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Case Studied of Fundamental of soil properties and their correlation of soil in Battambang Provinces

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Abstract: *This study investigates the fundamental soil properties and their correlations in Battambang Province, Cambodia, to better understand subsurface behavior for geotechnical applications. Battambang, located in the northwestern region of the country, is primarily composed of clayey and silty soils that have compacted over time. A total of 33 boreholes were analyzed using field Standard Penetration Tests (SPT) and laboratory Unconfined Compression Tests (UCT). Results indicate that undrained shear strength (s_u) are increase with depth, suggesting that deeper soil layers are denser and more suitable for shallow foundations. Empirical correlations were developed to estimate shear strength from field data, expressed as $s_u = 6.6\ N$ and $s_u = 7.5\ N_{60}$. These equations provide practical tools for predicting soil strength where limited testing is available. Moreover, a weak correlation was observed between the Plasticity Index (PI) and shear strength, while the Liquidity Index (LI) showed minimal influence. A strong positive relationship was identified between undrained shear strength and Young's modulus (E_i and E_{50}), indicating that stiffer soils possess higher resistance to deformation. The results highlight the significance of soil depth, moisture content, and compaction in geotechnical design and demonstrate that Battambang soils generally exhibit good bearing capacity for construction purposes.*

Keywords: Battambang Province, Undrained Shear Strength, SPT, Young's Modulus, Plasticity Index

1. INTRODUCTION

Soil properties play a crucial role in understanding subsurface behavior for geotechnical design and construction. Parameters such as undrained shear strength (s_u), Plasticity Index (*PI*), Liquidity Index (*LI*), and Standard Penetration Test (*SPT*) *N-values* are key indicators for assessing soil strength and stability. These parameters help engineers evaluate soil behavior under load and determine suitable foundation types, ensuring the safety and performance of engineering structures. In geotechnical practice, the relationship among these parameters is often used to estimate soil strength and stiffness when laboratory or field data are limited [8], [14].

Battambang Province, located in the northwestern region of Cambodia, is an area characterized by clayey and silty soils that have compacted naturally over time. These soils are widely used for construction purposes, including buildings, roads, and other infrastructure. As development expands in this region, understanding the geotechnical properties of Battambang soils becomes increasingly important for predicting soil performance and ensuring stability in foundation design. The study of local soil characteristics provides essential information for engineers to anticipate settlement, bearing capacity, and deformation behavior.

Previous studies in Cambodia, such as the work of Touch et al. (2014) in Phnom Penh, have established empirical correlations between field and laboratory parameters. Their study proposed a practical equation, $s_u = 5.5N$, linking undrained shear strength with *SPT N-values* for fine-grained soils. However, this relationship may not accurately represent soils in other provinces due to regional variations in soil type, moisture content, and compaction. Battambang's soils, for instance, have distinct mechanical characteristics and depositional conditions, making it necessary to develop localized correlations for better prediction of soil strength [1].

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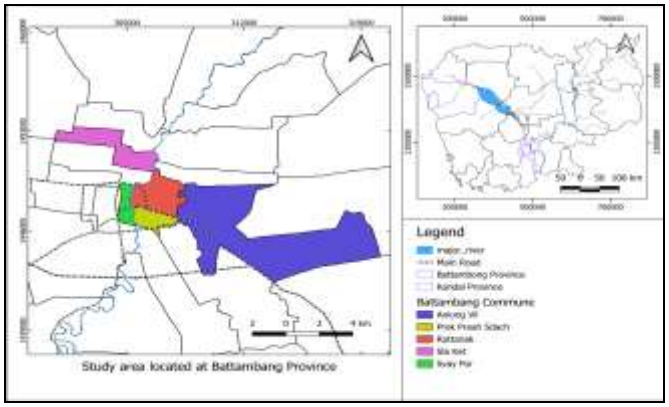


Fig. 1. Location of the 15 datas used in this study for Battambang Province

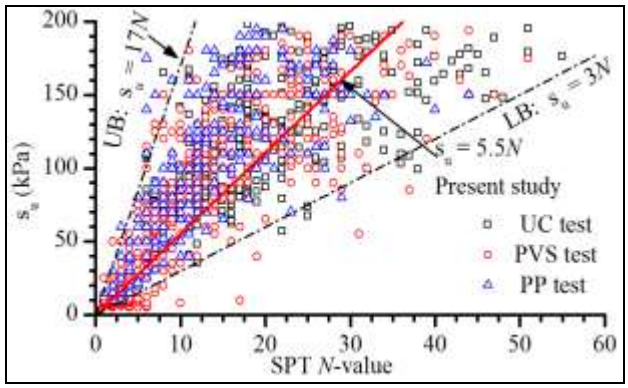


Fig. 2. Empirical correlations of the undrained shear strength to the *SPT N-value* of Phnom Penh fine-grained soils. [1]

The influence of soil indices such as *PI* and *LI* on undrained shear strength has also been widely discussed in earlier works. Bjerrum and Simons (1960) demonstrated that shear strength decreases as the Liquidity Index increases, due to the weakening effect of higher moisture content. Similarly [2], Leroueil and Hight (2003) reported that the ratio of undrained shear strength to effective overburden pressure increases with the Plasticity Index, especially for clayey soils [3]. These studies highlight the significance of *PI* and *LI* in determining soil strength and behavior under different environmental conditions.

Young's modulus (E_i and E_{50}), derived from the Unconfined Compression Test (*UCT*), is another important parameter that reflects the stiffness and deformation capacity of soil. The correlation between shear strength and Young's modulus provides insight into how soil resists deformation and bears loads. Establishing reliable empirical relationships between these properties can improve geotechnical interpretation and reduce the need for extensive field investigations [15].

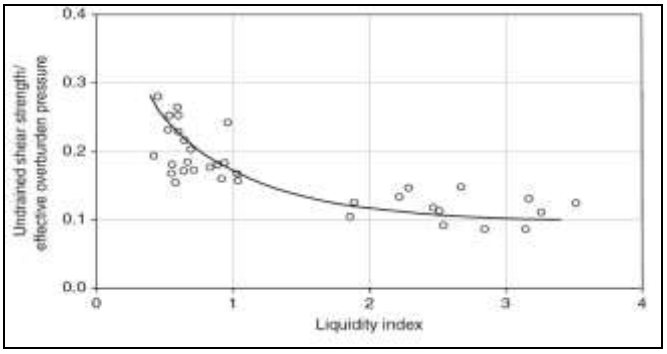


Fig. 3. Correlation between shear strength and liquidity index. [2]

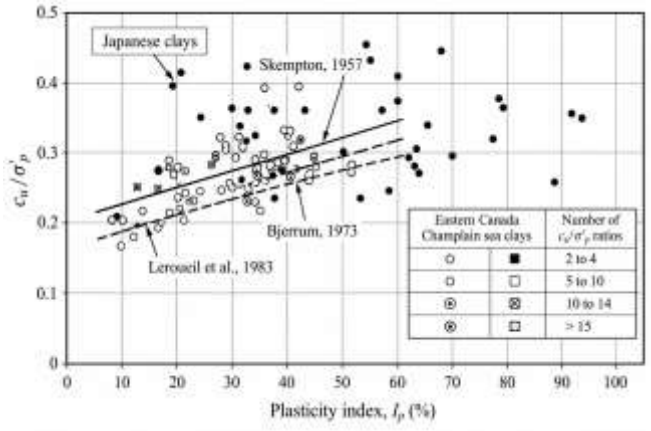


Fig. 4. Variation of the (s_u/σ'_{v0}) ratio with *PI* [3]

The present study focuses on analyzing and correlating the fundamental soil properties in Battambang Province to better understand subsurface conditions and improve geotechnical design practices. A total of 33 boreholes were examined using field Standard Penetration Tests (*SPT*) and laboratory Unconfined Compression Tests (*UCT*) for estimating soil strength from field data. Furthermore, it examines the relationships between s_u, *PI*, *LI*, and Young's modulus (E_i and E_{50}) to evaluate how these parameters influence soil stiffness and deformation characteristics.

The scope of this research is limited to the Battambang region, where soil samples were collected and analyzed to establish these correlations. The findings are expected to support future geotechnical investigations by providing reference data for predicting soil strength and stiffness with limited testing. Overall, this study emphasizes the importance of integrating depth, moisture content, and compaction effects in soil evaluation and demonstrates that Battambang soils generally exhibit good bearing capacity suitable for construction applications.

2. METHODOLOGY

2.1 Site Investigation

The *SPT* was conducted following the ASTM D1586 (1999) procedure. A split-spoon sampler was driven into the ground using a 63.5 kg hammer dropped from a height of 762 mm (30 inches). The total number of blows required to penetrate 300 mm of soil after the first 150 mm seating drive was recorded as the *N-value* [4].

To standardize the results, corrections for hammer efficiency, borehole diameter, rod length, and sampler type were applied to obtain the corrected *N-value* (N_{60}) as expressed in Equation:

$$N_{60} = C_b C_r N (E_m / 60) \quad \text{(Eq. 1)}$$

where:
N = Raw SPT blow count
E_m = the measured hammer energy efficiency (%)
C_b = the borehole diameter correction factor
C_r = the rod length correction factor

2.2 Laboratory Test

2.2.1 Moisture Content

The moisture content (W) is defined as the ratio of the weight of water to the weight of dry soil solids [11]. It was determined using the oven-drying method at 105°C–115°C until constant weight was achieved. The formula used:

$$W = (W_w / W_s) \times 100 \quad \text{(Eq. 2)}$$

Where:
W_w = Weight of water in the sample
W_s = Weight of dry soil solids

2.2.2 Specific Gravity

The specific gravity (Gs) was determined using a pycnometer according to ASTM D854 [5]. It represents the ratio of the weight of soil solids to the weight of an equal volume of water at the same temperature and was calculated as:

$$G_s = M_s / ((M_{pw,t} - M_{pws,t}) + M_s) \quad \text{(Eq. 3)}$$

where
M_s = mass of dry soil
$M_{pw,t}$ = mass of pycnometer filled with water
$M_{pws,t}$ = mass of pycnometer filled with water and soil

2.2.3 Grain Size Analysis

A sieve analysis is conducted by taking a measured amount of dry, well-pulverized soil and passing it through a stack of progressively finer sieves with a pan at the bottom. This percentage is generally referred to as percent finer [8]. Table 1 contains a list of U.S. sieve numbers and the corresponding size of their openings. These sieves are commonly used for the analysis of soil for classification purposes [12].

Table 1. List of U.S

Sieve No.	Opening (mm)
4	4.75
6	3.35
8	2.36
10	2
16	1.18
20	0.85
30	0.6
40	0.425
50	0.3
60	0.25
80	0.18
100	0.15
140	0.106
170	0.088
200	0.075
270	0.053

Two parameters can be determined from the grain-size distribution curves of coarse-grained soil: (1) the uniformity coefficients and (2) the coefficient of gradation, or coefficient of curvature. These coefficients are:

$$C_u = D_{60} / D_{10} \quad \text{(Eq. 4)}$$

Or

$$C_c = (D_{30})^2 / (D_{60} \times D_{10}) \quad \text{(Eq. 5)}$$

where
D_{10}, D_{30}, D_{60} = the diameters corresponding to percent finer than 10, 30, and 60%, respectively (see Figure 5)

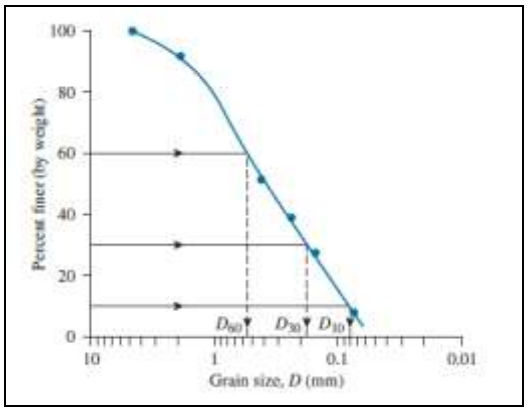


Fig. 5. Grain-size distribution curve of a coarse-grained soil obtained from sieve analysis [8]

2.2.4 Atterberg Limits

The Atterberg limits test was conducted to determine the boundaries between the different states of consistency for fine-grained soils. The liquid limit (*LL*) and plastic limit (*PL*) were determined using the Casagrande device [8], [13]. The plasticity index (*PI*) was calculated as:

$$PI = LL - PL \quad \text{(Eq. 6)}$$

Where
PI = plastic index
LL = liquid Limit
PL = plastic limit

From the analysis of hundreds of liquid limit tests, the U.S. Army Corps of Engineers (1949) at the Waterways Experiment Station in Vicksburg, Mississippi [6], proposed an empirical equation of the form:

$$LL = W_N (N/25)^{tan\beta} \quad \text{(Eq. 7)}$$

Where
N = the number of blows in the liquid limit device required to close a 12.7 mm (0.5 in.) groove
W_N = the corresponding moisture content, and $tan\,\beta$ is 0.121. (note that $tan\,\beta$ is not equal to 0.121 for all soil types, as it may vary depending on the soil's characteristics)

While The plastic limit is identified by repeatedly rolling a small portion of clay into thin threads until they reach a diameter of about 3 mm. Burmister (1949) classified the plasticity index in a qualitative manner as follows:

Table 2. Classification of soil plasticity based on the Plasticity Index (PI) (Das, 2010)

PI	Description
0	nonplastic
1 - 5	Slightly plastic
5 - 10	Low plasticity
10 - 20	Medium plasticity
20 - 40	High plasticity
>40	Very high plasticity

2.2.5 Unconfined Compression Test (UCT)

The Unconfined Compression Test (ASTM D2166) was performed on undisturbed cylindrical soil specimens, typically 38 mm in diameter and 76 mm in height, to determine their compressive strength and deformation characteristics under axial load [9].

The sample was placed between the loading plates of a compression testing machine, and an axial load was applied at a constant strain rate of 0.5–2% per minute until failure occurred. During the test, the applied load and the corresponding axial deformation were recorded to develop a stress–strain curve, as illustrated in Figure 6:



Fig. 6. Procedure of Unconfined Compression Test

The undrained shear strength can be estimated by using:

$$s_u = q_u / 2 \quad \text{(Eq. 8)}$$

Where
s_u = undrianed shear strength
q_u = unconfined compressive strength
However, in other to get s_u we need to determine q_u by using:

$$q_u = \sigma = F / A' \quad \text{(Eq. 9)}$$

where
F = load applied at failure (KN)
A' = corrected cross-section area (m^2)

The initial Young's modulus (E_i) and secant modulus (E_{50}) were determined from the stress–strain curve:

$$E_i = \Delta\sigma / \Delta\varepsilon_I \quad \text{(Eq. 10)}$$

$$E_{50} = \sigma_{50} / \varepsilon_{50} \quad \text{(Eq. 11)}$$

Where
Δ_σ = change in axial stress
$\Delta_{\varepsilon i}$ = initial strain interval
σ_{50} = stress at 50% of maximum load
ε_{50} = strain at 50% of failure

2.2.6 UU Test

According to Skempton and Henkel [10], the undrained shear strength (C_u) for normally consolidated clays is empirically related to the *PI* as shown in the equation:

$$C_u = 0.11 + 0.0037PI \quad \text{(Eq. 12)}$$

3. RESULTS AND DISCUSSION

The analysis focused on the correlation among those subsoil properties to provide a clearer understanding of soil behavior underneath the surface in Battambang. However, we need to note that all the data are only from the area that we have found in Battambang province.

3.1 Correation of undrained shear strength and depth

According to the data in Battambang show the strength of the soil s_u steadily rises with increasing depth. In that cases, there is a gradual enhancement in soil strength with depth. The s_u values range from approximately 50 kPa to nearly 200 kPa. This consistent upward trend in both parameters suggests that the behavior of soils is influenced by the effects of depth and overburden pressure, which ease the consolidation of soil layers, ultimately enhancing both resistance and strength [8].

Even the graph shows a steady rise in s_u values; however, there are some changes in the results, especially at middle depths. These changes may be attributed to differences in soil type, moisture content, or other factors that can affect shear strength at different depths. Despite these changes, the overall trend indicates that soil strength generally increases with depth.

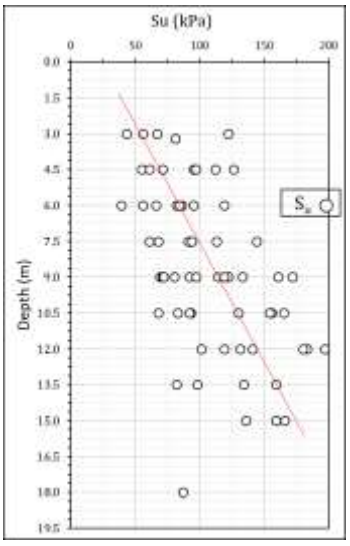


Fig. 7. Correlation of s_u versus depth

The observed trend of increasing s_u with depth reflects the compaction of deeper soil layers, which leads to greater strength due to the added pressure from the soil above. This behavior is common in many soil types, where deeper layers are more compact and better able to resist shear forces. However, the variability in s_u values at different depths highlights that soil properties can naturally differ, which should be taken into account in any thorough geotechnical study [14].

3.2 Correlation of undrained shear strength and N-value, N_{60}

The study explores the relationship between undrained shear strength (s_u) and both the Standard Penetration Test (*SPT*) *N-value* and the corrected N_{60} value in Battambang. The findings indicate a clear correlation between s_u and the *SPT N-value*, represented by the equation

$$s_u = 6.6N$$

This mean as the *N-value* increases, the undrained shear strength also tends to rise. The analysis establishes upper and lower bounds for this relationship, providing a range of expected s_u values based on different *N-values*.

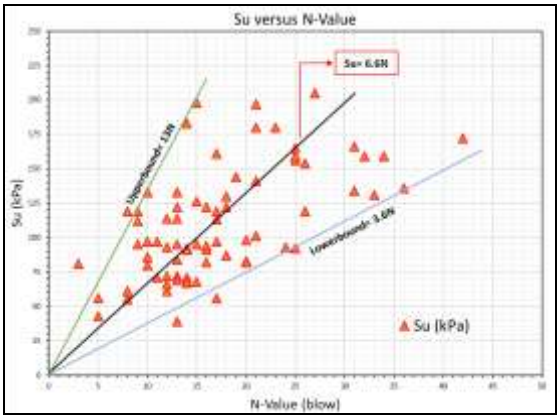


Fig. 8. The correlation of s_u *versus N-value* of soil at Battambang

Additionally, the corrected N_{60} value shows a similar trend, highlighting its relevance in estimating s_u. The relationship for N_{60} represented by the equation:

$$s_u = 7.5N_{60}$$

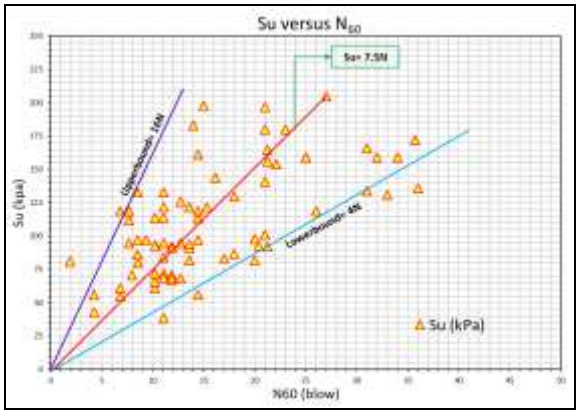


Fig. 9. The correlation of s_u versus N_{60} of soil at Battambang

Despite all these correlation, the data shows variability influenced by factors like soil structure, moisture content, and compaction, indicating that the relationship between undrained shear strength (s_u) and *N-values/N60* is not perfectly linear. Relying solely on these correlations could lead to significant errors in predicting shear strength. Therefore, it is essential to complement field data with laboratory testing and site investigations. While these correlations provide quick estimates, they should not replace thorough analyses that account for specific site conditions [14].

3.3 Correlation of Normalized shear strength with plasticity index and liquidity index

The correlation between undrained shear strength (s_u) and the Liquidity Index (*LI*) and Plasticity Index (*PI*) is significant in geotechnical engineering, as it provides insights into the mechanical behavior of cohesive soils. Understanding these correlations allows engineers to predict the soil's behavior under varying stress and moisture conditions, which is crucial for designing stable construction projects [8].

The relationship between undrained shear strength (s_u) normalized by effective vertical stress (σ'_{v0}) and the liquidity index (*LI*) was examined using data from Battambang soil samples, revealing that s_u decreases as *LI* increases, indicating a negative correlation between shear strength and liquidity index. Despite this trend, data show minor variance in the ratio (s_u/σ'_{v0}) across different *LI* values, ranging from:

$$0 \leq LI \leq 1.6$$

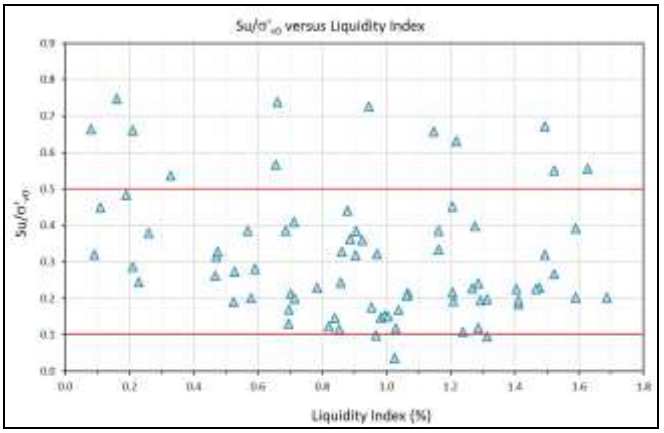


Fig. 10. The correlation of (s_u/σ'_{v0}) versus LI of soil at Battambang

Additionally, the analysis of the relationship between (s_u/σ'_{v0}) and *PI* indicated that *PI* values ranged from:

$$15 \leq PI \leq 35$$

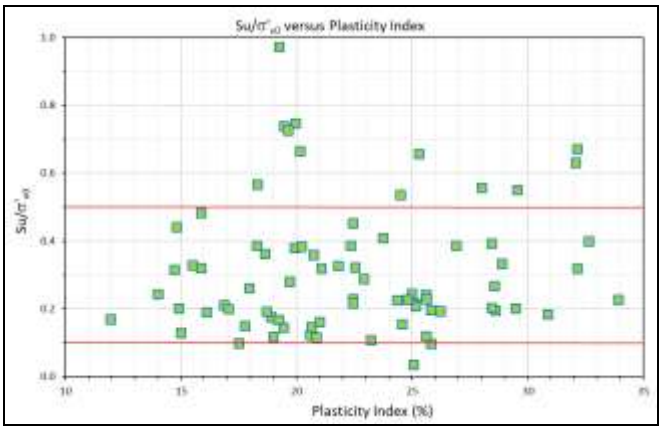


Fig. 11. Correlation of (s_u/σ'_{v0}) versus PI

By applying an estimated range, it was found that the (s_u/σ'_{v0}) values should stabilize around 0.17 to 0.22 based on PI values, while previous research suggests that (s_u/σ'_{v0})

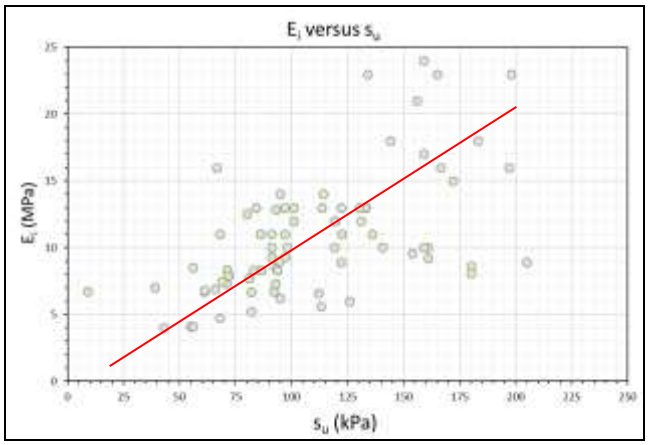
should ideally stabilize around 0.25 for soils with higher PI values, with the average for Battambang soil being approximately 0.20. The normalization of shear strength concerning both the Liquidity Index and Plasticity Index demonstrated that *LI* has a more significant effect on normalized shear strength, decreasing from 1.6 to 1.0, indicating that increased moisture content leads to a decrease in normalized shear strength [8].

In contrast, while *PI* shows a positive relationship with normalized shear strength, its impact remains minimal. When comparing the two indices, *PI* is more useful than *LI* for predicting shear strength, as it directly influences the soil's behavior under stress.

However, both indices should not be the sole focus for engineers; other factors affecting soil stability during design and construction must also be considered. The weak correlation between (s_u/σ'_{v0}) and *PI* suggests that, while both indices provide important insights into soil properties, engineers should exercise caution and conduct additional tests to obtain a comprehensive understanding of soil strength for safe and accurate design.

3.4 Correlation of undrained shear strength with young's modulus (E_i, E_{50})

The analysis of the correlation between the modulus of initial Young's modulus (E_i) and the secant modulus (E_{50}) with undrained shear strength (s_u) revealed a positive linear relationship, as demonstrated in the scatter plots. As the undrained shear strength increases, both E_i and E_{50} also tend to rise, indicating that stronger soils with higher shear strength exhibit greater stiffness. This finding aligns with previous studies, which suggest that materials with greater shear strength possess an enhanced ability to resist deformation, as reflected by a higher modulus of elasticity.



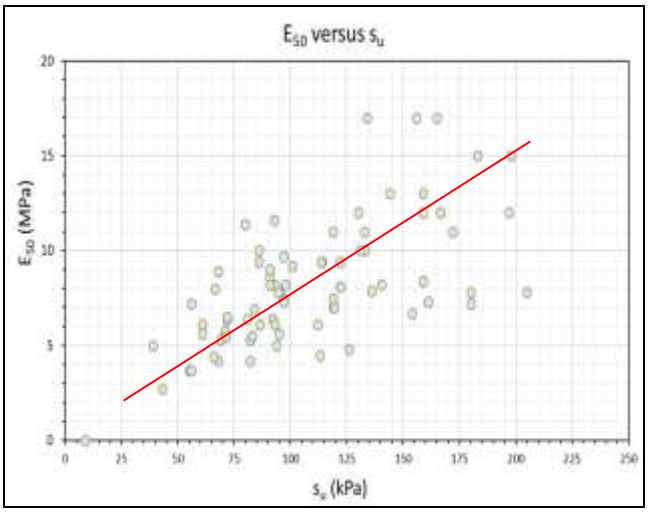


Fig. 12. Correlation of undrained shear strength with young'modulus (E_i, E_{50})

The scatter plots illustrate this correlation effectively, with Figure 12 showing the relationship between E_i and s_u, highlighting that increased shear strengths are associated with elevated initial Young's modulus. Additionally, a similar trend is observed for E_{50}, reinforcing the significance of this relationship. It is crucial to note that while laboratory testing remains the most accurate method for measuring s_u, various factors such as soil type and moisture content must be considered. In scenarios where laboratory tests are not feasible, relying on estimates from E_i or E_{50} can provide valuable insights.

Overall, the results underscore the importance of understanding soil stiffness in geotechnical applications, as both E_i and E_{50} serve as critical indicators of a soil's mechanical behavior in relation to its undrained shear strength [15].

4. CONCLUSIONS

This study examined the basic soil properties and their correlations in Battambang Province to understand local soil behavior for construction use. The results showed that the undrained shear strength (*su*) increases with depth, meaning deeper layers are stronger and more compact. Two practical equations, $su = 6.6N$ and $su = 7.5N_{60}$, were developed to estimate shear strength from field Standard Penetration Test (SPT) data. These equations can help predict soil strength when laboratory testing is limited. The study also found that the Liquidity Index (*LI*) has a negative effect on *su*, while the Plasticity Index (*PI*) has a weak positive relationship. This means that moisture content affects soil strength more than plasticity. In addition, a strong positive correlation was found between *su* and Young's modulus (*Ei* and E_{50}), showing that stiffer soils

have higher resistance to deformation. In general, the soils in Battambang have good bearing capacity and are suitable for shallow foundations. However, soil type and moisture content vary by location, so local testing is still important. Future studies should include more data from other provinces and use advanced tests to improve the accuracy of soil strength prediction in Cambodia.

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