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Comparison Between Measured and Extracted Values According to the Equations in the NOVO SPT Program

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ABSTRACT

The evaluation of the undrained shear strength (Su) in fine-grained soils plays a critical role in the context of geotechnical engineering applications. The introduction provides an overview of the significance of Su in the field of geotechnical engineering and highlights the complexity of estimating Su in fine-grained soils. This data was collected from multiple sources, which encompassed consulting engineering offices (collected from the soil test laboratories at the University of Anbar), private contracting companies, and various offices. Data collection is an indispensable step in attaining optimal outcomes. from Fallujah, which predominantly consist of silty clay and clayey silt. Field investigations were conducted to obtain Su values using field vane shear tests. the field-testing data, including borehole depth, SPT results, consistency, Su, Su from SPT NOVO, and soil description. The testing program involved determining the undrained shear strength of the soils using appropriate testing apparatus and procedures. The data acquired from the laboratory experimentation are analyzed to identify trends in Su and soil consistency. Based on the examination of the data, and the results obtained from the laboratory testing, it can be concluded that there is a relatively weak correlation between the undrained shear strength (Su) and the Standard Penetration Test (SPT) N-value. The correlations proposed by (Sowers 1979, Kulhawy 1990, Reese et al. 1976, and Terzaghi 1967) all show modest R2 values, indicating limited correlation between Su and N-value.

1. Introduction

The undrained shear strength (Su) represents an important geotechnical parameter. It influences the foundations stability and performance, slopes, and earth structures. For Accurate Su estimation, there are two main approaches: the first approach involves using correlations of measurements of shear wave velocity and effective overburden stress taken directly at the site, as well as Additional variables, such as the plasticity index, should also be considered or over consolidation ratio (Tiwari & Ajmera, 2021). The second approach involves conducting laboratory tests, Examples of these types of tests are direct shear, direct simple shear, and triaxial compression, or Shear testing conducted using a ring-shaped apparatus, to measure Su (Stark & Fernandez, 2020; Behnia et al. 2020). These tests provide information on the totally softened shear strength refers to the peak shear strength of remolded soil specimens (Moon & Ku, 2018). The assessment of the stability of initial landslides and compacted fills relies heavily on the determination of the fully softened shear strength (Tiwari & Ajmera, 2018).

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That recommended to assess the shear strength of a material in a totally softened state, direct shear test equipment is employed, as they are readily Commonly found in numerous geotechnical engineering laboratories. The field vane shear test (FVT) is commonly Utilized for the quantification of the undrained shear strength. (Su) of soils in-situ (Ayadat, 2021). This experiment entails the continuous rotation of a vane with four blades in the soil at a consistent speed. The maximum torque applied during this rotation immediately corresponds to the Su value. Undisturbed soil samples can yield Su values from unconfined compression tests conducted in the laboratory (Raheem 2021). Empirical correlations using Standard Penetration Test (SPT) blow counts (N-values) are often used to estimate undrained shear strength (Su) when direct measurement is not feasible (Kumar et al., 2019). It is evident that these correlations are obtained based on the parameters like type of soil, OCR (Over Consideration Ratio) and the effective stress (Xu, 2018; Tang et al., 2018). Determining Su accurately is important especially in geotechnical analysis and design of various applications, which includes stability of slopes, bearing capacity of foundation, and lateral earth pressures. If Su is overemphasized, then, the constructions are potentially unsafe, whereas it is underestimated, the constructions are very costly and conservative. This article compiles data on Su values from laboratory testing, focusing on unconfined compression tests on undisturbed soil samples from boreholes, to understand their reliability and limitations. The data should include corresponding SPT-N values from the same depth intervals. Apply the different empirical correlations to the compiled field data to be estimating Su values. Compare the estimated Su values to actual measured values from laboratory tests. Evaluate the accuracy and reliability of each correlation.

2. Literature Review

Several papers provide insights into this topic. Stark and Fernandez (2020) discuss the softened strength (FSS) is regarded as the major governing shear strength parameter for cut slopes and recommend empirical correlations to analyze the relationship between stress and finite strain softening (FSS) envelope that is dependent on stress. Jiang et al. (2018) determined spatially varying soil properties that explore the application of Bayesian analysis and assess slope reliability, providing a method to optimize test programs. Konrad (2018) postulates a correlation between the undrained strength of soil, blow count values, and particular soil properties for evaluating hydraulic fills against flow sliding. Tiwari and Ajmera (2018) emphasize the importance of measuring the shear strength of a material in its fully softened state by direct shear tests and recommend Employing constant volume direct simple shear devices to precisely capture the curved shear envelopes that have undergone complete softening. Finally, Camilo et al. (2018) present a SU-based landslide susceptibility model that incorporates various predictors and statistical analyses to identify the primary controls on slope stability. There are several methods commonly employed for the estimation of the unconsolidated undrained shear strength (Su) of fine-grained soils. Field vane shear tests (FVST) directly measure in-situ shear strength using a four-bladed vane rotated into the soil (Stefanow & Dudziński, 2021). Standard penetration tests (SPT) require operating a split spoon sampler while driving into the ground and correlating the blow count (N-value) with Su (Xu, 2018). Cone penetration tests (CPT) use an instrumented cone tip to measure tip resistance (qc) and sleeve friction, with correlations proposed between Su and qc. Laboratory shear testing, such as consolidated undrained (CU) and unconsolidated undrained (UU) tests, directly measure stress-strain behavior and peak Su (Meehan et al. 2017). However, sample quality issues can impact measured Su (Kayabalı et al., 2015). Every technique possesses distinct benefits and constraints. FVST is available as on-site measurements but can be limited as compared with SPT/CPT, which allows continuous soil profiles, but the Su is required to be estimated indirectly. Laboratory tests provide a direct quantification of the undrained shear strength (Su); however, the accuracy of these measurements can be affected by sample disturbance and perturbation. Su estimates may be supported by more data from different methods in order to increase its reliability level. Vane shear tests (VST) offer accurate measures of undrained shear strength (Su) in soft to medium clays, but they have a tendency to overestimate the Su values in stiff clays with fissures (Hov et al. 2021). Out of the tests available, the dilatometer (DMT) and the pressure meter (PMT) were found to give more concrete results concerning the effects of fissuring (Jamiolkowski et al. 1985). Cabalar et al. (2020) provided a detailed assessment of in-situ test methods especially, Vane Shear Test (VST), Pressure Meter Test (PMT), and Dilatometer Test (DMT) for determining Su. Stands for piezocone penetration test (CPTU) were found to provide the most consistent Su estimates, especially where VST might give inaccurate results in stiff fissured clays. Earlier studies have revealed how the undrained shear strength (Su) values can be correlated with the normalized SPT resistance (N1) 60 for clay. The association between Su and (N1)60 was proposed by Baldi while information such as plasticity were also considered. There is evidence that this association has been applicable at some of the clay locations. It is important to acknowledge that natural clays have different physical and mineralogical properties, which means there is no consistent link between Su and other factors like fluidity index (IL) and water content ratio (WCR) (Shimobe & Spagnoli, 2020). Moreover, the proportion of sand and the grading properties of clay-sand mixes have been discovered to have a substantial impact on the Su values obtained from vane shear and fall cone tests (Cabalar et al., 2020). For the clay-rich sediments, as also mentioned earlier, the index correlation (IL) between the undrained shear strength (Su) and liquidity has been proven only partially; therefore, the widely ranged consistencies in these sediments play a vital role, as stated by Andreasson (2019). The relationship between Su at the plastic and liquid limits remains contentious. While some studies advocate for a consistent ratio between the two strengths, others propose a broader range of values (Persson, 2017). The literature review focuses on assessing Su through field testing and the utilization of Standard Penetration Test (SPT-N) values. It emphasizes method for estimating (N1)60 from Cone Penetration Test (CPT) data, which can subsequently be used to predict Su via a specific relationship.

$$\boldsymbol{Su = (N1)60/15} \tag{1}$$

This combined

$$\boldsymbol{CPT - (N1)60 - Su} \tag{2}$$

This approach has shown improved Su predictions compared to direct stands for cone penetration test CPT-based methods (Ahmad et al. 2021).

The city of Fallujah is in the Al-Anbar province of western Iraq. The soil in this area is predominantly alluvial deposits consisting of silty clay and clayey silt. Testing of undrained shear strength (Su) provides an indication of the cohesive strength of these fine-grained soils. Several field investigations have been conducted in Fallujah to obtain Su measurements. In this study, it was found that the measured Su values using field vane shear tests.

The soils encountered in the study that typically stiff - very stiff clays and silty clays. More recent field work found Su between 1.33-500 kPa across 28 reading of the city using a hand-held shear vane. Borehole logs described layers of clay and silty clay to depths of at least 10 meters. In summary, undrained shear strengths measured in situ at Fallujah fall predominantly. The near-surface soils consist primarily of stiff to hard clays and silty clays with high plasticity. I hope this overview provides useful context on soil conditions and strength properties from field investigations in the Fallujah City.

The provided Field Testing contains data from various soil investigation projects, including Al-Khansa school, Fallujah cement plant, and Al-Adal residential complex. The Field Testing presents information on the borehole depth, standard penetration test (SPT) results (N, N60, N1(60)), consistency, (Su) of clay, (Su) from SPT NOVO, and soil description. Additionally, the table includes values from four different methods: (Sowers (1979), Kulhawy and Mayne (1990), Reese, Touma, and O'Neill (1976), and Terzaghi and Peck (1967)). Analyzing the Field Testing, we can observe the following trends:

- The " undrained shear strength" of clay (Su) generally grow with depth, indicating that the soil becomes stiffer and more resistant to deformation as we go deeper.
- The soil's consistency exhibits variation throughout various projects and depths. As an illustration, the soil of Al-Khansa school is characterized by high stiffness, ranging from very stiff to extremely hard. In contrast, the soil in Al-Adal residential complex is predominantly stiff.
- The undrained shear strength of clay obtained by SPT NOVO, commonly known as Su from SPT novo, exhibits variations across different projects and depths. In certain instances, the proximity to (Su) of clay is similar, whereas in other cases, it varies greatly.
- The descriptions of the soil give extensive additional data regarding the features and composition of the soil. These include color, surface texture and the availability of certain materials such as sand, silt, clay or gypseous soils.
- All the following outcomes were originated from the four different approaches (Sowers, 1979; Kulhawy and Mayne, 1990; Reese, Touma, and O'Neill, 1976; Terzaghi and Peck, 1967) provide diverse evaluations

of the Su of clay. These values can be utilized to compare and validate the outcomes arising from the SPT and the SPT NOVO techniques.

3. Study Objectives

This research seeks to evaluate the Su (undrained shear strength) of fine-grained soils through extensive testing in laboratory as well as integrating analytical evaluations through various mathematical models and formulae. The determination of the Su is obtained from field data, specifically utilizing the values of Standard Penetration Test (SPT-N).

4. Laboratory Testing and Data Analysis

Undrained shear strength (Su) is a crucial factor for geotechnical application and the measurement of clay soil's shear strength when fully saturated. Several techniques are employed to accurately determine Su, including laboratory testing and extensive field observations:

4.1 Comparative between SPT NOVO and field tests (SU)value

One of the most popular in situ testing methods is the correlation with the Standard Penetration Test (SPT) N-value. This method measures the standing ability of soil to resist penetration by a standard sampler, which is driven by a certain weight, and supplies important data for geotechnical purposes (design and analysis). Some of the most used correlations include those proposed by Sowers (1979), Kulhawy and Mayne (1990), Reese, Touma and O'Neill (1976), and Terzaghi and Peck (1967). The R2 values for these correlations range from 0.0025 to 0.0606, indicating a relatively weak correlation between (SPT) N-value and Su. On the other hand, laboratory testing group (1) can provide more accurate results. However, laboratory testing is more expensive and time-consuming than natural tests.

It is imperative to acknowledge that the undrained shear strength does not have a singular value, given its dependence on loading direction, soil anisotropy, strain rate, and stress history. When assessing the estimations of undrained shear strength (Su) utilizing Standard Penetration Test (SPT) N60 values, a comparison of the equations is necessary:

$$\boldsymbol{Su = 150\,N60/60 \leftrightarrow 275\,N60/60} \qquad \textbf{(3)}$$

This equation by Sowers provides a range of values for Su based on the N60 value. The range spans from 150 times N60/60 to 275 times N60/60. It suggests a linear relationship between Su and N60.

$$\boldsymbol{Su = 6xN60} \qquad \textbf{(4)}$$

Kulhawy and Mayne propose a simple linear equation where Su is equal to 6 times N60. It assumes a linear relationship between Su and N60, with a constant factor of 6.

$$\boldsymbol{Su = 7xN60} \qquad \textbf{(5)}$$

Reese, Touma, and O'Neill suggest another linear equation, where Su is equal to 7 times N60. Like the previous equation, it assumes a linear relationship between Su and N60, with a constant factor of 7.

$$\boldsymbol{Su = 6.3xN60} \qquad \textbf{(6)}$$

Terzaghi and Peck propose an equation where Su is equal to 6.3 times N60. Again, it assumes a linear relationship between Su and N60, with a constant factor of 6.3.

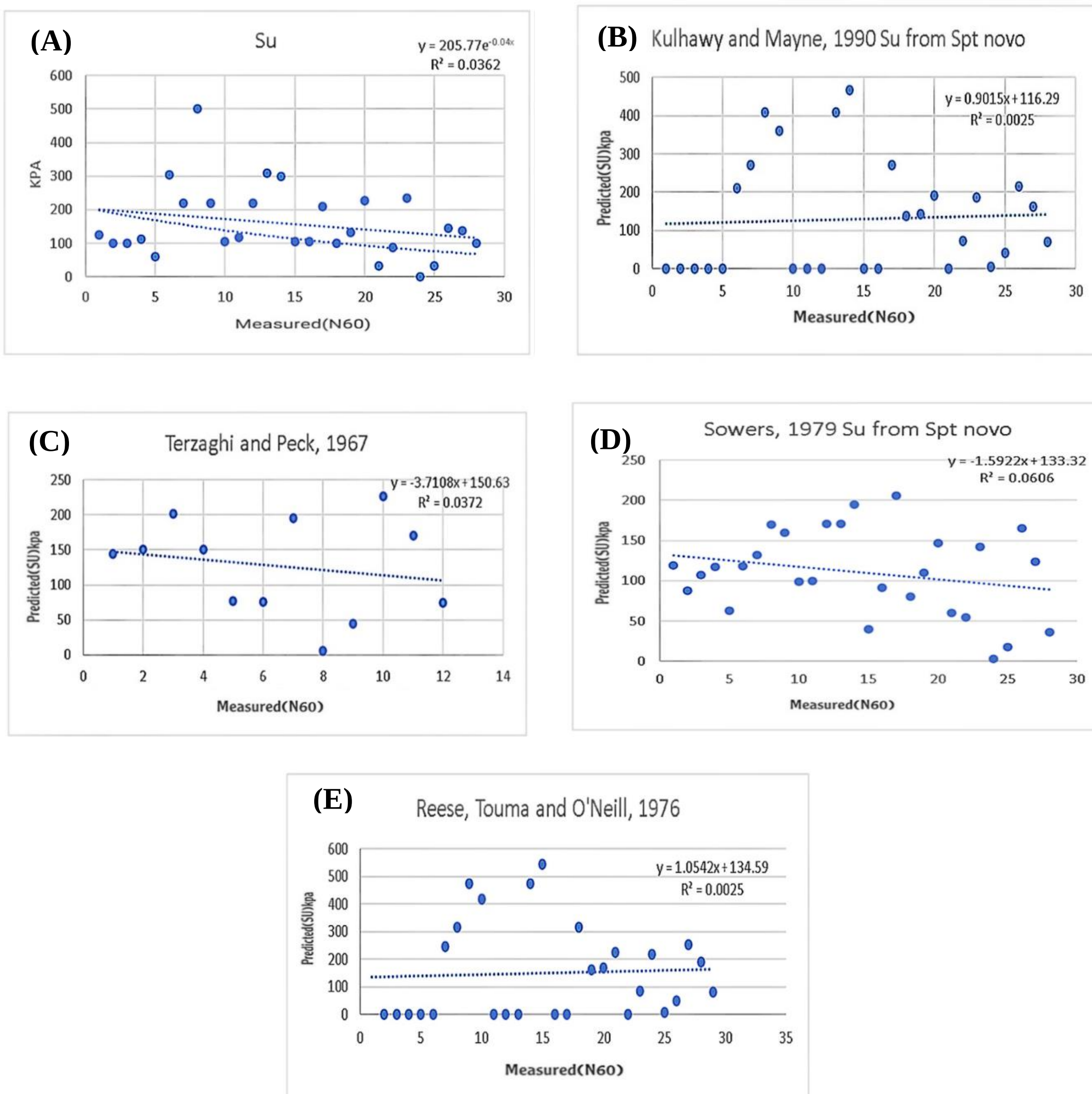

Fig. 1 A, Undrained shear strength of field, B, C, D, E) Undrained shear strength of SPT NOVO stated R2 values and equations for each result.

Table 1 – Comparison between field methods and SPT-NOVO.

	N60	Measured (Su)field	Sowers, 1979	Kulhawy and Mayne, 1990	Reese, Touma and O'Neill, 1976	Terzaghi and Peck, 1967
N	28	28	28	28	28	27
Max	78	500	206.25	468	546	491.4
Min	1	1.33	2.5	0	0	6.3
Av.	35	159	110	210	151	207
Sd	19.58	106.22	53.21	1148.94	173.76	120.56

Comparing these equations, we can observe the Sowers (1979) provides a range of values for Su based on N60, while the other equations provide a single value for Su. The equations by Kulhawy and Mayne (1990) and Reese, Touma, and O'Neill (1976) have a constant factor of 6 and 7, respectively, indicating a linear relationship between Su and N60 with different scaling factors. Terzaghi and Peck (1967) propose a slightly different scaling factor of 6.3, suggesting a slightly different linear relationship between Su and N60. It's important to note that these equations are empirical correlations and may have limitations and applicability restrictions. The accuracy and reliability of variations in these correlations may arise based on factors like the type of soil., testing conditions, and the specific site being analyzed. It is recommended to use these correlations cautiously and consider site-specific conditions and additional geotechnical data to validate their applicability and accuracy.

4.2 High correlation between SPT NOVO and field tests (SU)values

The field tests conducted to measure the "undrained shear strength" (Su) yielded an R2 value of 0.0362. The observed correlation between the obtained soil undrained shear strength (Su) values and the test results appears to be relatively modest. The SPT NOVO correlation, introduced by Terzaghi and Peck in 1967, demonstrates a slightly increased R2 value of 0.0372. This demonstrates that the SPT gives a slightly better relationship with the undrained shear strength than the field tests. Field tests and SPT NOVO correlation show moderately low R2 values, indicating moderate correlations with undrained shear strength, which resulted in limiting precise estimations of the undrained shear strength based on provided R2 values.

As the methodologies compared, the SPT NOVO correlation, established by Terzaghi and Peck (1967), shows a slightly higher R2 value, suggesting a slightly enhanced fit with undrained shear strength compared to field testing. However, it is important to recognize that R2 values alone do not offer a comprehensive assessment of the accuracy and reliability of the techniques. The precision and suitability evaluation of these methods, in engineering contexts, depend on factors like soil characteristics, sample quality, testing procedures, and equation applicability.

4.3 Mean of blows number comparison

The laboratory tests for undrained shear strength yield a mean value of 42.85714286 blows (N). The laboratory tests for undrained shear strength indicate a mean value of 42.85714286 blows (N). The SPT NOVO correlation is based on the average number of blows (N60) which is 35.21428571. In this correlation, the raw SPT blow count (N) is directly utilized to determine the undrained shear strength (Su) of the soil. When evaluating these two approaches, it is imperative to take into account the following:

1. Direct Measurement and Indirect Estimation Comparison: Although the undrained shear strength is directly measured from the laboratory testing, SPT NOVO correlation computes the undrained shear strength using the blow count of SPT. A direct and accurate quantitative evaluation of the characteristic were allowed by laboratory tests, while an indirect quantitative evaluation was offered via the SPT NOVO correlation.
2. Discrepancy in Blow Counts: The mean number of blows observed in the laboratory experiments (42.85714286) surpasses the mean number of blows predicted by the SPT NOVO correlation (35.21428571). This variance might imply disparities in testing conditions, energy levels, or other pertinent factors influencing the results.

Upon data analysis and laboratory findings, it becomes apparent that a subtle relationship exists between the undrained shear strength (Su) of soil in the field and the Standard Penetration Test (SPT) N-value. The correlations proposed by various researchers, including Sowers (1979), Kulhawy and Mayne (1990), Reese, Touma, and O'Neill (1976), and Terzaghi and Peck (1967), yield small R2 values. This demonstrates a limited relationship between the Su derived from field tests and that estimated from the SPT NOVO-value. Although natural laboratory testing provides more precise estimates of Su, it entails higher costs and is time-consuming compared to the SPT. In a similar manner, the Su is affected by factors such as loading direction, anisotropic nature of the soil, strain rate and stress history. The equations postulated by Stark and Fernandez (2020), which provides a linear relationship between Su and the N-value for Su estimation. They possess varying scaling factors, indicating discrepancies in the relationship between the undrained shear strength (Su) of clay and the Su of clay derived from SPT NOVO. It is prudent to use these empirical correlations cautiously, taking into account site-specific conditions and additional geotechnical data to validate their precision and dependability. Moreover, acknowledging the inherent limitations and applicability constraints of these correlations is important alongside soil type and testing conditions. Further research and testing are needed to improve correlations in this specific area. Additionally, comprehensive geotechnical studies and conducting site-specific analysis can yield more accurate estimations of undrained shear strength, facilitating improved design and analysis for engineering purposes.

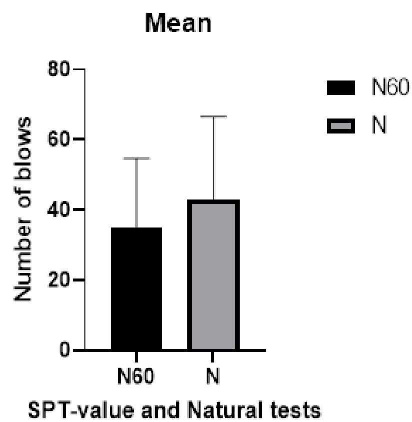

Fig. 2 Undrained shear strength with number of Cycle of (Su) for sites from the city of Fallujah in KPA.

5. CONCLUSION AND RECOMMENDATIONS

The assessment of the undrained shear strength (Su) in fine-grained soils is a complex task requiring careful consideration of various factors. Analyzing field-testing data from different soil study programs in Fallujah presents distinct parameters. Clay's undrained shear strength typically increases with depth, indicating greater soil stiffness and resistance to deformation. Soil consistency varies across projects and depths, and Su values obtained from SPT NOVO also differ. Soil descriptions provide additional insights into soil composition. It is advisable to use a combination of techniques to determine Su in fine-textured soils, considering each method's limitations. Piezocone penetration tests (CPTU) are recommended for stiff fissured clays due to their reliable Su estimations. Further research is required to better understand the relationship between Su and other factors, especially in clay-rich sediments. Comprehensive research of the Su of fine-grained soils is essential for to evaluate slope stability, foundation designs, and infrastructure security. Advancements in testing techniques will enhance the precision and dependability of Su estimations, improving geotechnical engineering practices.

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