.00 | 2.65 |
| | | T13D10 | 18.00 | 2.64 |
| | | T13D15 | 25.50 | 2.62 |
| | BH 14 | T14D1 | 1.50 | @ |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | T14D4 | 6.00 | @ |
| | | T14UD1 | 7.50 | |
| | | T14D5 | 9.00 | 2.55 |
| | | T14UD2 | 10.50 | |
| | | T14D7 | 13.50 | 2.63 |
| | | T14D9 | 16.50 | 2.64 |
| | | T14D11 | 19.50 | 2.66 |
| | | T14D14 | 24.00 | 2.66 |
| | | T15D1 | 1.50 | @ |
| | | T15D4 | 6.00 | 2.51 |
| | | T15UD1 | 7.50 | |
| | | T15D5 | 9.00 | 2.52 |
| | BH 15 | T15UD2 | 10.50 | |
| | | T15D7 | 13.50 | 2.51 |
| | | T15D9 | 16.50 | 2.66 |
| | | T15D11 | 19.50 | 2.67 |
| | | T15D15 | 25.50 | 2.65 |
| | | T16D1 | 1.50 | @ |
| | | T16UD1 | 6.00 | |
| | | T16D4 | 7.50 | 2.55 |
| | | T16UD2 | 9.00 | |
| | BH 16 | T16D5 | 10.50 | 2.51 |
| | | T16D7 | 13.50 | 2.65 |
| | | T16D9 | 16.50 | 2.65 |
| | | T16D11 | 19.50 | 2.66 |
| | | T16D15 | 25.50 | 2.65 |
| | | T17D1 | 1.50 | @ |
| | BH 17 | T17D4 | 6.00 | 2.5 |
| | | T17UD1 | 7.50 | |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | T17D5 | 9.00 | 2.5 |
| | | T17UD2 | 10.50 | |
| | | T17D6 | 12.00 | 2.5 |
| | | T17D8 | 15.00 | 2.64 |
| | | T17D10 | 18.00 | 2.66 |
| | | T17D14 | 24.00 | 2.67 |
| | | T18D1 | 1.50 | 2.6 |
| | | T18D3 | 4.50 | 2.64 |
| | | T18UD1 | 7.50 | |
| | | T18D5 | 9.00 | 2.55 |
| | BH 18 | T18UD2 | 10.50 | |
| | | T18D6 | 12.00 | 2.51 |
| | | T18D8 | 15.00 | 2.61 |
| | | T18D11 | 19.50 | 2.62 |
| | | T18D14 | 24.00 | 2.64 |
| | | T19D1 | 1.50 | 2.64 |
| | | T19D3 | 4.50 | 2.60 |
| | | T19UD1 | 6.00 | |
| | | T19D4 | 7.50 | 2.50 |
| | BH 19 | T19UD2 | 9.00 | |
| | | T19D6 | 12.00 | 2.55 |
| | | T19D9 | 16.00 | 2.63 |
| | | T19D12 | 21.00 | 2.64 |
| | | T19D15 | 25.50 | 2.64 |
| | | T26D2 | 3.00 | @ |
| | | T26D4 | 6.00 | 2.52 |
| | BH 26 | T26UD1 | 7.50 | |
| | | T26D5 | 9.00 | 2.52 |
| | | T26UD2 | 10.50 | |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | T26D6 | 12.00 | 2.53 |
| | | T26D9 | 16.50 | 2.65 |
| | | T26D12 | 21.00 | 2.65 |
| | | T26D14 | 24.00 | 2.66 |
| | BH 27 | T27D1 | 1.50 | @ |
| | | T27D4 | 6.00 | 2.55 |
| | | T27UD1 | 7.50 | |
| | | T27D5 | 9.00 | 2.55 |
| | | T27UD2 | 10.50 | |
| | | T27D7 | 13.50 | 2.63 |
| | | T27D9 | 16.50 | 2.67 |
| | | T27D13 | 22.50 | 2.67 |
| | BH 28 | T28D2 | 3.00 | @ |
| | | T28D4 | 6.00 | 2.5 |
| | | T28UD1 | 7.50 | |
| | | T28D5 | 9.00 | 2.50 |
| | | T28UD2 | 10.50 | |
| | | T28D8 | 15.00 | 2.65 |
| | | T28D11 | 19.50 | 2.65 |
| | | T28D14 | 24.00 | 2.65 |
| | | T28D15 | 25.50 | 2.65 |
| | BH 29 | T29D1 | 1.50 | @ |
| | | T29D3 | 4.50 | 2.52 |
| | | T29UD1 | 6.00 | |
| | | T29D4 | 7.50 | 2.53 |
| | | T29UD2 | 9.00 | |
| | | T29D6 | 12.00 | 2.52 |
| | | T29D9 | 16.50 | 2.65 |
| | | T29D12 | 21.00 | 2.65 |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | T29D15 | 25.50 | 2.67 |
| | BH 30 | T30D1 | 1.50 | @ |
| | | T30D4 | 6.00 | 2.55 |
| | | T30UD1 | 7.50 | |
| | | T30D5 | 9.00 | 2.55 |
| | | T30UD2 | 10.50 | |
| | | T30D7 | 13.50 | 2.55 |
| | | T30D9 | 16.50 | 2.62 |
| | | T30D12 | 21.00 | 2.65 |
| | | T30D16 | 27.00 | 2.62 |
| | BH 31 | T31D2 | 3.00 | @ |
| | | T31D4 | 6.00 | @ |
| | | T31UD1 | 7.50 | |
| | | T31D5 | 9.00 | 2.55 |
| | | T31UD2 | 10.50 | |
| | | T31D6 | 12.00 | 2.55 |
| | | T31D8 | 15.00 | 2.64 |
| | | T31D11 | 19.50 | 2.63 |
| | | T31D14 | 24.00 | 2.62 |
| Lot PT 21044 | BH 20 | T20D1 | 1.50 | 2.61 |
| | | T20D3 | 4.50 | 2.56 |
| | | T20D4 | 6.00 | 2.5 |
| | | T20UD1 | 7.50 | |
| | | T20D5 | 9.00 | 2.5 |
| | | T20UD2 | 10.50 | |
| | | T20D6 | 12.00 | 2.59 |
| | | T20D12 | 21.00 | 2.66 |
| | | T20D15 | 25.50 | 2..66 |
| | BH 21 | T21D1 | 1.50 | 2.61 |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | T21D3 | 4.50 | 2.56 |
| | | T21UD1 | 6.00 | |
| | | T21D4 | 7.50 | 2.53 |
| | | T21UD2 | 9.00 | |
| | | T21D6 | 12.00 | 2.65 |
| | | T21D8 | 15.00 | 2.62 |
| | | T21D10 | 18.00 | 2.59 |
| | | T21D15 | 25.50 | 2.59 |
| | | T22D2 | 3.00 | @ |
| | | T22D3 | 4.50 | @ |
| | | T22UD1 | 6.00 | |
| | BH 22 | T22D4 | 7.50 | 2.51 |
| | | T22UD2 | 9.00 | |
| | | T22D5 | 10.50 | 2.51 |
| | | T22D7 | 13.50 | 2.6 |
| | | T22D9 | 16.50 | 2.64 |
| | | T22D14 | 24.00 | 2.62 |
| | | T23D1 | 1.50 | @ |
| | | T23D3 | 4.50 | 2.57 |
| | | T23UD1 | 6.00 | |
| | | T23D4 | 7.50 | 2.58 |
| | BH 23 | T23UD2 | 9.00 | |
| | | T23D5 | 10.50 | 2.63 |
| | | T23D7 | 13.50 | 2.63 |
| | | T23D10 | 18.00 | 2.63 |
| | | T23D14 | 24.00 | 2.66 |
| | | T24D1 | 1.50 | 2.57 |
| | BH 24 | T24D3 | 4.50 | 2.51 |
| | | T24UD1 | 6.00 | |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | T24D4 | 7.50 | 2..52 |
| | | T24UD2 | 9.00 | |
| | | T24D6 | 12.00 | 2.53 |
| | | T24D9 | 16.50 | 2.64 |
| | | T24D12 | 21.00 | 2.65 |
| | | T24D14 | 24.00 | 2.67 |
| | BH 25 | T25D1 | 1.50 | 2.6 |
| | | T25D3 | 4.50 | 2.51 |
| | | T25UD1 | 6.00 | |
| | | T25D5 | 10.50 | 2.67 |
| | | T25D7 | 13.50 | 2.61 |
| | | T25D9 | 16.50 | 2.65 |
| | | T25D11 | 19.50 | 2.69 |
| | | T25D14 | 24.00 | 2.65 |
| Lot PT 120188 | BH1 | SA1D3 | 4.50 | 2.63 |
| | | SA1D5 | 7.50 | 2.668 |
| | | SA1UD1 | 9.50 | |
| | | SA1D7 | 10.50 | 2.513 |
| | | SA1D10 | 15.00 | 2.575 |
| | | SA1UD2 | 15.50 | |
| | | SA1D12 | 18.00 | 2.6 |
| | | SA1D17 | 25.50 | 2.58 |
| | BH2 | SA2D2 | 3.00 | 2.612 |
| | | SA2UD1 | 3.40 | |
| | | SA2D4 | 6.00 | LS |
| | | SA2D6 | 9.00 | 2.624 |
| | | SA2D9 | 13.50 | 2.628 |
| | | SA2D11 | 16.50 | 2.601 |
| | | SA2D14 | 21.00 | 2.509 |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| Lot PT 120185 | BH3 | SA3D1 | 1.50 | 2.612 |
| | | SA3D3 | 4.50 | LS |
| | | SA3D5 | 7.50 | LS |
| | | SA3UD1 | 9.50 | |
| | | SA3D7 | 10.50 | 2.583 |
| | | SA3D12 | 18.00 | 2.55 |
| | | SA3D14 | 21.00 | 2.524 |
| | BH4 | SA4UD1 | 2.00 | |
| | | SA4D2 | 3.00 | 2.545 |
| | | SA4D4 | 7.50 | OM |
| | | SA4D5 | 9 | 2.579 |
| | | SA4UD3 | 9.5 | |
| | | SA4D6 | 10.50 | 2.618 |
| | | SA4D10 | 16.50 | 2.6 |
| | | SA4D12 | 19.50 | 2.683 |
| | BH1 | SB1D1 | 1.50 | 2.583 |
| | | SB1C1 | 4.50 | |
| | | SB1D4 | 9.00 | 2.55 |
| | | SB1D5 | 10.50 | 2.552 |
| | | SB1D6 | 12.00 | 2.485 |
| | | SB1D7 | 13.50 | 2.566 |
| | | SB1D11 | 21.00 | 2.637 |
| | | SB1C4 | 29.00 | |
| | BH2 | SB2D3 | 6.00 | 2.562 |
| | | SB2D4 | 4.50 | |
| | | SB2U3 | 8.00 | |
| | | SB2D5 | 9.00 | 2.602 |
| | | SB2D6 | 10.50 | |
| | | SB2D9 | 15.00 | 2.575 |

| Location | Borehole | Name of Sample | Depth (m) | Specific Gravity |
|---|---|---|---|---|
| | | SB2D10 | 16.50 | 2.588 |
| | | SB2D11 | 18.00 | 2.645 |
| | | SB2C1 | 29.00 | |
| | BH3 | SB3D2 | 3.00 | 2.638 |
| | | SB3D3 | 3.00 | |
| | | SB3D5 | 9.00 | 2.652 |
| | | SB3D6 | 10.50 | 2.608 |
| | | SB3D8 | 13.50 | 2.624 |
| | | SB3D9 | 15.00 | 2.608 |
| | | SB3D14 | 24.00 | 2.603 |
| | BH4 | SB4D1 | 1.50 | |
| | | SB4D4 | 6.00 | 2.542 |
| | | SB4D5 | 7.50 | 2.62 |
| | | SB4D6 | 9.00 | 2.574 |
| | | SB4U3 | 9.50 | |
| | | SB4D7 | 10.50 | 2.574 |
| | | SB4D8 | 12.00 | 2.539 |
| | | SB4D12 | 18.00 | 2.606 |

# APPENDIX 12

Detail for Soil Composition and Classification

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| Lot PT21044 | BH 1 | T1D2 | @ | @ | @ | @ | Very soft, medium to dark brown, PEAT |
| | | T1D4 | 0 | 1 | 72 | 27 | Soft pale to light grey, SILT of High Plasticity |
| | | T1UD1 | | | | | Light grey, sandy CLAY |
| | | T1D5 | 0 | 1 | 71 | 28 | Medium stiff, light grey, SILT or High Plasticity |
| | | T1UD2 | | | | | Pale to light grey, sandy CLAY |
| | | T1D8 | 1 | 56 | 29 | 15 | Very stiff, light to medium grey, sandy SILT of Intermediate Plasticity |
| | | T1D12 | 0 | 64 | 26 | 10 | Medium dense, medium grey, very silty SAND of High Plasticity |
| | | T1D14 | 0 | 64 | 25 | 11 | Very dense, pale togrey, very silty SAND of Intermediate Plasticity |
| | BH 2 | T2D1 | @ | @ | @ | @ | Soft, dark brown, PEAT |
| | | T2D3 | @ | @ | @ | @ | Medium stiff, medium to dark brown, PEAT |
| | | T2UD1 | | | | | Light to medium grey, sandy CLAY |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T2D4 | 1 | 1 | 34 | 64 | Soft, light to medium grey, slightly sandy CLAY of High Plasticity with presence of decayed wood |
| | | T2UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T2D6 | 0 | 1 | 34 | 65 | Medium stiff, light grey, slightly sandy CLAY of High Plasticity with presence of organic matter |
| | | T2D9 | 0 | 82 | 18 | | Medium dense, light to medium grey, silty SAND |
| | | T2D12 | 0 | 85 | 15 | | Medium dense, medium grey, silty SAND with organic matter |
| | | T2D15 | 0 | 77 | 16 | 7 | Very dense, medium grey, silty SAND with traces of gravel |
| | BH 3 | T3D2 | @ | @ | @ | @ | Soft, medium to dark brown, PEAT |
| | | T3D4 | 0 | 1 | 26 | 73 | Soft, light to medium grey, slightly sandy CLAY of High Plasticity with presence of decayed wood |
| | | T3UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T3D5 | 0 | 1 | 28 | 71 | Medium stiff, pale to light grey, CLAY of High Plasticity with presence of organic matter |
| | | T3UD2 | | | | | Medium grey, sandy CLAY |
| | | T3D6 | 0 | 1 | 25 | 74 | Medium stiff, pale to light grey, CLAY of High Plasticity with presence of organic matter |
| | | T3D8 | 0 | 44 | 41 | 15 | Medium stiff, light grey, sandy SILT of High Plasticity with presence of organic matter |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T3D10 | 0 | 63 | 24 | 13 | Very stiff, pale to light grey, very sandy SILT of Intermediate Plasticity with presence of organic matter |
| | | T3D14 | 0 | 58 | 26 | 16 | Hard, light to medium grey, very sandy SILT of Intermediate Plasticity with presence of organic matter |
| | BH 4 | T4D1 | @ | @ | @ | @ | Soft, dark brown, PEAT |
| | | T4D3 | @ | @ | @ | @ | ditto |
| | | T4UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T4D4 | 0 | 1 | 38 | 61 | Soft pale to light grey, CLAY of Very High Plasticity with presence of organic matter |
| | | T4UD2 | | | | | Pale to light grey, sandy CLAY |
| | | T4D6 | 0 | 1 | 32 | 67 | Medium stidd, light to medium grey, CLAY of High Plasticity |
| | | T4D8 | 0 | 78 | 16 | 6 | Medium dense, light grey, silty SAND |
| | | T4D10 | 0 | 74 | 16 | 10 | Medium dense, light grey, silty SAND |
| | | T4D15 | 0 | 72 | 18 | 10 | Very dense, light to medium grey, silty SAND with traces of gravel |
| | BH 5 | T5D1 | @ | @ | @ | @ | Medium stiff, medium to dark brown, PEAT |
| | | T5D4 | 1 | 2 | 27 | 70 | Soft pale to light grey, slightly sandy CLAY of Very High Plasticity with presence of organic matter |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T5UD1 | | | | | Light grey, sandy CLAY with some organic matter |
| | | T5D5 | 2 | 29 | 28 | 41 | Medium stiff, light grey, slightly sandy SILT of High Plasticity with some decayed wood |
| | | T5UD2 | | | | | Light grey, sandy SILT with some decayed wood |
| | | T5D7 | 0 | 75 | 17 | 8 | Loose, pale grey, silty SAND with traces of clay |
| | | T5D9 | 0 | 67 | 20 | 13 | ditto |
| | | T5D13 | 0 | 56 | 30 | 14 | Very stiff, light grey, sandy SILT of Intermediate Plasticity |
| | | T5D16 | 0 | 63 | 24 | 13 | Hard, light grey, very sandy SILT of Intermediate Plasticity |
| | BH 6 | T6D1 | @ | @ | @ | @ | Soft, dark grey, brown, PEAT |
| | | T6D4 | 2 | 2 | 24 | 72 | Soft, dark brown, CLAY of High Plasticity with trace of sand |
| | | T6UD1 | | | | | Medium grey, sandy CLAY |
| | | T6D5 | 2 | 1 | 27 | 70 | Soft, light grey, sandy CLAY of Intermediate plasticity with some decayed wood |
| | | T6UD2 | | | | | Light grey, sandy CLAY with some decayed wood |
| | | T6D6 | 0 | 1 | 33 | 66 | Medium stiff, medium grey, CLAY of Very High Plasticity with some decayed wood |
| | | T6D8 | 1 | 67 | 21 | 11 | Medium dense, light brown, very silty SAND |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T6D10 | 0 | 80 | 13 | 7 | Medium dense, light grey, silty SAND |
| | | T6D14 | 0 | 75 | 18 | 7 | Very dense, light grey, silty SAND |
| | BH 7 | T7D1 | @ | @ | @ | @ | Medium stiff, medium to dark brown, PEAT |
| | | T7D3 | @ | @ | @ | @ | Soft, dark brown, PEATwith traces of clay |
| | | T7UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T7D4 | 0 | 4 | 35 | 61 | Soft, medium grey, slightly sandy CLAY of High Plasticity |
| | | T7UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T7D6 | 2 | 1 | 31 | 68 | Medium stiff, light grey, CLAY of Very High Permeability with organic matter |
| | | T7D9 | 0 | 54 | 32 | 14 | Stiff, light to medium grey, sandy SILT of Intermediate Plasticity |
| | | T7D11 | 0 | 59 | 31 | 10 | Very stiff, pale to light grey, sandy SILT of Intermediate Plasticity |
| | | T7D15 | 0 | 68 | 12 | | Very dense, light to medium grey, silty SAND with traces of gravel |
| | BH 8 | T8D1 | @ | @ | @ | @ | Medium stiff to dark brown, PEAT |
| | | T8D3 | @ | @ | @ | @ | ditto |
| | | T8UD1 | | | | | Light to medium grey, sandy CLAY |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T8D4 | 4 | 32 | 38 | 26 | Msdium stiff, pale to light grey, dark brown, sandy SILT of Intermediate Plasticity with presence of organic material |
| | | T8D6 | 1 | 15 | 52 | 32 | Medium stiff, pale to light grey, slightly sandy SILT of Intermediate Plasticity |
| | | T8D8 | 1 | 14 | 53 | 32 | Stiff pale to light grey, slightly sandy SILT of High Plasticity |
| | | T8D11 | 0 | 76 | 16 | 8 | Medium dense, pale to light grey, silty SAND of Intermediate Plasticity |
| | | T8D14 | 0 | 81 | 19 | | Very dense, pale to light grey, silty SAND |
| | BH 9 | T9D1 | @ | @ | @ | @ | Soft, medium to dark brown, PEAT |
| | | T9D3 | @ | @ | @ | @ | Soft, dark brown, PEAT |
| | | T9UD1 | | | | | Pale to light grey, sandy CLAY |
| | | T9D4 | 0 | 1 | 60 | 33 | Very soft, pale to light grey, SILT of High Plasticity |
| | | T9UD2 | | | | | Pale grey, sandy CLAY |
| | | T9D7 | 0 | 1 | 66 | 30 | Soft, light grey, SILT of High Plasticity |
| | | T9D9 | 0 | 58 | 30 | 12 | Very stiff, light to medium grey, sandy SILT of Intermediate Plasticity |
| | | T9D12 | 1 | 85 | 14 | | Medium dense, pale to light grey, SAND |
| | | T9D15 | 0 | 81 | 19 | | Very dense, pale grey, fine SAND with traces of gravel |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | BH10 | T10D2 | @ | @ | @ | @ | Very soft, dark brown, PEAT |
| | | T10UD1 | | @ | @ | @ | Light grey, sandy CLAY |
| | | T10D4 | 0 | 2 | 69 | 29 | Very soft, light to medium grey, SILT of Extremely High Plasticity |
| | | T10UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T10D5 | 0 | 1 | 66 | 33 | Soft, pale to light grey, SILT of High Plasticity with organic matter |
| | | T10D8 | 0 | 45 | 40 | 15 | Stiff, medium grey, sandy SILT of Intermediate Plasticity |
| | | T10D10 | 0 | 60 | 26 | 14 | Medium dense, medium grey, very silty SAND of Intermediate Plasticity |
| | | T10D14 | 0 | 80 | 14 | 6 | Very dense, light grey, silty SAND |
| | BH 11 | T11D1 | @ | @ | @ | @ | Very soft, dark brown, PEAT |
| | | T11UD1 | | | | | Pale to light grey, sandy CLAY with presence of organic matter |
| | | T11D3 | 0 | 2 | 65 | 33 | Very sofy, light grey, SILT of Extremely High Plasticity |
| | | T11UD2 | | | | | Pale to light grey, sandy CLAY |
| | | T11D5 | 0 | 10 | 61 | 28 | Soft, light grey, slightly sandy SILT of High Plasticity with organic matter |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T11D6 | 0 | 22 | 57 | 21 | Very stiff, pale to ligh brown, slightly sandy SILT of Intermediate Plasticity |
| | | T11D10 | 0 | 66 | 20 | 14 | Medium dense, pale to light brown, whitish, silty SAND |
| | | T11D15 | 44 | 32 | 15 | 9 | Very dense, pale to light brown, yellowish, sandy GRAVEL with traces of SILT |
| | BH 12 | T12D 2 | @ | @ | @ | @ | Very soft, dark grey, grey, PEAT with some clay |
| | | T12UD1 | | | | | Pale grey, sandy CLAY |
| | | T12D4 | 1 | 1 | 66 | 32 | Soft, pale grey, SILT of Very High Plasticity with organic matter |
| | | T12UD2 | | | | | Pale grey, sandy CLAY with organic matter |
| | | T12D6 | 2 | 17 | 57 | 24 | Medium stiff , light grey, SILT of Very High Plasticity with traces of sand and organic matter |
| | | T12D9 | 0 | 9 | 67 | 24 | Stiff, pale grey, SILT of High Plasticity with traces of sand |
| | | T12D10 | 0 | 10 | 66 | 24 | Very stiff, pale grey, SILT of Intermediate Plasticity with traces of sand |
| | | T12D14 | 0 | 83 | 17 | | Very dense, light brown, silty SAND |
| | BH 13 | T13D1 | @ | @ | @ | @ | Medium stiff, medium to dark brown, PEAT |
| | | T13D3 | @ | @ | @ | @ | Medium stiff, dark brown, PEAT |
| | | T13UD1 | | | | | Light to medium grey, sandy CLAY |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T13D4 | 2 | 1 | 27 | 70 | Soft, light to medium grey, CLAY of Extremely Hight Plasticity with traces of sand |
| | | T13UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T13D6 | 4 | 1 | 36 | 59 | Medium stiff, pale to light grey, CLAY of Extremely High Plasticity with organic matter |
| | | T13D8 | 0 | 75 | 18 | 7 | Medium dense, pale to light grey, silty SAND |
| | | T13D10 | 0 | 70 | 22 | 8 | Medium dense, light to medium grey, silty SAND |
| | | T13D15 | 0 | 60 | 29 | 11 | Hard, pale to light grey, sandy SILT of Intermediate Plastucuty |
| | BH 14 | T14D1 | @ | @ | @ | @ | Soft medium to dark brown, PEAT |
| | | T14D4 | @ | @ | @ | @ | ditto |
| | | T14UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T14D5 | 5 | 1 | 57 | 37 | Medium stiff, light to medium grey, SILT of High Plasticity |
| | | T14UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T14D7 | 1 | 66 | 22 | 11 | Loose, light to medium grey, very silty SAND |
| | | T14D9 | 1 | 69 | 20 | 10 | ditto |
| | | T14D11 | 0 | 82 | 18 | | ditto |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T14D14 | 1 | 77 | 15 | 7 | Very dense, pale to light grey, silty SAND with traces of gravel |
| | BH 15 | T15D1 | @ | @ | @ | @ | Medium stiff, medium to dark brown, PEAT |
| | | T15D4 | 1 | 6 | 34 | 59 | Soft, pale to light grey, sandy CLAY of High Plasticity |
| | | T15UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T15D5 | 3 | 8 | 28 | 61 | Soft, light grey, sandy CLAY of Intermediate plasticity |
| | | T15UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T15D7 | 1 | 2 | 31 | 66 | Medium stiff, light grey, CLAY of Hight Plasticity |
| | | T15D9 | 0 | 78 | 14 | 8 | Medium dense, pale grey, silty SAND |
| | | T15D11 | 0 | 86 | 14 | | Dense, pale to light grey, silty SAND |
| | | T15D15 | 0 | 78 | 18 | 6 | Very dense, pale to light grey, silty SAND |
| | BH 16 | T16D1 | @ | @ | @ | @ | Medium stiff, medium to dark brown, PEAT |
| | | T16UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T16D4 | 0 | 3 | 66 | 31 | Soft, pale to light grey, SILT of High Plasticity |
| | | T16UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T16D5 | 1 | 2 | 29 | 68 | Medium stiff, light grey, CLAY of Hight Plasticity with traces of sand |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T16D7 | 0 | 76 | 18 | 6 | Loose, light to medium grey, silty SAND |
| | | T16D9 | 1 | 72 | 17 | 10 | Medium dense, light to medium grey, silty SAND |
| | | T16D11 | 1 | 80 | 19 | | Dense, light to medium grey, silty SAND with traces of gravel |
| | | T16D15 | 0 | 75 | 19 | 6 | Very dense, pale to light grey, silty SAND with traces of gravel |
| | BH 17 | T17D1 | @ | @ | @ | @ | Very soft, dark brown, grey, PEAT |
| | | T17D4 | 0 | 1 | 31 | 68 | Soft, dark brown, grey, PEAT |
| | | T17UD1 | | | | | Mediu, grey, grey, sandy CLAY |
| | | T17D5 | 0 | 1 | 37 | 62 | Medium stiff, light grey, grey, CLAY of Extremely High Plasticity |
| | | T17UD2 | | | | | Light grey, grey, CLAY |
| | | T17D6 | 0 | 1 | 25 | 74 | Medium stiff, medium grey, CLAY of Extremely High Plasticity with organic matter |
| | | T17D8 | 0 | 71 | 17 | 12 | Medium dense, medium grey, silty SAND with traces of clay |
| | | T17D10 | 0 | 80 | 13 | 7 | ditto |
| | | T17D14 | 0 | 84 | 16 | | Dense, light grey, silty SAND |
| | BH 18 | T18D1 | 1 | 49 | 34 | 16 | Stiff, light to medium grey, sandy SILT of Intermediate Plasticity |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T18D3 | 21 | 48 | 21 | 10 | Loose, light brown, silty SAND with tracse of clay |
| | | T18UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T18D5 | 0 | 4 | 60 | 36 | Medium stiff, medium grey, SILT of High Plasticity with traces of sand |
| | | T18UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T18D6 | 0 | 4 | 34 | 62 | Medium stiff, pale to light grey, SILT of High Plasticity with traces of sand |
| | | T18D8 | 0 | 57 | 32 | 11 | Very stiff, light grey, sandy SILT of Intermediate Plasticity |
| | | T18D11 | 1 | 58 | 28 | 13 | Very stiff, light to medium grey, sandy SILT of Intermediate Plasticity |
| | | T18D14 | 0 | 69 | 20 | 11 | Very dense, light to medium grey, silty SAND |
| | BH 19 | T19D1 | 24 | 44 | 24 | 8 | Loose, dark browm, silty SAND with some gravel |
| | | T19D3 | 1 | 50 | 31 | 18 | Medium stiff, dark brown, grey, sandy SILT of Intermediate Plasticity |
| | | T19UD1 | | | | | Medium grey, sandy CLAY |
| | | T19D4 | 0 | 1 | 27 | 72 | Medium stiff, medium grey, CLAY of Extremely High Plasticity |
| | | T19UD2 | | | | | Medium grey, sandy CLAY |
| | | T19D6 | 0 | 5 | 63 | 32 | Medium stiff, medium grey, SILT of High Plasticity with traces of sand |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T19D9 | 0 | 66 | 24 | 10 | ditto |
| | | T19D12 | 0 | 69 | 21 | 10 | Medium dense, light grey, silty SAND |
| | | T19D15 | 0 | 71 | 18 | 11 | Very dense, light grey, silty SAND |
| | BH 26 | T26D2 | @ | @ | @ | @ | ditto |
| | | T26D4 | 1 | 9 | 33 | 57 | Soft, light to medium grey, slightly sandy CLAY of Extremely High Plasticity |
| | | T26UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T26D5 | 2 | 9 | 24 | 65 | Soft, light grey, slightly sandy CLAY of Extremely High Plasticity |
| | | T26UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T26D6 | 2 | 11 | 31 | 56 | Medium stiff, light to medium grey, slightly sandy CLAY of Extremely High Plasticity |
| | | T26D9 | 1 | 73 | 8 | 18 | ditto |
| | | T26D12 | 0 | 75 | 9 | 16 | Medium dense, pale to light grey, silty SAND |
| | | T26D14 | 0 | 82 | 18 | | Very dense, pale to light grey, SAND |
| | BH 27 | T27D1 | @ | @ | @ | @ | Soft, dark grey, PEAT |
| | | T27D4 | 0 | 1 | 59 | 40 | Medium stiff, light grey, grey, SILT of High Plasticity |
| | | T27UD1 | | | | | Light grey, sand CLAY with organic matter |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T27D5 | 11 | 4 | 56 | 29 | Soft, light grey, grey, SILT of Extremely High Plasticity with traces of gravel |
| | | T27UD2 | | | | | Light grey, sandy CLAYwith decayed wood and organic matter |
| | | T27D7 | 0 | 66 | 20 | 14 | Loose, light brown, silty SAND with very High Plasticity |
| | | T27D9 | 0 | 83 | 17 | | ditto |
| | | T27D13 | 0 | 83 | 17 | | Very dense, light brown, silty SAND |
| | BH 28 | T28D2 | @ | @ | @ | @ | ditto |
| | | T28D4 | 0 | 2 | 34 | 64 | Soft, dark brown, dark grey, PEAT |
| | | T28UD1 | | | | | Medium grey, sandy CLAY |
| | | T28D5 | 0 | 1 | 29 | 70 | Medium stiff, medium grey, sandy CLAY of Very High Plasticity with traces of organic matter |
| | | T28UD2 | | | | | Medium grey, sandy CLAY |
| | | T28D8 | 1 | 76 | 17 | 6 | Medium dense, light brown, grey, silty SAND |
| | | T28D11 | 0 | 74 | 19 | 7 | Medium dense, light grey, brown, silty SAND of Intermediate Plasticity |
| | | T28D14 | 0 | 77 | 15 | 8 | Dense, light grey, brown, silty SAND of Intermediate Plasticity |
| | | T28D15 | 1 | 74 | 19 | 6 | Very dense, light grey, brownish, silty SAND of Intermediate Plasticity |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | BH 29 | T29D1 | @ | @ | @ | @ | Very soft, dark brown, grey, PEAT |
| | | T29D3 | 2 | 9 | 24 | 65 | Soft, dark brown, grey, slightly sandy Clay of Extremely High Plasticity |
| | | T29UD1 | | | | | Medium grey, sandy CLAY with some peat |
| | | T29D4 | 2 | 13 | 26 | 59 | Soft, medium grey, slightly sandy CLAY of Extremely High Plasticity |
| | | T29UD2 | | | | | Medium grey, sandy CLAY |
| | | T29D6 | 1 | 8 | 35 | 56 | Medium stiff, light grey, slightly sandy CLAY of Extremely High Plasticity |
| | | T29D9 | 1 | 73 | 18 | 8 | ditto |
| | | T29D12 | 0 | 77 | 17 | 6 | Dense, light grey, silty SAND with traces of gravel |
| | | T29D15 | 1 | 85 | 15 | | Very dense, light grey, SAND with traces of gravel |
| | BH 30 | T30D1 | @ | @ | @ | @ | Medium stiff, dark brown, PEAT |
| | | T30D4 | 0 | 3 | 61 | 36 | Soft, pale to light grey, SILT of High Plasticity with organic matter |
| | | T30UD1 | | | | | Pale to light grey, sandy CLAY with presence of decayed wood and organic matterial |
| | | T30D5 | 0 | 2 | 71 | 27 | Soft, pale to light grey, SILT of High Plasticity |
| | | T30UD2 | | | | | Light grey, sandy CLAY |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T30D7 | 0 | 2 | 60 | 38 | Medium stiff, pale to light grey, sandy SILT of High Plasticity |
| | | T30D9 | 0 | 60 | 29 | 11 | Stiff, pale to light grey, sandy SILT of Intermediate Plasticity |
| | | T30D12 | 0 | 75 | 16 | 9 | Medium dense, pale to light grey, silty SAND |
| | | T30D16 | 0 | 61 | 28 | 11 | Hard, light grey, sandy SILT of Intermediate Plasticity |
| | BH 31 | T31D2 | @ | @ | @ | @ | Medium stiff, dark brown, PEAT |
| | | T31D4 | @ | @ | @ | @ | Medium stiff, medium to dark brown, PEAT |
| | | T31UD1 | | | | | Pale to light grey, sandy CLAY |
| | | T31D5 | 0 | 2 | 62 | 36 | Soft, pale to light grey, SILT of High Plasticity with presence of decayed wood |
| | | T31UD2 | | | | | Light to medium grey, sandy CLAY |
| | | T31D6 | 0 | 1 | 63 | 36 | Medium stiff, pale to light grey, SILT of High Plasticity |
| | | T31D8 | 0 | 69 | 19 | 12 | Medium dense, light to medium grey, silty SAND |
| | | T31D11 | 0 | 66 | 25 | 9 | Dense, light to medium grey, silty SAND |
| | | T31D14 | 0 | 62 | 27 | 11 | Hard, light to medium grey, sandy SILT of Intermediate Plasticity with traces of gravel |
| | BH 20 | T20D1 | 1 | 54 | 31 | 14 | Stiff, pale to light brown, sandy SILT of Intermediate Plasticity |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| **Lot PT 21044** | | T20D3 | 1 | 30 | 48 | 21 | Stiff, light brown, slightly sandy SILT of Intermediate Plasticity |
| | | T20D4 | 0 | 1 | 27 | 72 | Soft, light to medium grey, CLAY of Extremely Hight Plasticity |
| | | T20UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T20D5 | 0 | 2 | 32 | 66 | Soft, medium grey, sandy CLAY |
| | | T20UD2 | | | | | Medium grey, sandy CLAY |
| | | T20D6 | 1 | 46 | 34 | 19 | Stiff, pale to light grey, sandy SILT of Intermediate Plasticity |
| | | T20D12 | 0 | 81 | 19 | | Medium dense, pale to light grey |
| | | T20D15 | 0 | 79 | 13 | 8 | Very dense, light grey, silty SAND with traces of gravel |
| | BH 21 | T21D1 | @ | @ | @ | @ | Soft, dark grey, brown, DECAYED WOOD |
| | | T21D3 | 1 | 22 | 31 | 46 | Soft, medium grey, grey, grey slightly sandy SILT of Extremely High Plasticity with some peat |
| | | T21UD1 | | | | | Medium grey, sandy CLAY |
| | | T21D4 | 0 | 13 | 25 | 62 | Medium stiff, medium grey, sandy CLAY of Very High Plasticity |
| | | T21UD2 | | | | | Medium grey, sandy CLAY |
| | | T21D6 | 0 | 75 | 15 | 10 | Medium dense, light grey, sandy SILT of Intermediate Plasticity |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T21D8 | 0 | 58 | 26 | 16 | ditto |
| | | T21D10 | 0 | 46 | 36 | 18 | Very stiff, light grey, sandy SILT of Intermediate Plasticity |
| | | T21D15 | 0 | 46 | 35 | 19 | Very dense, light grey, brownish, silty SAND |
| | BH 22 | T22D2 | @ | @ | @ | @ | Dark brown, grey, DECAYED WOOD |
| | | T22D3 | @ | @ | @ | @ | Dark brown, grey, PEAT with some clay |
| | | T22UD1 | | | | | Medium grey, grey, sandy CLAY |
| | | T22D4 | 0 | 4 | 37 | 59 | Medium stiff, medium grey, CLAY of Very High Plasticity with traces of sand |
| | | T22UD2 | | | | | Medium grey, sandy CLAY |
| | | T22D5 | 0 | 7 | 23 | 70 | Medium stiff, medium grey, CLAY of Very High Plasticity with tracse of sand |
| | | T22D7 | 1 | 49 | 35 | 15 | Very stiff, light grey, sandy SILT of Intermediate Plasticity |
| | | T22D9 | 0 | 70 | 23 | 7 | Medium dense, light grey, very silty SAND |
| | | T22D14 | 0 | 58 | 26 | 16 | Hard, light grey, sandy SILT of Intermediate Plasticity |
| | BH 23 | T23D1 | @ | @ | @ | @ | Soft, dark grey, brown, DECAYED WOOD |
| | | T23D3 | 0 | 37 | 45 | 18 | Medium stiff, medium grey, grey, sandy SILT of Intermediate Plasticity |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T23UD1 | | | | | Medium grey, sandy CLAY |
| | | T23D4 | 0 | 42 | 42 | 16 | Medium stiff, light grey, sandy SILT of Intermediate Plasticity |
| | | T23UD2 | | | | | Light grey, sandy CLAY |
| | | T23D5 | 0 | 67 | 24 | 9 | Loose, light grey, very silty SAND |
| | | T23D7 | 0 | 65 | 26 | 9 | Medium dense, light grey, very silty SAND |
| | | T23D10 | 0 | 67 | 21 | 12 | Medium dense, light grey very silty SAND |
| | | T23D14 | 0 | 78 | 15 | 7 | Very dense, light grey, silty SAND |
| | BH 24 | T24D1 | 2 | 35 | 41 | 22 | Stiff, light to medium brown, sandy SILT of Intermediate Plasticity |
| | | T24D3 | 0 | 5 | 38 | 57 | Soft, pale to light grey, slightly sandy CLAY of Extremely High Plasticity |
| | | T24UD1 | | | | | Light grey, sandy CLAY |
| | | T24D4 | 1 | 10 | 36 | 53 | Medium stiff, pale to light grey, slightly sandy CLAY of Extremely High Plasticity |
| | | T24UD2 | | | | | Pale to light grey, sandy CLAY |
| | | T24D6 | 0 | 13 | 26 | 61 | Medium stiff, light to medium grey, slightly sandy CLAY of Extremely High Plasticity |
| | | T24D9 | 0 | 71 | 21 | 8 | ditto |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | T24D12 | 0 | 73 | 18 | 9 | Medium dense, pale to light grey, very silty SAND |
| | | T24D14 | 0 | 86 | 14 | | Very dense, pale to light grey, silty SAND |
| | BH 25 | T25D1 | 2 | 46 | 31 | 21 | Stiff, light to medium brown, sandy SILT of High Plasticity |
| | | T25D3 | 0 | 3 | 39 | 58 | Soft, light grey, CLAY of High Plasticity with traces of SAND |
| | | T25UD1 | | | | | Light to medium grey, sandy CLAY |
| | | T25D5 | 0 | 84 | 16 | | Loose, light grey, SAND with traces of clay |
| | | T25D7 | 2 | 87 | 11 | | Very stiff, light brown, sandy SILT of Intermediate Plasticity |
| | | T25D9 | 1 | 95 | 4 | | ditto |
| | | T25D11 | | | | | Dense, pale to light grey, silty SAND |
| | | T25D14 | 0 | 3 | 66 | 31 | Very dense, pale to light grey, silty SAND |
| Lot PT 120188 | BH1 | SA1D3 | 0 | 25 | 60 | 15 | silty SAND |
| | | SA1D5 | | | | | slightly silty SAND |
| | | SA1UD1 | 1 | 49 | 41 | 9 | sandy SILT with some organic matter (wood) |
| | | SA1D7 | 6 | 50 | 38 | 6 | slightly sandy SILT |
| | | SA1D10 | 8 | 59 | 23 | 10 | slightly sandy SILT |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | SA1UD2 | | | | | slightly sandy SILT |
| | | SA1D12 | 2 | 21 | 52 | 15 | sandy SILT with some organic matter (wood) |
| | | SA1D17 | 0 | 84 | 16 | | sandy SILT |
| | BH2 | SA2D2 | 8 | 59 | 23 | 10 | very silty SAND |
| | | SA2UD1 | | | | | very silty SAND |
| | | SA2D4 | 2 | 21 | 62 | 15 | slightly sandy SILT with some organic matter (wood) |
| | | SA2D6 | 0 | 84 | 16 | | silty SAND |
| | | SA2D9 | 1 | 82 | 17 | | silty SAND |
| | | SA2D11 | 0 | 84 | 16 | | silty SAND |
| | | SA2D14 | 6 | 36 | 50 | 8 | sandy SILT |
| | BH3 | SA3D1 | 0 | 20 | 62 | 18 | silty SAND |
| | | SA3D3 | 3 | 77 | 19 | 1 | slightly sandy SILT with some organic matter (wood) |
| | | SA3D5 | 3 | 71 | 25 | 1 | slightly sandy SILT |
| | | SA3UD1 | | | | | sandy SILT |
| | | SA3D7 | 0 | 45 | 40 | 15 | slightly sandy SILT |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | SA3D12 | 18 | 25 | 49 | 8 | silty SAND with some organic matter (wood) |
| | | SA3D14 | 0 | 48 | 41 | 11 | very silty SAND |
| | BH4 | SA4UD1 | | | | | sandy SILT |
| | | SA4D2 | 0 | 65 | 27 | 8 | sandy SILT |
| | | SA4D4 | 1 | 86 | 13 | | sandy SILT with some organic matter (wood) |
| | | SA4D5 | 2 | 43 | 47 | 8 | sandy SILT |
| | | SA4UD3 | | 45 | | | sandy SILT |
| | | SA4D6 | | | | | sandy SILT |
| | | SA4D10 | 0 | 17 | 36 | 47 | silty SAND |
| | | SA4D12 | 0 | 5 | 38 | 57 | sandy SILT |
| Lot PT 120185 | BH1 | SB1D1 | 0 | 12 | 40 | 48 | sandy SILT |
| | | SB1C1 | 0 | 19 | 46 | 35 | SANDSTONE |
| | | SB1D4 | 28 | 55 | 17 | | slightly sandy CLAY |
| | | SB1D5 | | | | | slightly sandy CLAY |
| | | SB1D6 | 2 | 51 | 27 | 20 | slightly sandy CLAY |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | SB1D7 | | | | | slightly sandy CLAY |
| | | SB1D11 | | | | | silty SAND |
| | | SB1C4 | 5 | 48 | 31 | 16 | highly weathered, SCHIST |
| | BH2 | SB2D3 | | | | | sandy SILT |
| | | SB2D4 | 0 | 10 | 54 | 36 | sandy SILT |
| | | SB2U3 | 0 | 5 | 49 | 46 | sandy SILT |
| | | SB2D5 | 72 | 25 | 3 | | sandy SILT with organic matter (wood) |
| | | SB2D6 | | | | | ORGANIC MATTER (wood) |
| | | SB2D9 | 46 | 49 | 5 | | slightly sandy SILT |
| | | SB2D10 | | | | | slightly sandy SILT |
| | | SB2D11 | 38 | 54 | 8 | | slightly silty GRAVEL |
| | | SB2C1 | 0 | 4 | 39 | 57 | SANDSTONE |
| | BH3 | SB3D2 | 1 | 85 | 14 | | slightly silty SAND |
| | | SB3D3 | 14 | 84 | 2 | | slightly silty SAND |
| | | SB3D5 | 24 | 36 | 37 | 3 | slightly silty SAND |
| | | SB3D6 | | | | | slightly sandy CLAY |
| | | SB3D8 | 7 | 44 | 28 | 21 | silty SAND |

| Location | Borehole | Name of Sample | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Subsoil Classification (BSCS) |
|---|---|---|---|---|---|---|---|
| | | SB3D9 | 5 | 41 | 31 | 23 | slightly silty SAND with some organic matter (wood) |
| | | SB3D14 | 0 | 13 | 64 | 23 | sandy SILT |
| | BH4 | SB4D1 | | | | | silty GRAVEL |
| | | SB4D4 | 7 | 44 | 28 | 21 | sandy SILT |
| | | SB4D5 | 5 | 41 | 31 | 23 | sandy SILT |
| | | SB4D6 | 2 | 9 | 66 | 23 | sandy SILT |
| | | SB4U3 | | | | | slightly sandy SILT |
| | | SB4D7 | 0 | 13 | 64 | 23 | slightly sandy SILT |
| | | SB4D8 | 0 | 17 | 57 | 26 | slightly sandy SILT |
| | | SB4D12 | 6 | 83 | | 11 | silty SAND |

# APPENDIX 13

Photographs taken during the site study







Borehole Drilling Activity During Site Investigation at The Study Area.

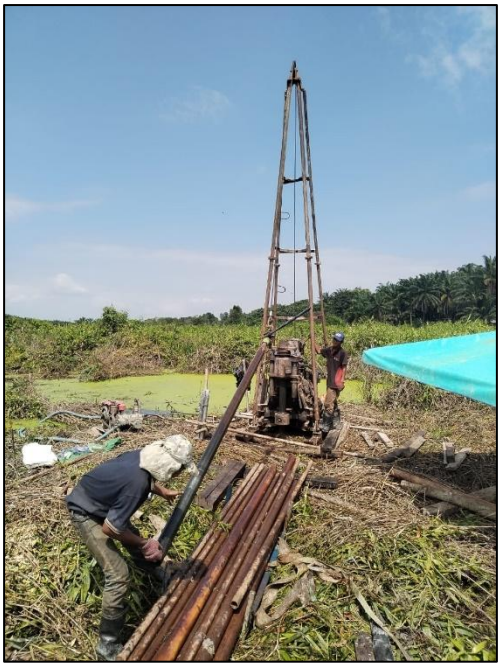


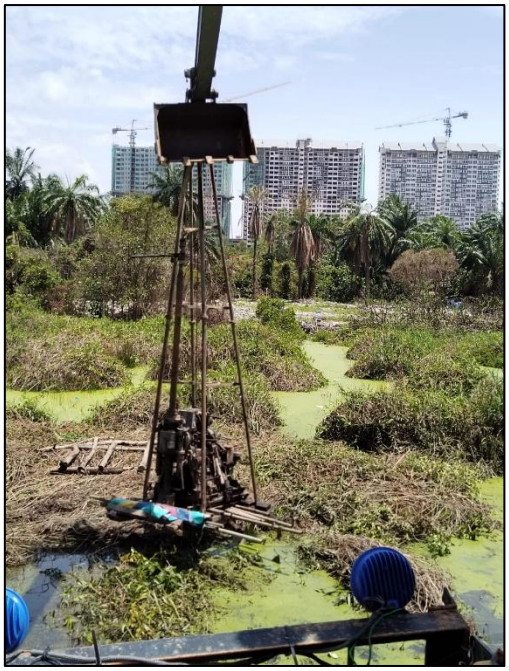







Soil sample retrieved from Borehole









The site condition is swampy at Lot PT 21044, Cyberjaya.




Laboratory testing work carried out on soil samples.

# APPENDIX 14

Representative Borehole Logs at PT 21044, Cyberjaya (BH1)

**MAJUMEC BINA SDN BHD**

SOIL INVESTIGATION
DEEP BORING LOG

| | | | |
|---|---|---|---|
| Project: | Cadangan Pembangunan Bercampur | | |
| Location: | PT 21044, seluas 152 Ekar, Dengkil | | |
| Type of boring: | Rotary Wash Boring | Reduced Level (m): 8.325 | Borehole No.: BH - 1 |
| Type of rig: | YWE-D90R | | |
| Ø of boring: | 89/115 mm | Coordinates: mE 403329.781 | Sheet No.: 1 of 3 |
| Casing detail: | NW/HW | mN 320104.387 | |

| Date & Time | Boring Depth | Ground Water | Depth (m) | Sample | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | Depth (m) | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31.1.23 11.30am | 0m | | 0.000<br>0.300 | | | | | | | | | | Top soil: medium to dark brown, PEAT |
| | 1m | | 1.500<br>1.950 | P1 D1<br>R = 27% | 1 | 2 | 1 | 0 | 1 | 0 | 2 | | Very soft, medium to dark brown, PEAT |
| | 2m | | | | | | | | | | | | |
| | 3m | | 3.000<br>3.450 | P2 D2<br>R = 31% | 1 | 0 | 1 | 0 | 1 | 0 | 2 | | Soft, dark brown, PEAT |
| | 4m | | | | | | | | | | | | |
| | 5m | | 4.500<br>4.950 | P3 D3<br>R = 49% | 1 | 1 | 2 | 2 | 1 | 1 | 6 | | Medium stiff, dark brown, PEAT with traces of clay |
| | | | | | | | | | | | | 5.60 | |
| | 6m | | 6.000<br>6.500 | P4 D4<br>R = 47% | 1 | 0 | 1 | 1 | 0 | 1 | 3 | | Soft, pale to light grey, SILT of High Plasticity |
| | 7m | | | | | | | | | | | 7.20 | |
| | 8m | | 7.500<br>8.200 | UD-1<br>R = 100% | | | | | | | | | Light grey, sandy CLAY |
| | | | | | | | | | | | | 8.60 | |
| | 9m | | 9.000<br>9.450 | P5 D5<br>R = 51% | 1 | 0 | 1 | 0 | 1 | 2 | 4 | | Medium stiff, light grey, SILT of High Plasticity |
| | 10m | | | | | | | | | | | | |

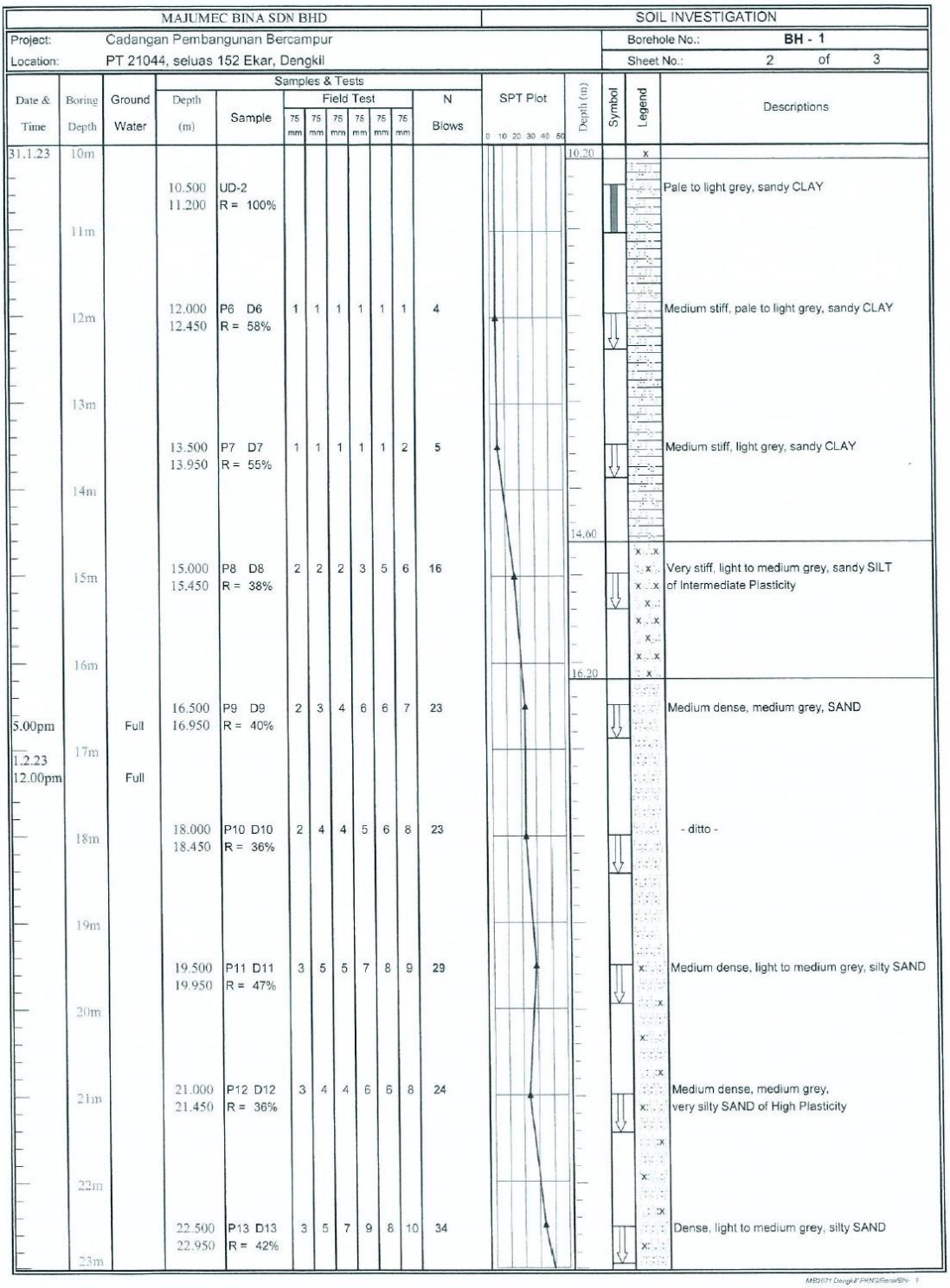
Legend:
P: Standard Penetration Test (SPT)
UD: Undisturbed Sample
PS: Piston Sampler
C: Core Sample
D: Disturbed Sample
R: Recovery Ratio (%)
VS: Vane Shear Test
PT: Pressuremeter Test
FHP: Falling Head Permeability Test

Consistency / Relative Density

| Cohesive Soil (N) | Non Cohesive Soil (N) |
|---|---|
| 0 - 2 Very soft | 0 - 4 Very loose |
| 2 - 4 Soft | 4 - 10 Loose |
| 4 - 8 Medium stiff | 10 - 30 Medium dense |
| 8 - 15 Stiff | 30 - 50 Dense |
| 15 - 30 Very stiff | > 50 Very dense |
| > 30 Hard | |

CRR: Core Recovery Ratio (%)
RQD: Rock Quality Designation (%)

Logged by: Danish



MAJUMEC BINA SDN BHD

SOIL INVESTIGATION

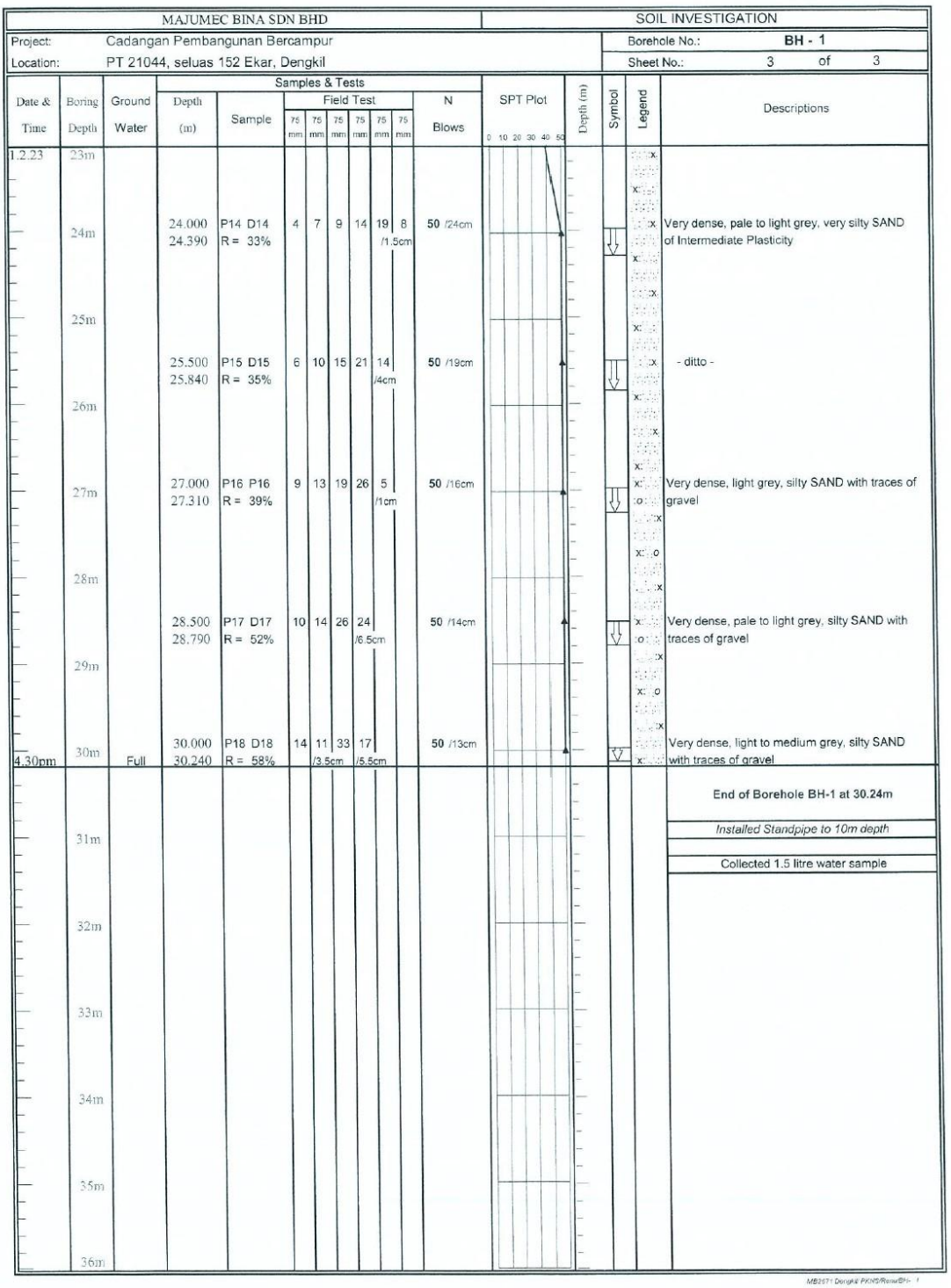
Project: Cadangan Pembangunan Bercampur

Location: PT 21044, seluas 152 Ekar, Dengkil

Borehole No.: BH - 1

Sheet No.: 2 of 3

| Date & Time | Boring Depth | Ground Water | Depth (m) | Sample | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | SPT Plot 0 10 20 30 40 50 | Depth (m) | Symbol | Legend | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31.1.23 | 10m | | | | | | | | | | | | 10.20 | | x | |
| | | | 10.500<br>11.200 | UD-2<br>R = 100% | | | | | | | | | | | | Pale to light grey, sandy CLAY |
| | 11m | | | | | | | | | | | | | | | |
| | 12m | | 12.000<br>12.450 | P6 D6<br>R = 58% | 1 | 1 | 1 | 1 | 1 | 1 | 4 | | | | | Medium stiff, pale to light grey, sandy CLAY |
| | 13m | | | | | | | | | | | | | | | |
| | | | 13.500<br>13.950 | P7 D7<br>R = 55% | 1 | 1 | 1 | 1 | 1 | 2 | 5 | | | | | Medium stiff, light grey, sandy CLAY |
| | 14m | | | | | | | | | | | | 14.60 | | | |
| | | | 15.000<br>15.450 | P8 D8<br>R = 38% | 2 | 2 | 2 | 3 | 5 | 6 | 16 | | | | | Very stiff, light to medium grey, sandy SILT of Intermediate Plasticity |
| | 15m | | | | | | | | | | | | | | | |
| | 16m | | | | | | | | | | | | 16.20 | | | |
| | | | 16.500<br>16.950 | P9 D9<br>R = 40% | 2 | 3 | 4 | 6 | 6 | 7 | 23 | | | | | Medium dense, medium grey, SAND |
| 5.00pm | | Full | | | | | | | | | | | | | | |
| 1.2.23 | 17m | | | | | | | | | | | | | | | |
| 12.00pm | | Full | | | | | | | | | | | | | | |
| | | | 18.000<br>18.450 | P10 D10<br>R = 36% | 2 | 4 | 4 | 5 | 6 | 8 | 23 | | | | | - ditto - |
| | 18m | | | | | | | | | | | | | | | |
| | 19m | | | | | | | | | | | | | | | |
| | | | 19.500<br>19.950 | P11 D11<br>R = 47% | 3 | 5 | 5 | 7 | 8 | 9 | 29 | | | | | Medium dense, light to medium grey, silty SAND |
| | 20m | | | | | | | | | | | | | | | |
| | | | 21.000<br>21.450 | P12 D12<br>R = 36% | 3 | 4 | 4 | 6 | 6 | 8 | 24 | | | | | Medium dense, medium grey, very silty SAND of High Plasticity |
| | 21m | | | | | | | | | | | | | | | |
| | 22m | | | | | | | | | | | | | | | |
| | | | 22.500<br>22.950 | P13 D13<br>R = 42% | 3 | 5 | 7 | 9 | 8 | 10 | 34 | | | | | Dense, light to medium grey, silty SAND |
| | 23m | | | | | | | | | | | | | | | |



MAJUMEC BINA SDN BHD

SOIL INVESTIGATION

Project: Cadangan Pembangunan Bercampur

Location: PT 21044, seluas 152 Ekar, Dengkil

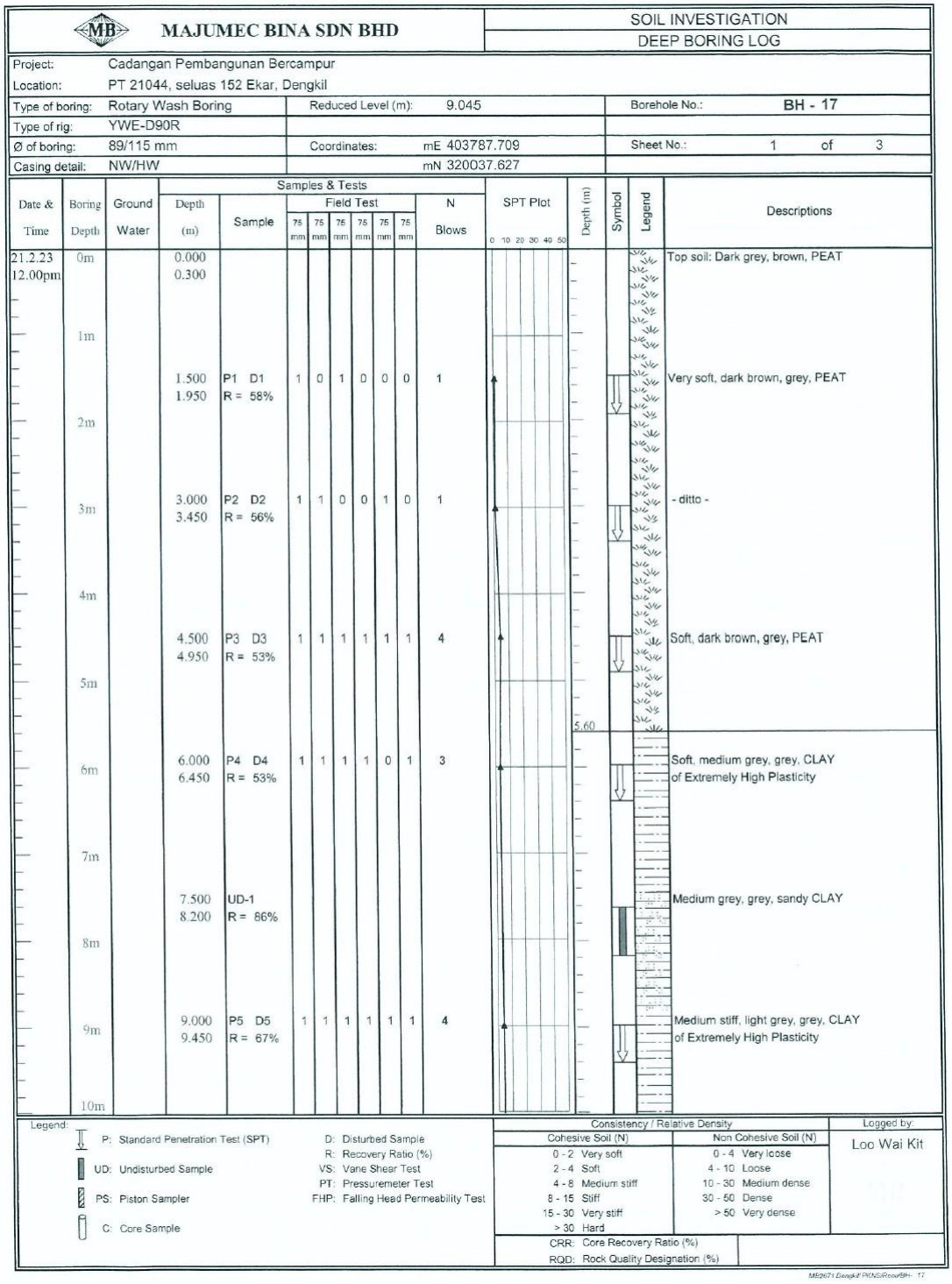
Borehole No.: BH - 1

Sheet No.: 3 of 3

| Date & Time | Boring Depth | Ground Water | Samples & Tests: Depth (m) | Sample | Field Test: 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | SPT Plot (0 10 20 30 40 50) | Depth (m) | Symbol | Legend | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.2.23 | 23m | | | | | | | | | | | | | | | |
| | 24m | | 24.000<br>24.390 | P14 D14<br>R = 33% | 4 | 7 | 9 | 14 | 19<br>/1.5cm | 8 | 50 /24cm | | | | | Very dense, pale to light grey, very silty SAND of Intermediate Plasticity |
| | 25m | | | | | | | | | | | | | | | |
| | | | 25.500<br>25.840 | P15 D15<br>R = 35% | 6 | 10 | 15 | 21 | 14<br>/4cm | | 50 /19cm | | | | | - ditto - |
| | 26m | | | | | | | | | | | | | | | |
| | 27m | | 27.000<br>27.310 | P16 P16<br>R = 39% | 9 | 13 | 19 | 26 | 5<br>/1cm | | 50 /16cm | | | | | Very dense, light grey, silty SAND with traces of gravel |
| | 28m | | | | | | | | | | | | | | | |
| | | | 28.500<br>28.790 | P17 D17<br>R = 52% | 10 | 14 | 26 | 24<br>/6.5cm | | | 50 /14cm | | | | | Very dense, pale to light grey, silty SAND with traces of gravel |
| | 29m | | | | | | | | | | | | | | | |
| 4.30pm | 30m | Full | 30.000<br>30.240 | P18 D18<br>R = 58% | 14 | 11<br>/3.5cm | 33 | 17<br>/5.5cm | | | 50 /13cm | | | | | Very dense, light to medium grey, silty SAND with traces of gravel |
| | 31m | | | | | | | | | | | | | | | End of Borehole BH-1 at 30.24m<br>*Installed Standpipe to 10m depth*<br>Collected 1.5 litre water sample |
| | 32m | | | | | | | | | | | | | | | |
| | 33m | | | | | | | | | | | | | | | |
| | 34m | | | | | | | | | | | | | | | |
| | 35m | | | | | | | | | | | | | | | |
| | 36m | | | | | | | | | | | | | | | |

# APPENDIX 15

Representative Borehole Logs at PT 21044, Cyberjaya (BH17)



MAJUMEC BINA SDN BHD

SOIL INVESTIGATION
DEEP BORING LOG

| | | | |
|---|---|---|---|
| Project: | Cadangan Pembangunan Bercampur | | |
| Location: | PT 21044, seluas 152 Ekar, Dengkil | | |
| Type of boring: | Rotary Wash Boring | Reduced Level (m): 9.045 | Borehole No.: BH - 17 |
| Type of rig: | YWE-D90R | | |
| Ø of boring: | 89/115 mm | Coordinates: mE 403787.709 | Sheet No.: 1 of 3 |
| Casing detail: | NW/HW | mN 320037.627 | |

| Date & Time | Boring Depth | Ground Water | Samples & Tests: Depth (m) | Sample | Field Test: 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | SPT Plot (0 10 20 30 40 50) | Depth (m) | Symbol | Legend | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21.2.23 12.00pm | 0m | | 0.000 | | | | | | | | | | | | | Top soil: Dark grey, brown, PEAT |
| | | | 0.300 | | | | | | | | | | | | | |
| | 1m | | | | | | | | | | | | | | | |
| | | | 1.500 | P1 D1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | | | | | Very soft, dark brown, grey, PEAT |
| | | | 1.950 | R = 58% | | | | | | | | | | | | |
| | 2m | | | | | | | | | | | | | | | |
| | | | 3.000 | P2 D2 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | | | | | - ditto - |
| | 3m | | 3.450 | R = 56% | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | 4m | | | | | | | | | | | | | | | |
| | | | 4.500 | P3 D3 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | | | | | Soft, dark brown, grey, PEAT |
| | | | 4.950 | R = 53% | | | | | | | | | | | | |
| | 5m | | | | | | | | | | | | 5.60 | | | |
| | | | 6.000 | P4 D4 | 1 | 1 | 1 | 1 | 0 | 1 | 3 | | | | | Soft, medium grey, grey, CLAY of Extremely High Plasticity |
| | 6m | | 6.450 | R = 53% | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | 7m | | | | | | | | | | | | | | | |
| | | | 7.500 | UD-1 | | | | | | | | | | | | Medium grey, grey, sandy CLAY |
| | | | 8.200 | R = 86% | | | | | | | | | | | | |
| | 8m | | | | | | | | | | | | | | | |
| | | | 9.000 | P5 D5 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | | | | | Medium stiff, light grey, grey, CLAY of Extremely High Plasticity |
| | 9m | | 9.450 | R = 67% | | | | | | | | | | | | |
| | 10m | | | | | | | | | | | | | | | |

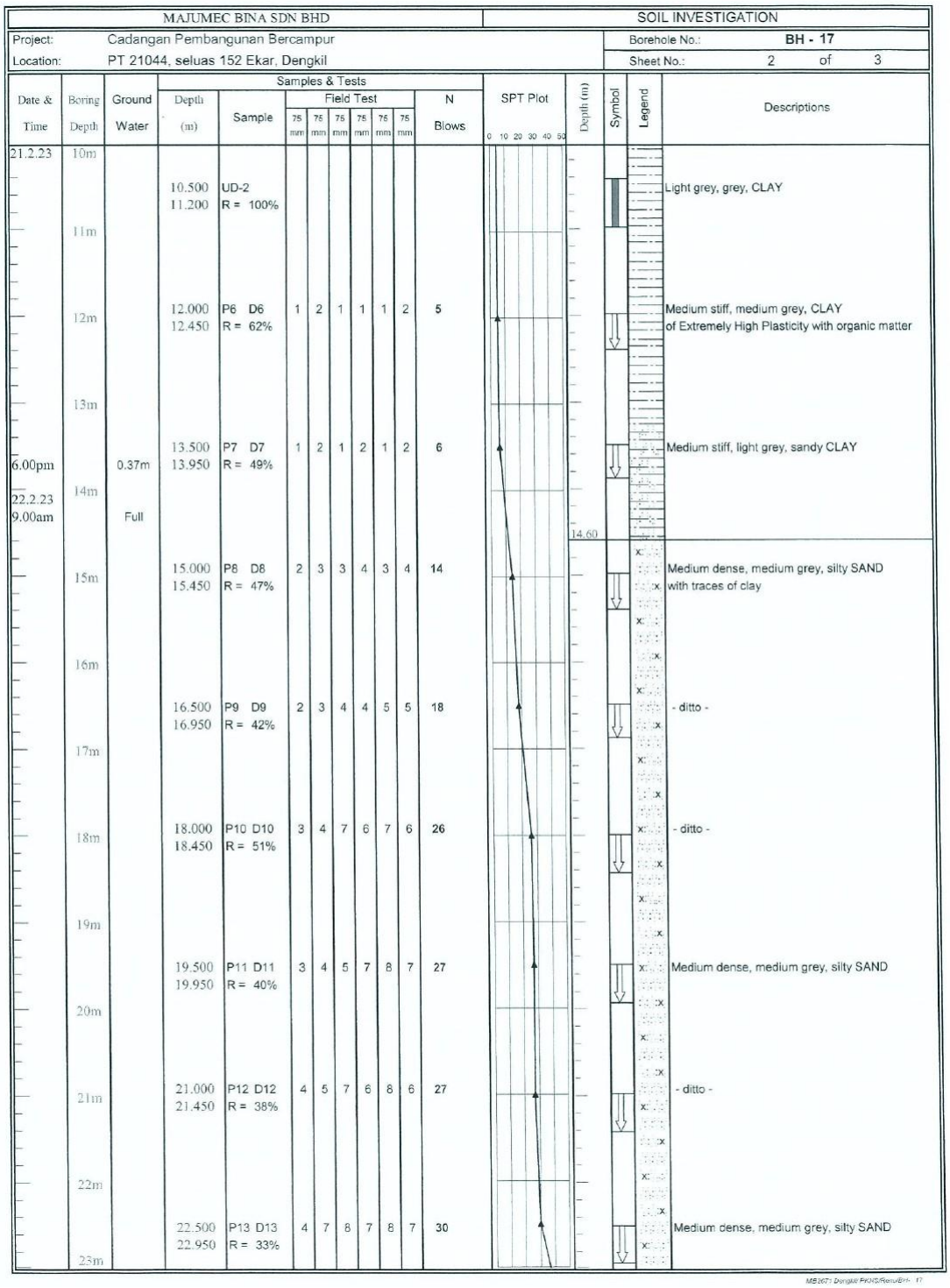
Legend:
- P: Standard Penetration Test (SPT)
- UD: Undisturbed Sample
- PS: Piston Sampler
- C: Core Sample
- D: Disturbed Sample
- R: Recovery Ratio (%)
- VS: Vane Shear Test
- PT: Pressuremeter Test
- FHP: Falling Head Permeability Test

Consistency / Relative Density

| Cohesive Soil (N) | Non Cohesive Soil (N) |
|---|---|
| 0 - 2 Very soft | 0 - 4 Very loose |
| 2 - 4 Soft | 4 - 10 Loose |
| 4 - 8 Medium stiff | 10 - 30 Medium dense |
| 8 - 15 Stiff | 30 - 50 Dense |
| 15 - 30 Very stiff | > 50 Very dense |
| > 30 Hard | |

CRR: Core Recovery Ratio (%)
RQD: Rock Quality Designation (%)

Logged by: Loo Wai Kit



MAJUMEC BINA SDN BHD

SOIL INVESTIGATION

Project: Cadangan Pembangunan Bercampur

Location: PT 21044, seluas 152 Ekar, Dengkil

Borehole No.: BH - 17

Sheet No.: 2 of 3

| Date & Time | Boring Depth | Ground Water | Depth (m) | Sample | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21.2.23 | 10m | | 10.500 | UD-2 | | | | | | | | Light grey, grey, CLAY |
| | | | 11.200 | R = 100% | | | | | | | | |
| | 11m | | | | | | | | | | | |
| | 12m | | 12.000 | P6 D6 | 1 | 2 | 1 | 1 | 1 | 2 | 5 | Medium stiff, medium grey, CLAY |
| | | | 12.450 | R = 62% | | | | | | | | of Extremely High Plasticity with organic matter |
| | 13m | | | | | | | | | | | |
| | | | 13.500 | P7 D7 | 1 | 2 | 1 | 2 | 1 | 2 | 6 | Medium stiff, light grey, sandy CLAY |
| 6.00pm | | 0.37m | 13.950 | R = 49% | | | | | | | | |
| 22.2.23 | 14m | | | | | | | | | | | |
| 9.00am | | Full | | | | | | | | | | |
| | | | | | | | | | | | | 14.60 |
| | 15m | | 15.000 | P8 D8 | 2 | 3 | 3 | 4 | 3 | 4 | 14 | Medium dense, medium grey, silty SAND |
| | | | 15.450 | R = 47% | | | | | | | | with traces of clay |
| | 16m | | | | | | | | | | | |
| | | | 16.500 | P9 D9 | 2 | 3 | 4 | 4 | 5 | 5 | 18 | - ditto - |
| | | | 16.950 | R = 42% | | | | | | | | |
| | 17m | | | | | | | | | | | |
| | | | 18.000 | P10 D10 | 3 | 4 | 7 | 6 | 7 | 6 | 26 | - ditto - |
| | 18m | | 18.450 | R = 51% | | | | | | | | |
| | 19m | | | | | | | | | | | |
| | | | 19.500 | P11 D11 | 3 | 4 | 5 | 7 | 8 | 7 | 27 | Medium dense, medium grey, silty SAND |
| | | | 19.950 | R = 40% | | | | | | | | |
| | 20m | | | | | | | | | | | |
| | | | 21.000 | P12 D12 | 4 | 5 | 7 | 6 | 8 | 6 | 27 | - ditto - |
| | 21m | | 21.450 | R = 38% | | | | | | | | |
| | 22m | | | | | | | | | | | |
| | | | 22.500 | P13 D13 | 4 | 7 | 8 | 7 | 8 | 7 | 30 | Medium dense, medium grey, silty SAND |
| | 23m | | 22.950 | R = 33% | | | | | | | | |

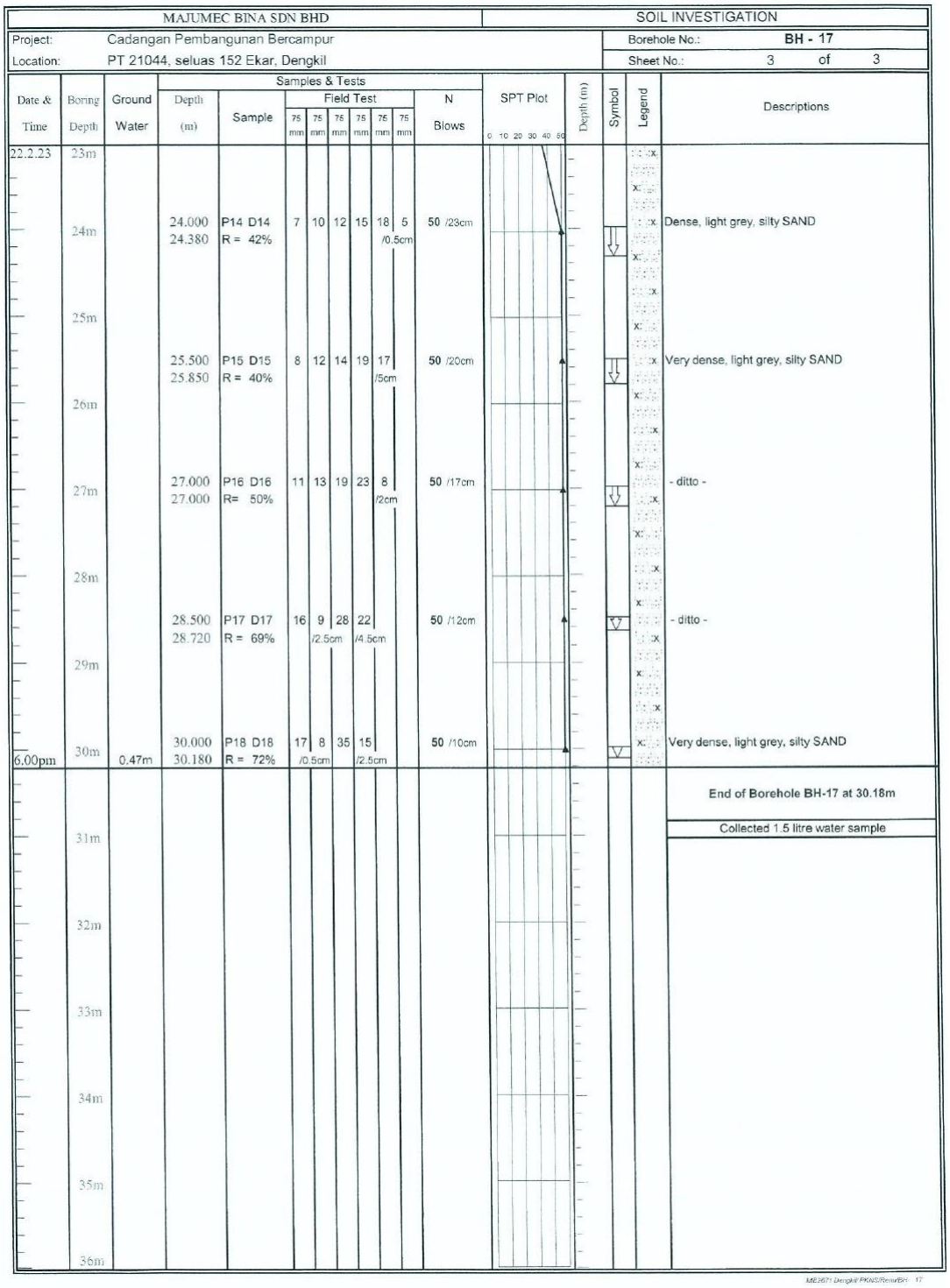
SPT Plot: 0 10 20 30 40 50

Depth (m)

Symbol

Legend

MB267: Dengkil PKNS/Rem/Bh. 17



MAJUMEC BINA SDN BHD — SOIL INVESTIGATION

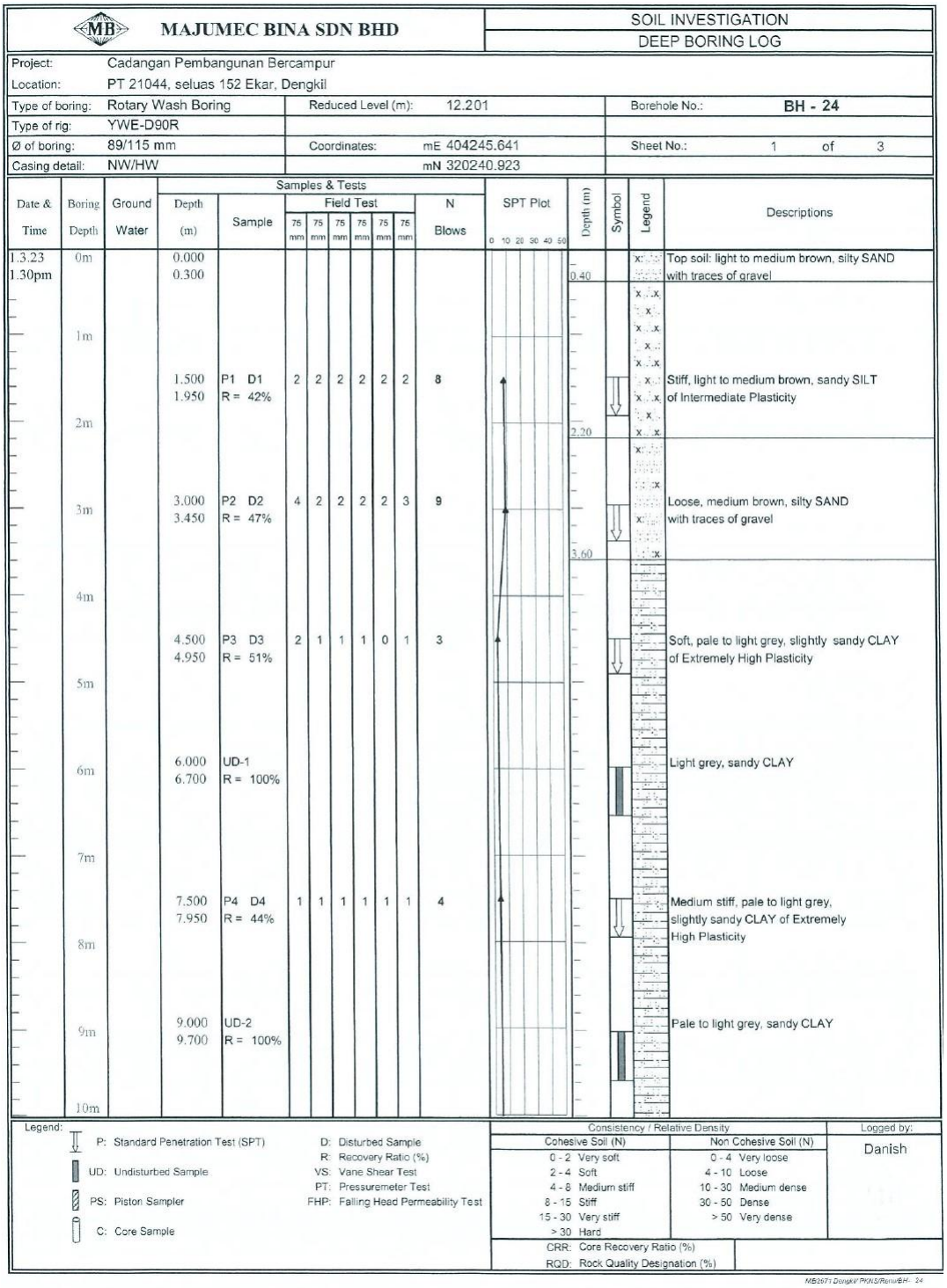
Project: Cadangan Pembangunan Bercampur
Location: PT 21044, seluas 152 Ekar, Dengkil
Borehole No.: BH - 17
Sheet No.: 3 of 3

| Date & Time | Boring Depth | Ground Water | Samples & Tests: Depth (m) | Sample | Field Test: 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | SPT Plot (0 10 20 30 40 50) | Depth (m) | Symbol | Legend | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22.2.23 | 23m | | | | | | | | | | | | | | | |
| | 24m | | 24.000<br>24.380 | P14 D14<br>R = 42% | 7 | 10 | 12 | 15 | 18 /0.5cm | 5 | 50 /23cm | | | | | Dense, light grey, silty SAND |
| | 25m | | | | | | | | | | | | | | | |
| | | | 25.500<br>25.850 | P15 D15<br>R = 40% | 8 | 12 | 14 | 19 | 17 /5cm | | 50 /20cm | | | | | Very dense, light grey, silty SAND |
| | 26m | | | | | | | | | | | | | | | |
| | 27m | | 27.000<br>27.000 | P16 D16<br>R= 50% | 11 | 13 | 19 | 23 | 8 /2cm | | 50 /17cm | | | | | - ditto - |
| | 28m | | | | | | | | | | | | | | | |
| | | | 28.500<br>28.720 | P17 D17<br>R = 69% | 16 | 9 /2.5cm | 28 | 22 /4.5cm | | | 50 /12cm | | | | | - ditto - |
| | 29m | | | | | | | | | | | | | | | |
| 6.00pm | 30m | 0.47m | 30.000<br>30.180 | P18 D18<br>R = 72% | 17 | 8 /0.5cm | 35 | 15 /2.5cm | | | 50 /10cm | | | | | Very dense, light grey, silty SAND |
| | | | | | | | | | | | | | | | | End of Borehole BH-17 at 30.18m |
| | 31m | | | | | | | | | | | | | | | Collected 1.5 litre water sample |
| | 32m | | | | | | | | | | | | | | | |
| | 33m | | | | | | | | | | | | | | | |
| | 34m | | | | | | | | | | | | | | | |
| | 35m | | | | | | | | | | | | | | | |
| | 36m | | | | | | | | | | | | | | | |

ME2671 Dengkil PKNS Rev/BH - 17

# APPENDIX 16

Representative Borehole Logs at PT 21044, Cyberjaya (BH24)



MAJUMEC BINA SDN BHD

SOIL INVESTIGATION
DEEP BORING LOG

| | | | | | |
|---|---|---|---|---|---|
| Project: | Cadangan Pembangunan Bercampur | | | | |
| Location: | PT 21044, seluas 152 Ekar, Dengkil | | | | |
| Type of boring: | Rotary Wash Boring | Reduced Level (m): | 12.201 | Borehole No.: | BH - 24 |
| Type of rig: | YWE-D90R | | | | |
| Ø of boring: | 89/115 mm | Coordinates: | mE 404245.641 | Sheet No.: | 1 of 3 |
| Casing detail: | NW/HW | | mN 320240.923 | | |

| Date & Time | Boring Depth | Ground Water | Samples & Tests: Depth (m) | Sample | Field Test: 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | SPT Plot (0 10 20 30 40 50) | Depth (m) | Symbol | Legend | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.3.23 1.30pm | 0m | | 0.000 | | | | | | | | | | | | | |
| | | | 0.300 | | | | | | | | | | 0.40 | | | Top soil: light to medium brown, silty SAND with traces of gravel |
| | 1m | | | | | | | | | | | | | | | |
| | | | 1.500 | P1 D1 | 2 | 2 | 2 | 2 | 2 | 2 | 8 | | | | | Stiff, light to medium brown, sandy SILT |
| | | | 1.950 | R = 42% | | | | | | | | | | | | of Intermediate Plasticity |
| | 2m | | | | | | | | | | | | 2.20 | | | |
| | | | 3.000 | P2 D2 | 4 | 2 | 2 | 2 | 2 | 3 | 9 | | | | | Loose, medium brown, silty SAND |
| | 3m | | 3.450 | R = 47% | | | | | | | | | | | | with traces of gravel |
| | | | | | | | | | | | | | 3.60 | | | |
| | 4m | | | | | | | | | | | | | | | |
| | | | 4.500 | P3 D3 | 2 | 1 | 1 | 1 | 0 | 1 | 3 | | | | | Soft, pale to light grey, slightly sandy CLAY |
| | | | 4.950 | R = 51% | | | | | | | | | | | | of Extremely High Plasticity |
| | 5m | | | | | | | | | | | | | | | |
| | | | 6.000 | UD-1 | | | | | | | | | | | | Light grey, sandy CLAY |
| | 6m | | 6.700 | R = 100% | | | | | | | | | | | | |
| | 7m | | | | | | | | | | | | | | | |
| | | | 7.500 | P4 D4 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | | | | | Medium stiff, pale to light grey, |
| | | | 7.950 | R = 44% | | | | | | | | | | | | slightly sandy CLAY of Extremely |
| | 8m | | | | | | | | | | | | | | | High Plasticity |
| | | | 9.000 | UD-2 | | | | | | | | | | | | Pale to light grey, sandy CLAY |
| | 9m | | 9.700 | R = 100% | | | | | | | | | | | | |
| | 10m | | | | | | | | | | | | | | | |

Legend:
- P: Standard Penetration Test (SPT)
- UD: Undisturbed Sample
- PS: Piston Sampler
- C: Core Sample
- D: Disturbed Sample
- R: Recovery Ratio (%)
- VS: Vane Shear Test
- PT: Pressuremeter Test
- FHP: Falling Head Permeability Test

Consistency / Relative Density

| Cohesive Soil (N) | Non Cohesive Soil (N) |
|---|---|
| 0 - 2 Very soft | 0 - 4 Very loose |
| 2 - 4 Soft | 4 - 10 Loose |
| 4 - 8 Medium stiff | 10 - 30 Medium dense |
| 8 - 15 Stiff | 30 - 50 Dense |
| 15 - 30 Very stiff | > 50 Very dense |
| > 30 Hard | |

CRR: Core Recovery Ratio (%)
RQD: Rock Quality Designation (%)

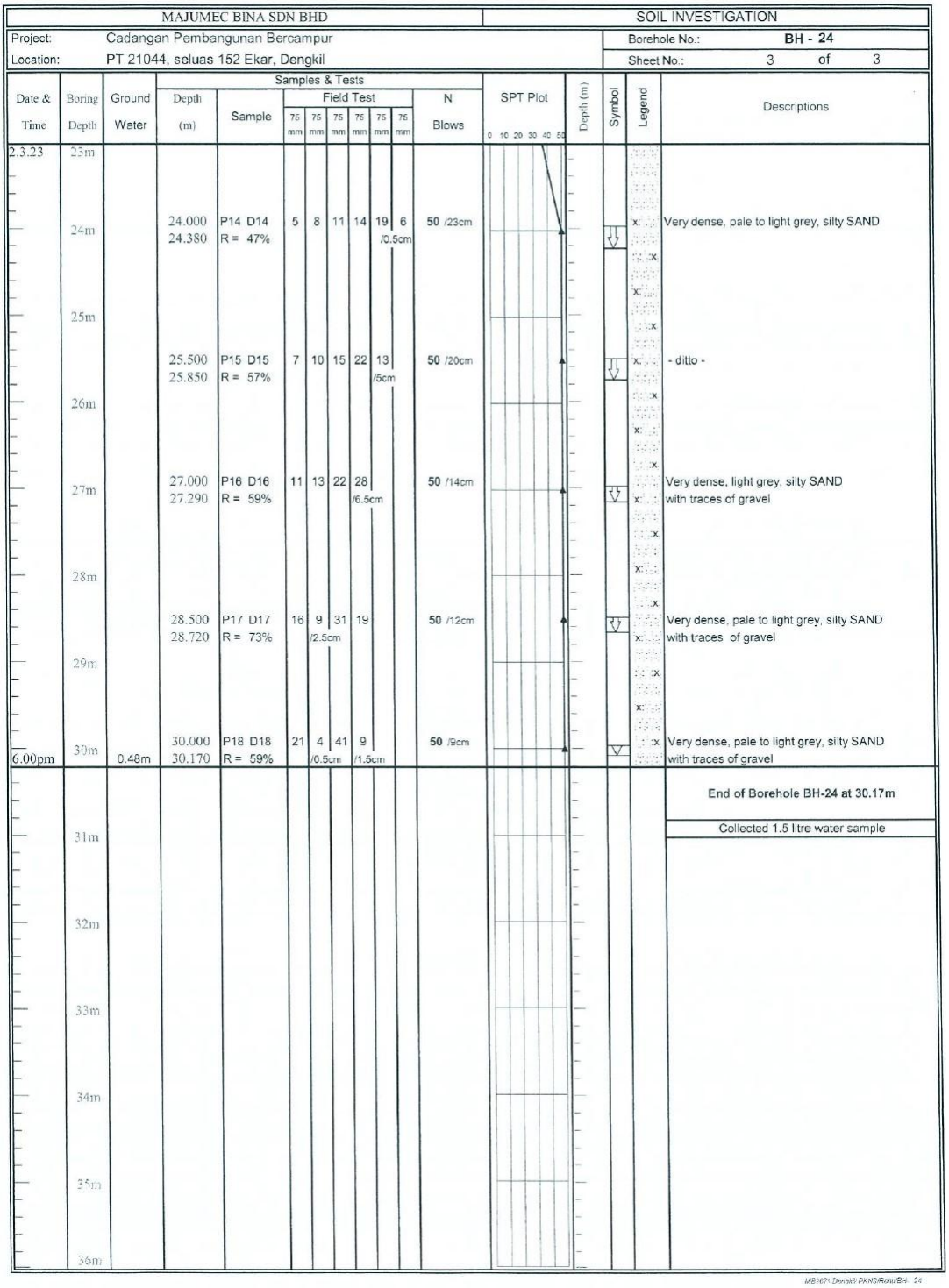
Logged by: Danish

MB2671 Dongkil PKNS/Rev/BH - 24

MAJUMEC BINA SDN BHD — SOIL INVESTIGATION

Project: Cadangan Pembangunan Bercampur
Location: PT 21044, seluas 152 Ekar, Dengkil
Borehole No.: BH - 24
Sheet No.: 2 of 3

| Date & Time | Boring Depth | Ground Water | Samples & Tests: Depth (m) | Sample | Field Test: 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | SPT Plot (0 10 20 30 40 50) | Depth (m) | Symbol | Legend | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.3.23 | 10m | | | | | | | | | | | | | | | |
| | | | 10.500 | P5 D5 | 1 | 1 | 1 | 1 | 1 | 2 | 5 | | | | | Medium stiff, pale to light grey, sandy CLAY |
| 5.00pm | | 0.14m | 10.950 | R = 51% | | | | | | | | | | | | |
| 2.3.23 | 11m | | | | | | | | | | | | | | | |
| 9.00am | | 0.81m | | | | | | | | | | | | | | |
| | 12m | | 12.000 | P6 D6 | 1 | 1 | 1 | 1 | 2 | 2 | 6 | | | | | Medium stiff, light to medium grey, slightly sandy CLAY of Extremely High Plasticity with presence of organic material |
| | | | 12.450 | R = 44% | | | | | | | | | | | | |
| | 13m | | | | | | | | | | | | 13.20 | | | |
| | | | 13.500 | P7 D7 | 2 | 3 | 3 | 3 | 2 | 3 | 11 | | | | | Medium dense, pale to light grey, SAND with traces of clay |
| | | | 13.950 | R = 42% | | | | | | | | | | | | |
| | 14m | | | | | | | | | | | | | | | |
| | 15m | | 15.000 | P8 D8 | 2 | 3 | 3 | 3 | 4 | 4 | 14 | | | | | Medium dense, pale to light grey, very silty SAND |
| | | | 15.450 | R = 53% | | | | | | | | | | | | |
| | 16m | | | | | | | | | | | | | | | |
| | | | 16.500 | P9 D9 | 2 | 4 | 4 | 5 | 7 | 5 | 21 | | | | | - ditto - |
| | | | 16.950 | R = 56% | | | | | | | | | | | | |
| | 17m | | | | | | | | | | | | | | | |
| | 18m | | 18.000 | P10 D10 | 3 | 5 | 5 | 5 | 7 | 8 | 25 | | | | | Medium dense, light grey, SAND |
| | | | 18.450 | R = 42% | | | | | | | | | | | | |
| | 19m | | | | | | | | | | | | | | | |
| | | | 19.500 | P11 D11 | 4 | 6 | 7 | 7 | 8 | 9 | 31 | | | | | Dense, pale to light grey, SAND |
| | | | 19.950 | R = 44% | | | | | | | | | | | | |
| | 20m | | | | | | | | | | | | | | | |
| | 21m | | 21.000 | P12 D12 | 5 | 5 | 5 | 6 | 8 | 9 | 28 | | | | | Medium dense, pale to light grey, very silty SAND |
| | | | 21.450 | R = 40% | | | | | | | | | | | | |
| | 22m | | | | | | | | | | | | | | | |
| | | | 22.500 | P13 D13 | 5 | 5 | 6 | 7 | 7 | 10 | 30 | | | | | Dense, pale grey, SAND with traces of gravel |
| | | | 22.950 | R = 36% | | | | | | | | | | | | |
| | 23m | | | | | | | | | | | | | | | |



MAJUMEC BINA SDN BHD | SOIL INVESTIGATION

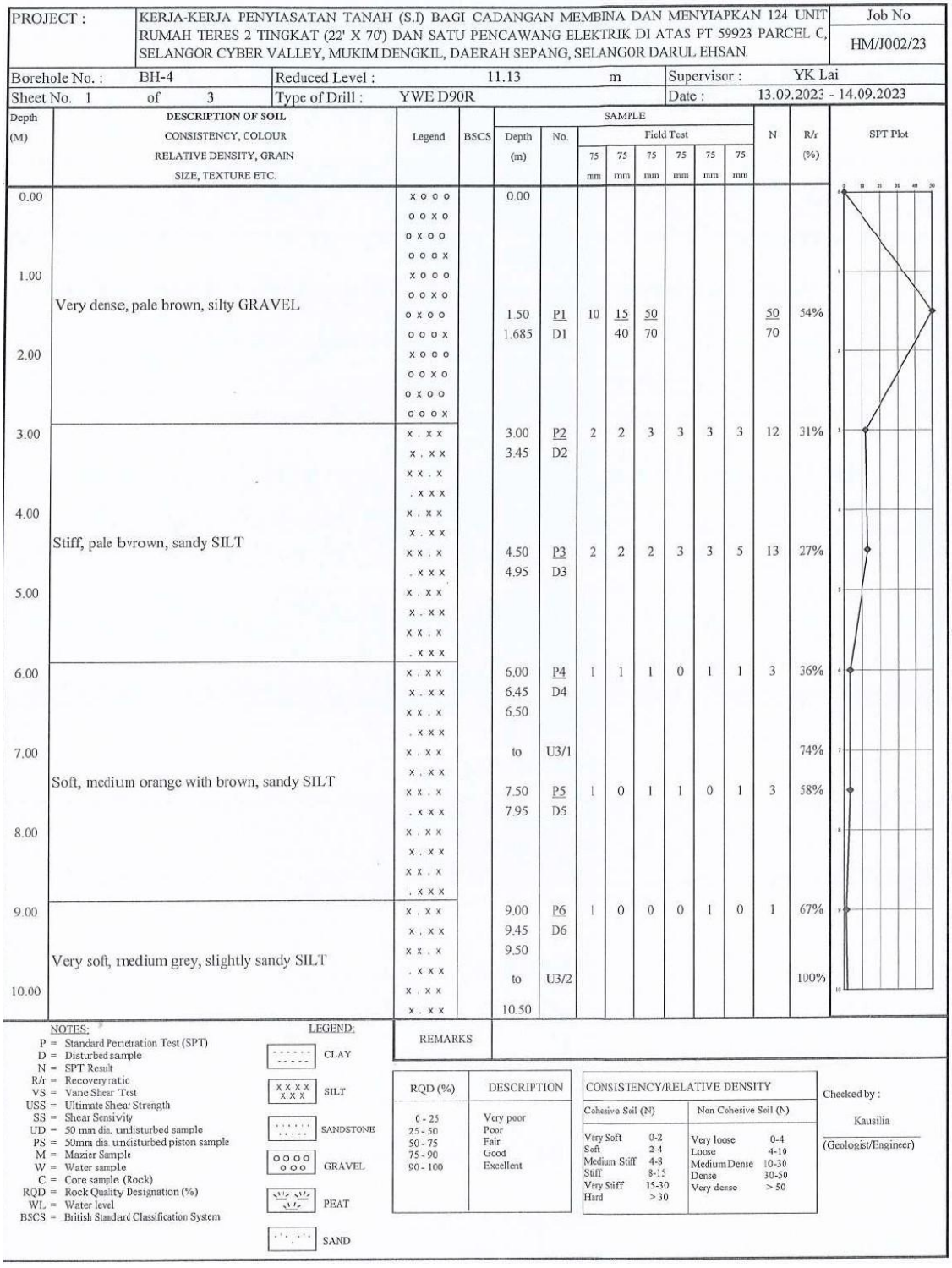
Project: Cadangan Pembangunan Bercampur
Location: PT 21044, seluas 152 Ekar, Dengkil
Borehole No.: BH - 24
Sheet No.: 3 of 3

| Date & Time | Boring Depth | Ground Water | Samples & Tests: Depth (m) | Sample | Field Test: 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N Blows | SPT Plot (0 10 20 30 40 50) | Depth (m) | Symbol | Legend | Descriptions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.3.23 | 23m | | | | | | | | | | | | | | | |
| | 24m | | 24.000<br>24.380 | P14 D14<br>R = 47% | 5 | 8 | 11 | 14 | 19 | 6 /0.5cm | 50 /23cm | | | | | Very dense, pale to light grey, silty SAND |
| | 25m | | 25.500<br>25.850 | P15 D15<br>R = 57% | 7 | 10 | 15 | 22 | 13 /5cm | | 50 /20cm | | | | | - ditto - |
| | 26m | | | | | | | | | | | | | | | |
| | 27m | | 27.000<br>27.290 | P16 D16<br>R = 59% | 11 | 13 | 22 | 28 /6.5cm | | | 50 /14cm | | | | | Very dense, light grey, silty SAND with traces of gravel |
| | 28m | | | | | | | | | | | | | | | |
| | 29m | | 28.500<br>28.720 | P17 D17<br>R = 73% | 16 | 9 /2.5cm | 31 | 19 | | | 50 /12cm | | | | | Very dense, pale to light grey, silty SAND with traces of gravel |
| 6.00pm | 30m | 0.48m | 30.000<br>30.170 | P18 D18<br>R = 59% | 21 | 4 /0.5cm | 41 | 9 /1.5cm | | | 50 /9cm | | | | | Very dense, pale to light grey, silty SAND with traces of gravel |
| | 31m | | | | | | | | | | | | | | | End of Borehole BH-24 at 30.17m |
| | 32m | | | | | | | | | | | | | | | Collected 1.5 litre water sample |
| | 33m | | | | | | | | | | | | | | | |
| | 34m | | | | | | | | | | | | | | | |
| | 35m | | | | | | | | | | | | | | | |
| | 36m | | | | | | | | | | | | | | | |

MB2671 Dengkil PKNS/Rawi/BH 24

# APPENDIX 17

Representative Borehole Log at Lot 120185, Selangor Cyber Valley, Selangor (BH4)



| PROJECT : | KERJA-KERJA PENYIASATAN TANAH (S.I) BAGI CADANGAN MEMBINA DAN MENYIAPKAN 124 UNIT RUMAH TERES 2 TINGKAT (22' X 70') DAN SATU PENCAWANG ELEKTRIK DI ATAS PT 59923 PARCEL C, SELANGOR CYBER VALLEY, MUKIM DENGKIL, DAERAH SEPANG, SELANGOR DARUL EHSAN. | Job No HM/J002/23 |
|---|---|---|
| Borehole No. : BH-4 | Reduced Level : 11.13 m | Supervisor : YK Lai |
| Sheet No. 1 of 3 | Type of Drill : YWE D90R | Date : 13.09.2023 - 14.09.2023 |

| Depth (M) | DESCRIPTION OF SOIL CONSISTENCY, COLOUR RELATIVE DENSITY, GRAIN SIZE, TEXTURE ETC. | Legend | BSCS | SAMPLE Depth (m) | No. | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N | R/r (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | | x o o o | | 0.00 | | | | | | | | | |
| | | o o x o | | | | | | | | | | | |
| | | o x o o | | | | | | | | | | | |
| | | o o o x | | | | | | | | | | | |
| 1.00 | | x o o o | | | | | | | | | | | |
| | | o o x o | | | | | | | | | | | |
| | Very dense, pale brown, silty GRAVEL | o x o o | | 1.50 | P1 | 10 | 15 | 50 | | | | 50 | 54% |
| | | o o o x | | 1.685 | D1 | | 40 | 70 | | | | 70 | |
| 2.00 | | x o o o | | | | | | | | | | | |
| | | o o x o | | | | | | | | | | | |
| | | o x o o | | | | | | | | | | | |
| | | o o o x | | | | | | | | | | | |
| 3.00 | | x . x x | | 3.00 | P2 | 2 | 2 | 3 | 3 | 3 | 3 | 12 | 31% |
| | | x . x x | | 3.45 | D2 | | | | | | | | |
| | | x x . x | | | | | | | | | | | |
| | | . x x x | | | | | | | | | | | |
| 4.00 | | x . x x | | | | | | | | | | | |
| | | x . x x | | | | | | | | | | | |
| | Stiff, pale bvrown, sandy SILT | x x . x | | 4.50 | P3 | 2 | 2 | 2 | 3 | 3 | 5 | 13 | 27% |
| | | . x x x | | 4.95 | D3 | | | | | | | | |
| 5.00 | | x . x x | | | | | | | | | | | |
| | | x . x x | | | | | | | | | | | |
| | | x x . x | | | | | | | | | | | |
| | | . x x x | | | | | | | | | | | |
| 6.00 | | x . x x | | 6.00 | P4 | 1 | 1 | 1 | 0 | 1 | 1 | 3 | 36% |
| | | x . x x | | 6.45 | D4 | | | | | | | | |
| | | x x . x | | 6.50 | | | | | | | | | |
| | | . x x x | | | | | | | | | | | |
| 7.00 | | x . x x | | to | U3/1 | | | | | | | | 74% |
| | | x . x x | | | | | | | | | | | |
| | Soft, medium orange with brown, sandy SILT | x x . x | | 7.50 | P5 | 1 | 0 | 1 | 1 | 0 | 1 | 3 | 58% |
| | | . x x x | | 7.95 | D5 | | | | | | | | |
| 8.00 | | x . x x | | | | | | | | | | | |
| | | x . x x | | | | | | | | | | | |
| | | x x . x | | | | | | | | | | | |
| | | . x x x | | | | | | | | | | | |
| 9.00 | | x . x x | | 9.00 | P6 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 67% |
| | | x . x x | | 9.45 | D6 | | | | | | | | |
| | | x x . x | | 9.50 | | | | | | | | | |
| | Very soft, medium grey, slightly sandy SILT | . x x x | | to | U3/2 | | | | | | | | 100% |
| 10.00 | | x . x x | | | | | | | | | | | |
| | | x . x x | | 10.50 | | | | | | | | | |

SPT Plot

NOTES:
P = Standard Penetration Test (SPT)
D = Disturbed sample
N = SPT Result
R/r = Recovery ratio
VS = Vane Shear Test
USS = Ultimate Shear Strength
SS = Shear Sensivity
UD = 50 mm dia. undisturbed sample
PS = 50mm dia. undisturbed piston sample
M = Mazier Sample
W = Water sample
C = Core sample (Rock)
RQD = Rock Quality Designation (%)
WL = Water level
BSCS = British Standard Classification System

LEGEND: CLAY, SILT, SANDSTONE, GRAVEL, PEAT, SAND

REMARKS

| RQD (%) | DESCRIPTION |
|---|---|
| 0 - 25 | Very poor |
| 25 - 50 | Poor |
| 50 - 75 | Fair |
| 75 - 90 | Good |
| 90 - 100 | Excellent |

| CONSISTENCY/RELATIVE DENSITY | | | |
|---|---|---|---|
| Cohesive Soil (N) | | Non Cohesive Soil (N) | |
| Very Soft | 0-2 | Very loose | 0-4 |
| Soft | 2-4 | Loose | 4-10 |
| Medium Stiff | 4-8 | Medium Dense | 10-30 |
| Stiff | 8-15 | Dense | 30-50 |
| Very Stiff | 15-30 | Very dense | > 50 |
| Hard | > 30 | | |

Checked by :
Kausilia
(Geologist/Engineer)

| PROJECT : | KERJA-KERJA PENYIASATAN TANAH (S.I) BAGI CADANGAN MEMBINA DAN MENYIAPKAN 124 UNIT RUMAH TERES 2 TINGKAT (22' X 70') DAN SATU PENCAWANG ELEKTRIK DI ATAS PT 59923 PARCEL C, SELANGOR CYBER VALLEY, MUKIM DENGKIL, DAERAH SEPANG, SELANGOR DARUL EHSAN. | Job No HM/J002/23 |
|---|---|---|

| Borehole No. : BH-4 | Reduced Level : 11.13 m | Supervisor : YK Lai |
|---|---|---|
| Sheet No. 2 of 3 | Type of Drill : YWE D90R | Date : 13.09.2023 - 14.09.2023 |

| Depth (M) | DESCRIPTION OF SOIL CONSISTENCY, COLOUR RELATIVE DENSITY, GRAIN SIZE, TEXTURE ETC. | Legend | BSCS | SAMPLE Depth (m) | No. | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N | R/r (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11.00 | Very soft to soft, medium grey, slightly sandy SILT | x . x x<br>x . x x<br>x x . x<br>. x x x<br>x . x x<br>x . x x | | 10.50<br>10.95 | P7<br>D7 | 0 | 0 | 1 | 0 | 0 | 1 | 2 | 58% |
| 12.00<br>13.00 | Soft, medium grey, slightly sandy SILT | x x . x<br>. x x x<br>x . x x<br>x . x x<br>x x . x<br>. x x x | | 12.00<br>12.45 | P8<br>D8 | 1 | 0 | 1 | 1 | 0 | 1 | 3 | 69% |
| 14.00 | Loose to medium dense, medium grey, clayey SAND | . . " . .<br>. " . . .<br>. . . " . .<br>. " . . .<br>. . " . .<br>. " . . . | | 13.50<br>13.95 | P9<br>D9 | 1 | 2 | 2 | 2 | 3 | 3 | 10 | 31% |
| 15.00<br>16.00 | Loose, light grey, clayey SAND | . . " . .<br>. " . . .<br>. . . " . .<br>. " . . .<br>. . " . .<br>. " . . . | | 15.00<br>15.45 | P10<br>D10 | 1 | 2 | 2 | 2 | 3 | 2 | 9 | 22% |
| 17.00 | Medium dense, light grey, clayey SAND | . . " . .<br>. " . . .<br>. . . " . .<br>. " . . .<br>. . " . .<br>. " . . . | | 16.50<br>16.95 | P11<br>D11 | 2 | 2 | 3 | 2 | 3 | 3 | 11 | 27% |
| 18.00<br>19.00 | Medium dense, light grey, silty SAND | . . . . x<br>. . x . .<br>x . . . .<br>. . . x . .<br>. . . . x<br>. . x . . | | 18.00<br>18.45 | P12<br>D12 | 2 | 3 | 3 | 4 | 5 | 5 | 17 | 49% |
| 20.00 | Medium dense, light grey, silty SAND with some organic matter | x . . . .<br>. . . x . .<br>. . . . x<br>. . x . . | | 19.50<br>19.95 | P13<br>D13 | 2 | 3 | 4 | 4 | 5 | 4 | 17 | 24% |
| | Very poor, medium grey, highly fractured, highly weathered, SANDSTONE | . . . . .<br>. . . . . | | 20.80 | | | | | | | | | |

SPT Plot

NOTES:
- P = Standard Penetration Test (SPT)
- D = Disturbed sample
- N = SPT Result
- R/r = Recovery ratio
- VS = Vane Shear Test
- USS = Ultimate Shear Strength
- SS = Shear Sensivity
- UD = 50 mm dia. undisturbed sample
- PS = 50mm dia. undisturbed piston sample
- M = Mazier Sample
- W = Water sample
- C = Core sample (Rock)
- RQD = Rock Quality Designation (%)
- WL = Water level
- BSCS = British Standard Classification System

LEGEND: CLAY, SILT, SANDSTONE, GRAVEL, PEAT, SAND

REMARKS

| RQD (%) | DESCRIPTION |
|---|---|
| 0 - 25 | Very poor |
| 25 - 50 | Poor |
| 50 - 75 | Fair |
| 75 - 90 | Good |
| 90 - 100 | Excellent |

| CONSISTENCY/RELATIVE DENSITY | | | |
|---|---|---|---|
| Cohesive Soil (N) | | Non Cohesive Soil (N) | |
| Very Soft | 0-2 | Very loose | 0-4 |
| Soft | 2-4 | Loose | 4-10 |
| Medium Stiff | 4-8 | Medium Dense | 10-30 |
| Stiff | 8-15 | Dense | 30-50 |
| Very Stiff | 15-30 | Very dense | > 50 |
| Hard | > 30 | | |

Checked by :
Kausilia
(Geologist/Engineer)

| PROJECT : | KERJA-KERJA PENYIASATAN TANAH (S.I) BAGI CADANGAN MEMBINA DAN MENYIAPKAN 124 UNIT RUMAH TERES 2 TINGKAT (22' X 70') DAN SATU PENCAWANG ELEKTRIK DI ATAS PT 59923 PARCEL C, SELANGOR CYBER VALLEY, MUKIM DENGKIL, DAERAH SEPANG, SELANGOR DARUL EHSAN. | Job No HM/J002/23 |
|---|---|---|

| Borehole No. : BH-4 | Reduced Level : 11.13 m | Supervisor : YK Lai |
|---|---|---|
| Sheet No. 3 of 3 | Type of Drill : YWE D90R | Date : 13.09.2023 - 14.09.2023 |

| Depth (M) | DESCRIPTION OF SOIL<br>CONSISTENCY, COLOUR<br>RELATIVE DENSITY, GRAIN SIZE, TEXTURE ETC. | Legend | BSCS | SAMPLE Depth (m) | No. | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N | R/r (%) | SPT Plot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21.00 | | | | | | | | | | | | | | |
| | | | | to 22.30 | C1 | | CL : 1.50m<br>CRR : 18% RQD : 0% | | | | | | | |
| 22.00 | | | | | | | | | | | | | | |
| 23.00 | Very poor, medium grey, highly fractured, highly weathered, SANDSTONE | | | to 23.80 | C2 | | CL : 1.50m<br>CRR : 38% RQD : 0% | | | | | | | |
| 24.00 | | | | | | | | | | | | | | |
| | | | | to 25.30 | C3 | | CL : 1.50m<br>CRR : 29% RQD : 0% | | | | | | | |
| 25.00 | | | | | | | | | | | | | | |
| | End of Borehole at depth : 25.30m | | | | | | | | | | | | | |

| Date | Time | W/L | Depth NW | Depth Boreholes |
|---|---|---|---|---|
| 13.09.2023 | 4.10pm | 1.75m | 10.50m | 10.95m |
| 14.09.2023 | 8.10am | 2.69m | 10.50m | 10.95m |
| 14.09.2023 | 3.50pm | 3.44m | 23.80m | 25.30m |

26.00
27.00
28.00
29.00
30.00
31.00

NOTES:
- P = Standard Penetration Test (SPT)
- D = Disturbed sample
- N = SPT Result
- R/r = Recovery ratio
- VS = Vane Shear Test
- USS = Ultimate Shear Strength
- SS = Shear Sensivity
- UD = 50 mm dia. undisturbed sample
- PS = 50mm dia. undisturbed piston sample
- M = Mazier Sample
- W = Water sample
- C = Core sample (Rock)
- RQD = Rock Quality Designation (%)
- WL = Water level
- BSCS = British Standard Classification System

LEGEND:
- CLAY
- SILT
- SANDSTONE
- GRAVEL
- PEAT
- SAND

REMARKS

| RQD (%) | DESCRIPTION |
|---|---|
| 0 - 25 | Very poor |
| 25 - 50 | Poor |
| 50 - 75 | Fair |
| 75 - 90 | Good |
| 90 - 100 | Excellent |

| CONSISTENCY/RELATIVE DENSITY | | | |
|---|---|---|---|
| Cohesive Soil (N) | | Non Cohesive Soil (N) | |
| Very Soft | 0-2 | Very loose | 0-4 |
| Soft | 2-4 | Loose | 4-10 |
| Medium Stiff | 4-8 | Medium Dense | 10-30 |
| Stiff | 8-15 | Dense | 30-50 |
| Very Stiff | 15-30 | Very dense | > 50 |
| Hard | > 30 | | |

Checked by :
Kausilia
(Geologist/Engineer)

# APPENDIX 18

Representative Borehole Log at Lot 120188, Selangor Cyber Valley, Selangor (BH2).

| PROJECT : | Cadangan Kerja-Kerja Penyiasatan Tanah (S.I) Bagi Cadangan Membina Dan Menyiapkan 156 Unit Rumah Superlink 2 Tingkat (20' X 75'), di Seksyen 6, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor Darul Ehsan | Job No HM/J001/23 |
|---|---|---|
| Borehole No. : BH-2 | Reduced Level : e.g.l m | Supervisor : Lau Kim Fui |
| Sheet No. 1 of 3 | Type of Drill : YWE D90R | Date : 18/05/2023-19/05/2023 |

| Depth (M) | DESCRIPTION OF SOIL: CONSISTENCY, COLOUR, RELATIVE DENSITY, GRAIN SIZE, TEXTURE ETC. | Legend | BSCS | SAMPLE Depth (m) | SAMPLE No. | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N | R/r (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | Top soil: Medium brown, sandy SILT | x . x x<br>x . x x<br>x x . x | | 0.00<br>to<br>0.50 | | | | | | | | | |
| 1.00 | Medium dense, medium brown, very silty SAND | . . x . .<br>x . . . .<br>. . . x .<br>. . . . x | | 1.50 | P1 | 1 | 2 | 2 | 3 | 3 | 3 | 11 | 64% |
| 2.00 | | . . . . x<br>. . x . .<br>x . . . .<br>. . . x .<br>. . . . x | | 1.95 | D1 | | | | | | | | |
| 3.00 | Very loose, medium brown, very silty SAND | . . . . x<br>. . x . . | | 3.00<br>3.45 | P2<br>D2 | 0 | 1 | 0 | 1 | 1 | 1 | 3 | 58% |
| 4.00 | | x . . . .<br>. . . x .<br>. . . . x<br>. . x . . | | 3.50<br>to<br>4.40 | UD-1 | | | | | | | | 56% |
| 5.00 | Loose to medium dense, medium brown, very silty SAND with some organic matter (woods) | x . . . .<br>. . . x .<br>. . . . x<br>. . x . .<br>x . . . .<br>. . . x . . | | 4.50<br>4.95 | P3<br>D3 | 5 | 7 | 4 | 2 | 2 | 2 | 10 | 22% |
| 6.00 | Soft, brownish grey, slightly sandy SILT with some organic matter (woods) | x . x x<br>x . x x | | 6.00<br>6.45 | P4<br>D4 | 1 | 2 | 1 | 0 | 1 | 1 | 3 | 38% |
| 7.00 | No recovery | | | 6.50<br>to | UD-2 | | | | | | | | 0% |
| | Soft to medium stiff, brownish grey mottled with light grey, sandy SILT with some organic matter (woods) | x . x x<br>x . x x | | 7.50<br>7.95 | P5<br>D5 | 1 | 0 | 1 | 1 | 1 | 1 | 4 | 73% |
| 8.00 | No recovery | | | 8.00<br>to | | | | | | | | | 0% |
| 9.00 | Medium dense, light grey, silty SAND | . . . . x<br>. . x . .<br>x . . . .<br>. . . x . .<br>. . . . x<br>. . x . . | | 9.00<br>9.45 | P6<br>D6 | 2 | 3 | 3 | 4 | 4 | 4 | 15 | 87% |
| 10.00 | | | | | | | | | | | | | |

SPT Plot

NOTES:
P = Standard Penetration Test (SPT)
D = Disturbed sample
N = SPT Result
R/r = Recovery ratio
VS = Vane Shear Test
USS = Ultimate Shear Strength
SS = Shear Sensivity
UD = 50 mm dia. undisturbed sample
PS = 50mm dia. undisturbed piston sample
M = Mazier Sample
W = Water sample
C = Core sample (Rock)
RQD = Rock Quality Designation (%)
WL = Water level
BSCS = British Standard Classification System

LEGEND: CLAY, SILT, SANDSTONE, GRAVEL, PEAT, SAND

REMARKS

| RQD (%) | DESCRIPTION |
|---|---|
| 0 - 25 | Very poor |
| 25 - 50 | Poor |
| 50 - 75 | Fair |
| 75 - 90 | Good |
| 90 - 100 | Excellent |

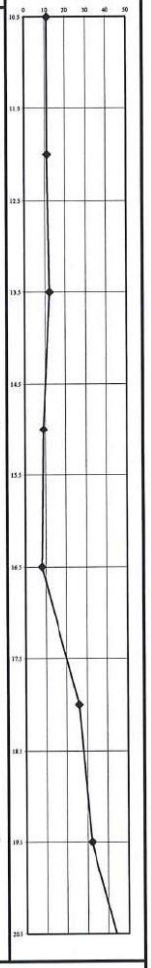
| CONSISTENCY/RELATIVE DENSITY | | | |
|---|---|---|---|
| Cohesive Soil (N) | | Non Cohesive Soil (N) | |
| Very Soft | 0-2 | Very loose | 0-4 |
| Soft | 2-4 | Loose | 4-10 |
| Medium Stiff | 4-8 | Medium Dense | 10-30 |
| Stiff | 8-15 | Dense | 30-50 |
| Very Stiff | 15-30 | Very dense | > 50 |
| Hard | > 30 | | |

Checked by :
Kausilia
(Geologist/Engineer)

| PROJECT : | Cadangan Kerja-Kerja Penyiasatan Tanah (S.I) Bagi Cadangan Membina Dan Menyiapkan 156 Unit Rumah Superlink 2 Tingkat (20' X 75'), di Seksyen 6, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor Darul Ehsan | Job No HM/J001/23 |
|---|---|---|
| Borehole No. : BH-2 | Reduced Level : e.g.l m | Supervisor : Lau Kim Fui |
| Sheet No. 2 of 3 | Type of Drill : YWE D90R | Date : 18/05/2023-19/05/2023 |

| Depth (M) | DESCRIPTION OF SOIL: CONSISTENCY, COLOUR, RELATIVE DENSITY, GRAIN SIZE, TEXTURE ETC. | Legend | BSCS | SAMPLE Depth (m) | SAMPLE No. | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N | R/r (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11.00 | Medium dense, light grey, silty SAND | | | 10.50 | P7 | 2 | 1 | 2 | 2 | 3 | 4 | 11 | 42% |
| | | | | 10.95 | D7 | | | | | | | | |
| 12.00 | Medium dense, brownish grey, silty SAND | | | 12.00 | P8 | 2 | 1 | 2 | 3 | 3 | 3 | 11 | 67% |
| | | | | 12.45 | D8 | | | | | | | | |
| 13.00 | | | | | | | | | | | | | |
| 14.00 | Medium dense, pale grey, silty SAND | | | 13.50 | P9 | 1 | 2 | 2 | 3 | 4 | 3 | 12 | 69% |
| | | | | 13.95 | D9 | | | | | | | | |
| 15.00 | Loose, pale grey, silty SAND | | | 15.00 | P10 | 2 | 1 | 1 | 2 | 3 | 3 | 9 | 51% |
| | | | | 15.45 | D10 | | | | | | | | |
| 16.00 | | | | | | | | | | | | | |
| | | | | 16.50 | P11 | 1 | 1 | 2 | 2 | 2 | 2 | 8 | 53% |
| | | | | 16.95 | D11 | | | | | | | | |
| 17.00 | | | | | | | | | | | | | |
| 18.00 | Very stiff, light grey, sandy SILT | | | 18.00 | P12 | 3 | 3 | 4 | 5 | 8 | 9 | 26 | 47% |
| | | | | 18.45 | D12 | | | | | | | | |
| 19.00 | | | | | | | | | | | | | |
| | | | | 19.50 | P13 | 3 | 4 | 5 | 7 | 9 | 11 | 32 | 51% |
| | | | | 19.95 | D13 | | | | | | | | |
| 20.00 | Hard, medium grey, sandy SILT | | | | | | | | | | | | |

SPT Plot



NOTES:
- P = Standard Penetration Test (SPT)
- D = Disturbed sample
- N = SPT Result
- R/r = Recovery ratio
- VS = Vane Shear Test
- USS = Ultimate Shear Strength
- SS = Shear Sensivity
- UD = 50 mm dia. undisturbed sample
- PS = 50mm dia. undisturbed piston sample
- M = Mazier Sample
- W = Water sample
- C = Core sample (Rock)
- RQD = Rock Quality Designation (%)
- WL = Water level
- BSCS = British Standard Classification System

LEGEND: CLAY, SILT, SANDSTONE, GRAVEL, PEAT, SAND

REMARKS

| RQD (%) | DESCRIPTION |
|---|---|
| 0 - 25 | Very poor |
| 25 - 50 | Poor |
| 50 - 75 | Fair |
| 75 - 90 | Good |
| 90 - 100 | Excellent |

| CONSISTENCY/RELATIVE DENSITY | | | |
|---|---|---|---|
| Cohesive Soil (N) | | Non Cohesive Soil (N) | |
| Very Soft | 0-2 | Very loose | 0-4 |
| Soft | 2-4 | Loose | 4-10 |
| Medium Stiff | 4-8 | Medium Dease | 10-30 |
| Stiff | 8-15 | Dense | 30-50 |
| Very Stiff | 15-30 | Very dense | >50 |
| Hard | >30 | | |

Checked by :
Kausilia
(Geologist/Engineer)

| PROJECT : | Cadangan Kerja-Kerja Penyiasatan Tanah (S.I) Bagi Cadangan Membina Dan Menyiapkan 156 Unit Rumah Superlink 2 Tingkat (20' X 75'), di Seksyen 6, Selangor Cyber Valley, Mukim Dengkil, Daerah Sepang, Selangor Darul Ehsan | Job No HM/J001/23 |
|---|---|---|

| Borehole No. : BH-2 | Reduced Level : e.g.1 m | Supervisor : Lau Kim Fui |
|---|---|---|
| Sheet No. 3 of 3 | Type of Drill : YWE D90R | Date : 18/05/2023-19/05/2023 |

| Depth (M) | DESCRIPTION OF SOIL<br>CONSISTENCY, COLOUR<br>RELATIVE DENSITY, GRAIN SIZE, TEXTURE ETC. | Legend | BSCS | SAMPLE Depth (m) | No. | Field Test 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | 75 mm | N | R/r (%) | SPT Plot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21.00 | | x . x x | | 21.00 | P14 | 4 | 7 | 13 | 17 | 20 | | 50 | 66% | |
| | | x . x x | | 21.35 | D14 | | | | | 50 | | 200 | | |
| | | x x . x | | | | | | | | | | | | |
| | | . x x x | | | | | | | | | | | | |
| 22.00 | | x . x x | | | | | | | | | | | | |
| | | x . x x | | | | | | | | | | | | |
| | | x x . x | | 22.50 | P15 | 6 | 13 | 21 | 29 | | | 50 | 76% | |
| | | . x x x | | 22.79 | D15 | | | | 65 | | | 140 | | |
| 23.00 | | x . x x | | | | | | | | | | | | |
| | | x . x x | | | | | | | | | | | | |
| | | x x . x | | | | | | | | | | | | |
| | | . x x x | | | | | | | | | | | | |
| 24.00 | Hard, medium grey, sandy SILT | x . x x | | 24.00 | P16 | 7 | 15 | 28 | 22 | | | 50 | 74% | |
| | | x . x x | | 24.27 | D16 | | | | 45 | | | 120 | | |
| | | x x . x | | | | | | | | | | | | |
| | | . x x x | | | | | | | | | | | | |
| 25.00 | | x . x x | | | | | | | | | | | | |
| | | x . x x | | | | | | | | | | | | |
| | | x x . x | | 25.50 | P17 | 9 | 15 | 31 | 19 | | | 50 | 84% | |
| | | . x x x | | 25.75 | D17 | | | | 25 | | | 100 | | |
| 26.00 | | x . x x | | | | | | | | | | | | |
| | | x . x x | | | | | | | | | | | | |
| | | x x . x | | | | | | | | | | | | |
| | | . x x x | | | | | | | | | | | | |
| 27.00 | | x . x x | | 27.00 | P18 | 10 | 15 | 34 | 16 | | | 50 | 82% | |
| | | x . x x | | 27.22 | D18 | | 55 | | 15 | | | 90 | | |
| | End of Borehole at depth : 27.22m | | | | | | | | | | | | | |
| 28.00 | | | | | | | | | | | | | | |
| 29.00 | | | | | | | | | | | | | | |
| 30.00 | | | | | | | | | | | | | | |
| 31.00 | | | | | | | | | | | | | | |

| Date | Time | W/L | Depth NW | Depth Boreholes |
|---|---|---|---|---|
| 18.05.2023 | 4.00pm | 2.40m | 18.00m | 18.45m |
| 19.05.2023 | 8.20am | 2.40m | 18.00m | 18.45m |
| 19.05.2023 | 11.30am | 1.20m | 27.00m | 27.22m |

NOTES:
- P = Standard Penetration Test (SPT)
- D = Disturbed sample
- N = SPT Result
- R/r = Recovery ratio
- VS = Vane Shear Test
- USS = Ultimate Shear Strength
- SS = Shear Sensivity
- UD = 50 mm dia. undisturbed sample
- PS = 50mm dia. undisturbed piston sample
- M = Mazier Sample
- W = Water sample
- C = Core sample (Rock)
- RQD = Rock Quality Designation (%)
- WL = Water level
- BSCS = British Standard Classification System

LEGEND: CLAY, SILT, SANDSTONE, GRAVEL, PEAT, SAND

REMARKS

| RQD (%) | DESCRIPTION |
|---|---|
| 0 - 25 | Very poor |
| 25 - 50 | Poor |
| 50 - 75 | Fair |
| 75 - 90 | Good |
| 90 - 100 | Excellent |

| CONSISTENCY/RELATIVE DENSITY | | | |
|---|---|---|---|
| Cohesive Soil (N) | | Non Cohesive Soil (N) | |
| Very Soft | 0-2 | Very loose | 0-4 |
| Soft | 2-4 | Loose | 4-10 |
| Medium Stiff | 4-8 | Medium Dense | 10-30 |
| Stiff | 8-15 | Dense | 30-50 |
| Very Stiff | 15-30 | Very dense | > 50 |
| Hard | > 30 | | |

Checked by :
Kausilia
(Geologist/Engineer)

# APPENDIX 19

Summary of Laboratory Test Result at PT 21044, Cyberjaya, Selangor
(BH1, BH17 & BH24)

| | Sample No. | Depth | | Classification (From Report) | SPT-N Value | Moisture Content, % | Bulk Density, Mg/m³ | Dry Density, Mg/m³ | Specific Gravity | Atterberg Limit | | | | Consolidation Test | | Chemical Test | | | | | Particle Size Distribution, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | From | To | | | | | | | Liquid Limit, % | Plasticity | Plastic Index | Classification | Pre Compression Load, kN/m² | Compression Index, Cc | pH Value | Sulphate Content,% | Organic Content, % | Chlorite Content, % | Mass Loss Ignition, % | Gravel, > 2 mm | Sand, 0.06 – 2 mm | Silt, < 0.06 mm | CLAY |
| BH 1 | D2 | 3.00 | 3.45 | Very soft, medium to dark brown, PEAT | 2 | 398 | @ | @ | @ | @ | @ | @ | | | | 4.8 | <0.01 | 27.39 | | | @ | @ | @ | @ |
| | D4 | 6.00 | 6.50 | Soft pale to light grey, SILT of High Plasticity | 3 | 46 | 1.685 | 1.154 | 2.55 | 57 | 34 | 23 | | | | | | | | | 0 | 1 | 72 | 27 |
| | UD1 | 7.50 | 8.20 | Light grey, sandy CLAY | | | | | | | | | | 57 | 0.259 | | | | | | | | | |
| | D5 | 9.00 | 9.45 | Medium stiff, light grey, SILT or High Plasticity | 4 | 40 | 1.688 | 1.206 | 2.55 | 55 | 33 | 22 | | | | 5.2 | <0.01 | 0.7 | | | 0 | 1 | 71 | 28 |
| | UD2 | 10.50 | 11.20 | Pale to light grey, sandy CLAY | | | | | | | | | | 59 | 0.199 | | | | | | | | | |
| | D8 | 15.00 | 15.45 | Very stiff, light to medium grey, sandy SILT of Intermediate Plasticity | 16 | 26 | 1.787 | 1.418 | 2.61 | 49 | 30 | 19 | | | | 6.2 | | | | | 1 | 56 | 29 | 15 |
| | D12 | 21.00 | 21.45 | Medium dense, medium grey, very silty SAND of High Plasticity | 24 | 22 | 1.882 | 1.543 | 2.63 | 45 | 30 | 15 | | | | 6.8 | | | | | 0 | 64 | 26 | 10 |
| | D14 | 24.00 | 24.39 | Very dense, pale togrey, very silty SAND of Intermediate Plasticity | 50 | 25 | 1.734 | 1.387 | 2.63 | 42 | 29 | 13 | | | | 6.9 | | | | | 0 | 64 | 25 | 11 |
| BH 17 | D1 | 1.50 | 1.95 | Very soft, dark brown, grey, PEAT | 1 | 280 | @ | @ | @ | @ | @ | @ | | | | | | | | | @ | @ | @ | @ |
| | D4 | 6.00 | 6.45 | Soft, dark brown, grey, PEAT | 4 | 125 | 1.357 | 0.603 | 2.5 | 118 | 43 | 75 | | | | | | | | | 0 | 1 | 31 | 68 |
| | UD1 | 7.50 | 8.20 | Mediu, grey, grey, sandy CLAY | | | | | | | | | | 28 | 1.172 | | | | | | | | | |
| | D5 | 9.00 | 9.45 | Medium stiff, light grey, grey, CLAY of Extremely High Plasticity | 4 | 128 | 1.345 | 0.59 | 2.5 | 125 | 42 | 83 | | | | 4.2 | 0.06 | 3.71 | | | 0 | 1 | 37 | 62 |
| | UD2 | 10.50 | 11.20 | Light grey, grey, CLAY | | | | | | | | | | 27 | 1.072 | | | | | | | | | |
| | D6 | 12.00 | 12.45 | Medium stiff, medium grey, CLAY of Extremely High Plasticity with organic matter | 5 | 122 | 1.365 | 0.615 | 2.5 | 117 | 43 | 74 | | | | | | | | | 0 | 1 | 25 | 74 |
| | D8 | 15.00 | 15.45 | Medium dense, medium grey, silty SAND with traces of clay | 14 | 22 | 1.936 | 1.587 | 2.64 | 48 | 29 | 19 | | | | | | | | | 0 | 71 | 17 | 12 |
| | D10 | 18.00 | 18.45 | ditto | 26 | 23 | 1.808 | 1.47 | 2.66 | 42 | 28 | 14 | | | | | | | | | 0 | 80 | 13 | 7 |
| | D14 | 24.00 | 24.38 | Dense, light grey, silty SAND | 50 | 26 | 1.819 | 1.444 | 2.67 | NP | NP | NP | | | | | | | | | 0 | 84 | 16 | |
| BH 24 | D1 | 1.50 | 1.95 | Stiff, light to medium brown, sandy SILT of Intermediate Plasticity | 8 | 23 | 1.935 | 1.573 | 2.57 | 44 | 29 | 15 | | | | | | | | | 2 | 35 | 41 | 22 |
| | D3 | 4.50 | 4.95 | Soft, pale to light grey, slightly sandy CLAY of Extremely High Plasticity | 3 | 88 | 1.425 | 0.758 | 2.51 | 121 | 44 | 77 | | | | 4.2 | 0.06 | 5.24 | | | 0 | 5 | 38 | 57 |
| | UD1 | 6.00 | 6.70 | Light grey, sandy CLAY | | | | | | | | | | 59 | 0.905 | | | | | | | | | |
| | D4 | 7.50 | 7.95 | Medium stiff, pale to light grey, slightly sandy CLAY of Extremely High Plasticity | 4 | 78 | 1.470 | 0.826 | 2..52 | 118 | 44 | 74 | | | | 4.0 | 0.07 | 3.96 | | | 1 | 10 | 36 | 53 |
| | UD2 | 9.00 | 9.70 | Pale to light grey, sandy CLAY | | | | | | | | | | 48 | 0.818 | | | | | | | | | |
| | D6 | 12.00 | 12.45 | Medium stiff, light to medium grey, slightly sandy CLAY of Extremely High Plasticity | 6 | 80 | 1.456 | 0.809 | 2.53 | 105 | 38 | 67 | | | | | | | | | 0 | 13 | 26 | 61 |
| | D9 | 16.50 | 16.95 | ditto | 21 | 21 | 1.941 | 1.604 | 2.64 | 45 | 30 | 15 | | | | | | | | | 0 | 71 | 21 | 8 |
| | D12 | 21.00 | 21.45 | Medium dense, pale to light grey, very silty SAND | 28 | 25 | 1.898 | 1.518 | 2.65 | 47 | 30 | 17 | | | | | | | | | 0 | 73 | 18 | 9 |
| | D14 | 24.00 | 24.38 | Very dense, pale to light grey, silty SAND | 50 | 25 | 1.829 | 1.463 | 2.67 | NP | NP | NP | | | | | | | | | 0 | 86 | 14 | |

# APPENDIX 20

Summary of Laboratory Test Result at Lot 120185 (BH4) & Lot 120188 (BH2)

**Lot 120185, Selangor Cyber Valley**

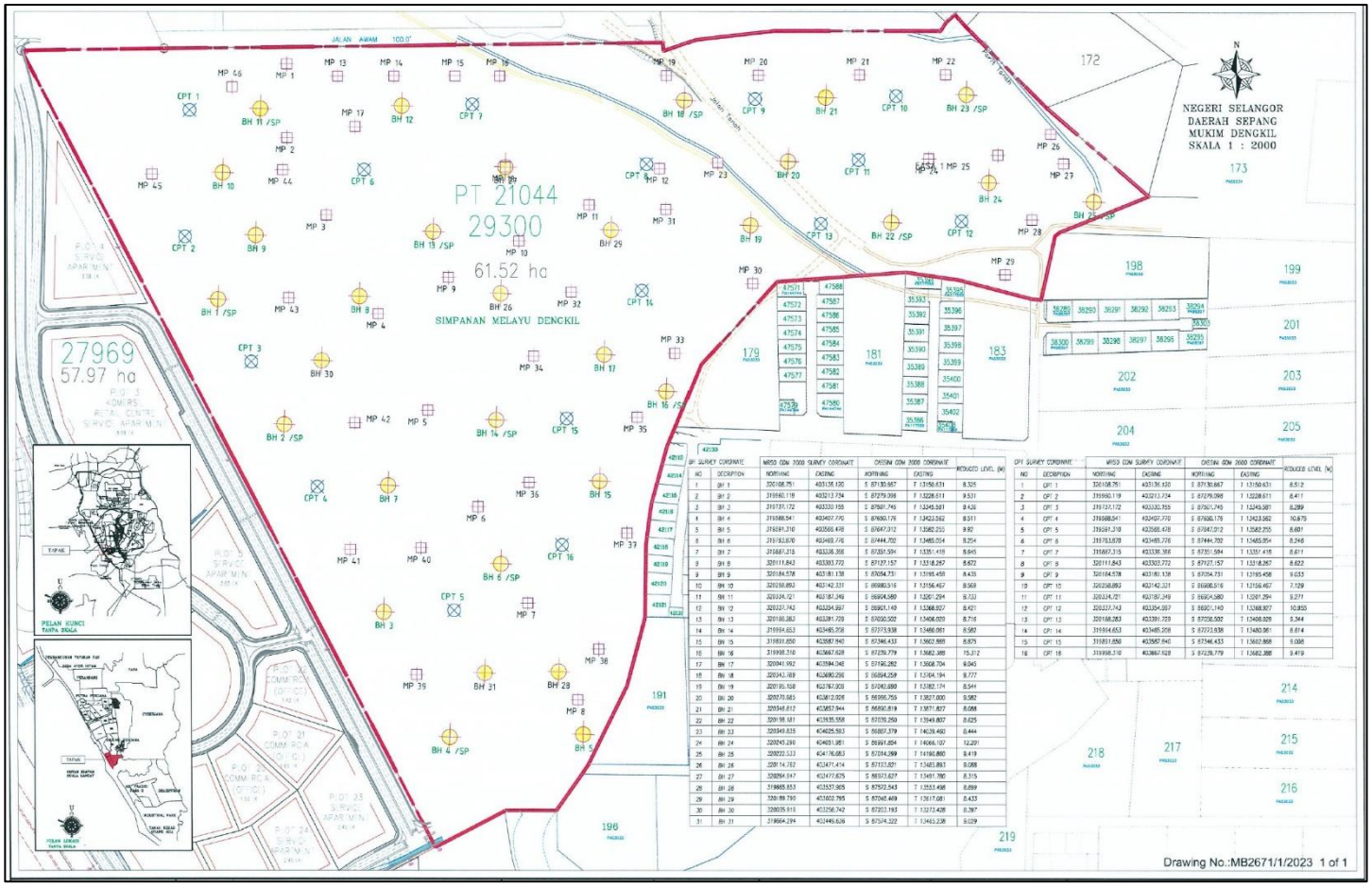
| | Sample No. | Depth From | Depth To | Classification (From Report) | SPT-N Value | Moisture Content, % | Bulk Density, Mg/m³ | Dry Density, Mg/m³ | Specific Gravity | Atterberg Limit: Liquid Limit, % | Atterberg Limit: Plasticity | Atterberg Limit: Plastic Index | Consolidation Test: Pre Compression Load, kN/m² | Consolidation Test: Compression Index, Cc | Chemical Test: pH Value | Particle Size Distribution, %: Gravel, > 2 mm | Sand, 0.06 – 2 mm | Silt, < 0.06 mm | CLAY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH 4 | D1 | 1.50 | 4.95 | silty GRAVEL | | | | | | | | | | | | | | | |
| | D4 | 6.00 | 6.45 | sandy SILT | 12 | 30 | 1.91 | 1.47 | | 47 | 20 | 27 | | | | 7 | 44 | 28 | 21 |
| | D5 | 7.50 | 7.95 | sandy SILT | 3 | 26 | 1.93 | 1.53 | | 48 | 18 | 30 | | | | 5 | 41 | 31 | 23 |
| | D6 | 9.00 | 9.45 | sandy SILT | 3 | 62 | 1.55 | 0.96 | | 78 | 31 | 47 | | | | 2 | 9 | 66 | 23 |
| | UD3 | 9.50 | 10.50 | slightly sandy SILT | | | | | | | | | 91 | 0.92 | | | | | |
| | D7 | 10.50 | 10.95 | slightly sandy SILT | 1 | 65 | 1.55 | 0.94 | | 82 | 30 | 52 | | | 5.3 | 0 | 13 | 64 | 23 |
| | D8 | 12.00 | 12.45 | slightly sandy SILT | 9 | 73 | 1.48 | 0.86 | | 100 | 41 | 59 | | | | 0 | 17 | 57 | 26 |
| | D12 | 18.00 | 18.45 | silty SAND | 17 | 27 | 2 | 1.57 | | LS | | | | | | 6 | 83 | 11 | |

**Lot 120188, Selangor Cyber Valley**

| | Sample No. | Depth From | Depth To | Classification (From Report) | SPT-N Value | Moisture Content, % | Bulk Density, Mg/m³ | Dry Density, Mg/m³ | Specific Gravity | Atterberg Limit: Liquid Limit, % | Atterberg Limit: Plasticity | Atterberg Limit: Plastic Index | Consolidation Test: Pre Compression Load, kN/m² | Consolidation Test: Compression Index, Cc | Chemical Test: pH Value | Particle Size Distribution, %: Gravel, > 2 mm | Sand, 0.06 – 2 mm | Silt, < 0.06 mm | CLAY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH 2 | D2 | 3.00 | 3.45 | sandy SILT | 3 | 26 | 1.95 | 1.55 | 2.612 | LS | | | | | | 8 | 59 | 23 | 10 |
| | UD1 | 3.50 | 4.40 | very silty SAND | | | | | | | | | 170 | 0.136 | | | | | |
| | D4 | 6.00 | 6.45 | very silty SAND | 3 | 63 | 1.68 | 1.03 | LS | LS | | | | | 3.74 | 2 | 21 | 62 | 15 |
| | D6 | 9.00 | 9.45 | slightly sandy SILT with some organic matter (wood) | 15 | 16 | 2.04 | 1.76 | 2.624 | LS | | | | | | 0 | 84 | 16 | |
| | D9 | 13.50 | 13.95 | silty SAND | 12 | 24 | 1.98 | 1.6 | 2.628 | LS | | | | | | 1 | 82 | 17 | |
| | D11 | 16.50 | 16.95 | silty SAND | 8 | 25 | 2 | 1.6 | 2.601 | LS | | | | | | 0 | 84 | 16 | |
| | D14 | 21.00 | 21.35 | silty SAND | 50 | 16 | 1.71 | 1.48 | 2.509 | 49 | 24 | 25 | | | | 6 | 36 | 50 | 8 |

# APPENDIX 21

Representative Borehole Layout Plan at PT 21044 Cyberjaya



# AUTHOR'S PROFILE



Nor Ashikin binti Yahaya obtained Master of Geotechnic Enginering (Hons.) in 2019 from University Teknologi Malaysia (UTM) Skudai, Johor Bahru, Malaysia. This PhD thesis, Development of an Empirical Modelling Framework for Estimating Physical Soil Properties Using Standard Penetration Test (SPT) *N*-Values, focuses on simplifying geotechnical assessment by developing reliable prediction models for soil properties such as Moisture Content, Specific Gravity, Clay content and Bulk Density using Standard Penetration Test (SPT) *N*-values and depth. Conducted at PT21044 in Cyberjaya, the study offers a faster, easier and more cost-effective method for estimating soil behaviour across large areas without full reliance on intensive laboratory testing. The models validated through statistical analysis including regression and paired t tests provide engineers with practical tools to support early design decisions in soft ground environments. The findings of this research contribute to the development of a practical empirical modelling framework for preliminary geotechnical assessment and reflect her research interest in geotechnical engineering, particularly in soft soil characterisation, site investigation and empirical modelling.

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