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Development of SPT and DCPT data Correlations for Foundation Design in Phnom Penh Capital City of Cambodia.

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Abstract: *The Standard Penetration Test (SPT) and Dynamic Cone Penetration Test (DCPT) are widely used in geotechnical site investigations to evaluate subsurface soil properties and foundation design parameters. In Cambodia, particularly within Phnom Penh Capital City, DCPT is often preferred for its simplicity and low cost, while SPT remains the standard reference test for design. However, the lack of reliable local correlations between SPT and DCPT results limits the practical application of DCPT data in engineering design. This study aims to develop empirical correlations between SPT-N_{60} and DCPT-N_{10} values for the typical soil conditions of Phnom Penh. Data SPT and DCP were collected from multiple boreholes where both tests were performed under the same site located about 0.5m from eachother. Statistical regression analyses were conducted to establish relationships between the two penetration resistance values, considering variations in soil type and depth. The results indicate strong linear and power-type correlations, with the coefficient of determination (R^2) ranging between 0.80 and 0.85 depending on soil classification. The developed equations allow the estimation of SPT-N_{60} values directly from DCPT-N_{10} data, providing a practical tool for foundation design in areas where only DCPT results are available. These local correlations contribute to more cost-effective and reliable geotechnical assessments within Phnom Penh's urban environment.*

Keywords: SPT; DCPT; correlation; foundation design; Phnom Penh; geotechnical engineering

1. INTRODUCTION

The study was conducted within Phnom Penh Capital City of Cambodia, the great socio-economic importance to the Kingdom of Cambodia, which was founded in 1431, immediately after the Khmer kings abandoned Angkor [10]. The rapid urban development has intensified the need for reliable and cost-effective subsurface investigations. The reliability of foundation design in geotechnical engineering depends heavily on accurate assessment of subsurface soil properties. Among the field investigation methods available, the Standard Penetration Test (SPT) and the Dynamic Cone Penetration Test (DCPT) are two of the most commonly used techniques to evaluate in-situ soil strength and resistance. The SPT, standardized under ASTM D1586, provides an index value, N_{60}, which has been extensively correlated with a variety of engineering parameters such as bearing capacity, relative density, and undrained shear strength. While the SPT remains the standard test for foundation design, it requires drilling equipment, trained personnel, and higher costs, which can be restrictive for small-scale or preliminary projects. In contrast, the DCPT, standardized under German (DIN) Standard, is a simpler and more economical test that measures dynamic resistance to cone penetration by recording the number of blows required to drive a cone a specified distance into the soil. The DCPT, on the other hand, can be conducted quickly and inexpensively, even in areas where borehole drilling is limited. Despite its advantages, DCPT data cannot be directly applied to design without conversion to equivalent SPT values due to differences in test energy, equipment configuration, and soil response.

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Globally, several studies have proposed empirical relationships between SPT-N_{60} and DCPT-N_{DCPT} values. These correlations, however, are highly dependent on local soil types, moisture conditions, and testing procedures. Correlations developed for soils in other regions, such as Thailand, Malaysia, or India, may not accurately represent the soft alluvial and floodplain deposits typical of Phnom Penh. The absence of locally calibrated relationships leads to uncertainty when using DCPT data for design, potentially resulting in either conservative or unsafe foundation estimates.

To address this gap, the present study focuses on developing local empirical correlations between SPT-N_{60} and DCPT-N_{10} results for Phnom Penh soils. Field data were collected from several sites across the city where both SPT and DCPT tests were conducted at comparable depths. The correlation between the two penetration resistance values was analyzed through statistical regression, with emphasis on the effects of soil type and depth. The derived relationships aim to enable engineers to convert DCPT-N_{10} results into equivalent SPT-N_{60} values, thereby allowing the use of established SPT-based design methods when only DCPT data are available.

The objectives of this study are as follows:

1. To collect and compile paired SPT and DCPT data from representative sites within Phnom Penh Capital City.
2. To analyze and establish empirical correlations between SPT-N_{60} and DCPT-N_{10} for different soil types.
3. To assess the applicability of the developed correlations in estimating foundation design parameters such as allowable bearing capacity.
4. To provide practical recommendations for the use of DCPT in routine geotechnical investigations in Phnom Penh.

The outcomes of this research are expected to enhance the efficiency and reliability of subsurface investigations in Cambodia, especially in Phnom Penh capital city. By developing locally validated correlations, the study contributes to cost-effective foundation design practices while ensuring engineering safety and consistency in urban construction projects.

2. LITERATURE REVIEW

2.1 Overview of In-Situ Penetration Tests

In-situ penetration tests are widely used in geotechnical engineering to evaluate soil resistance and strength characteristics directly in the field. Among these, the Standard Penetration Test (SPT) and the Dynamic Cone Penetration Test (DCPT) are the most common due to their simplicity and practical usefulness. The SPT, introduced in the early 20th century and standardized under ASTM D1586, involves driving a split-spoon sampler into the soil using a 63.5 kg hammer dropped from a height of 760 mm. The test result, known as the SPT-N value, represents the number of blows required to penetrate a depth of 300 mm after an initial seating drive of 150 mm. Corrections are applied to account for hammer energy efficiency, borehole diameter, rod length, and sampler type, resulting in the standardized SPT-N_{60} value.

The DCPT, standardized under German (DIN) Standard and ASTM D6951, operates on a similar principle but uses a solid steel cone (typically 60° apex angle) driven by a lighter hammer (10 kg) dropped from a height of 500mm to 575 mm. The DCPT-N_{DCPT} value corresponds to the number of blows required to drive the cone a specified distance, commonly 100 mm (DCP-N_{10}) or 300 mm (DCP-N_{30}), depending on local practice. Unlike the SPT, the DCPT can be performed rapidly without borehole drilling, making it highly economical and suitable for preliminary or small-scale projects.

2.2 Correlation Between SPT and DCPT

Numerous studies have beed performed to developed SPT-DCPT correlation in the past [2, 5, 6， 7, 8], and [8]. Various efforts have also been made to utilize the Dynamic Cone Penetrometer Test (DCPT) in estimating the allowable bearing capacity of shallow foundations. Numerous studies have attempted to correlate SPT-N_{60} values with DCPT-N_{DCPT} results to facilitate the use of DCPT data in engineering design. These correlations are typically empirical and site-specific, reflecting the influence of soil type, moisture content, density, and equipment differences.

Spyropoulos et al., (2025) was among the recently study to establish a relationship between SPT (N_{60}) and DCPT (N_{10}) values in Sandy soil, proposing that $N_{60} = 0.4658 \times N_{10} - 0.0807$.

Ampadu et al., (2018) established a relationship between NSPT and NDCP value in fined grained soil (above ground water level), proposing that:

$N_{SPT} = 0.216N_{DCP} + 7.76$.

Batuge et al., (2025) was also the recent finding who establish a relationship between SPT (N) and DCPT-N_{10} values in Sandy soil, proposing that $N = 1.61 \times N_{10} - 2.94$.

From these previous finding showing that the local calibration is essential, as differences in cone geometry, hammer energy, and soil fabric can produce large deviations from published correlations.

2.3 Factors Affecting Correlations

The accuracy of SPT–DCPT correlations depends on several variables:

- Soil Type and Grain Size: Cohesive soils such as clay tend to absorb energy, leading to lower penetration resistance compared to granular soils.
- Moisture Content and Saturation: High groundwater levels reduce penetration resistance by increasing pore pressure, particularly in soft clays and silts.
- Test Energy and Equipment Efficiency: Variations in hammer weight, drop height, and cone angle directly influence energy transfer to the soil.
- Depth and Overburden Pressure: Penetration resistance generally increases with depth due to confining pressure effects, although sensitivity in soft clays may cause irregular trends.

These factors imply that correlations developed for one region cannot be reliably applied elsewhere without proper adjustment or verification through local field data.

2.4 Summary of Research Gaps

From the review above, it is evident that:

1. Existing SPT–DCPT correlations vary widely and are highly site-specific.
2. No published studies currently provide empirical correlations for Phnom Penh soils.
3. There is a need for reliable, locally derived equations to improve the practical use of DCPT data for foundation design in Cambodia.

This study addresses these gaps by developing new empirical relationships between SPT-N_{60} and DCPT-N_{10} based on field data collected from multiple sites across Phnom Penh. The proposed correlations aim to serve as a practical tool for converting DCPT data into equivalent SPT values suitable for use in design calculations.

2.5 Geological and Geotechnical conditions of Phnom Penh area

Phnom Penh located in the southern part of Cambodia and it is situated at the confluence of the Mekong River, Bassac River and Tonle Sap River. Phnom Penh is situated on an extensive floodplain characterized by low relief and elevations generally ranging between 5 and 12 meters above mean sea level. The city has experienced rapid urban development over the past two decades, resulting in extensive construction of high-rise buildings, roads, and infrastructure on soft alluvial deposits. Understanding the geological and geotechnical characteristics of these deposits is therefore critical to ensure safe and economical foundation design.

Touch et al. (2014) characterized the subsoils of the Phnom Penh area into three parts, namely, the western, central and eastern parts. The subsoils of the western part mainly comprise of stiff to very stiff clay approximately 6-7 m thick overlying medium dense to very dense sand. The upper soil layers of the central part are a sequence of made ground, very soft to very stiff clay and hard silt with total thicknesses of about 27 m. Medium dense to very dense sand and stiff to very stiff clay layers can be found below the aforementioned soil layers. The eastern part consists of soft clay and silt layers 12 m thick. These soil layers are underlain by medium dense to very dense sand down to depths of 25-30 m [9]. The groundwater table is typically encountered between 1.0 and 3.0 meters below the surface, depending on season and local drainage.

3. METHODOLOGY

3.1 Overview

The methodology adopted in this study involves systematic collection, processing, and analysis of paired Standard Penetration Test (SPT) and Dynamic Cone Penetration Test (DCPT) data obtained from multiple geotechnical investigation sites within Phnom Penh Capital City. The overall procedure consisted of four major stages:

1. Data collection and site selection
2. Normalization and correction of field data
3. Statistical correlation and regression analysis
4. Evaluation of the developed correlations

The goal of this approach is to establish reliable empirical equations that relate DCPT-N_{10} values to SPT-N_{60} values, accounting for local soil characteristics and stratigraphic variations.

3.2 Data Collection and Site Selection

Data were collected from four (4) geotechnical investigation sites (5 paired bore holes of SPT and DCPT) located across the central, southern, northern, and west zones of Phnom Penh, including areas such as Khan Chroy Changvar, Khan Sensok, and Khan Chbar Ampov (Fig. 1). These areas were selected to represent a wide range of soil types typical of the city's alluvial deposits.



Fig. 1. Map showing the locations of investigated sites.



Fig. 2. SPT and DCP data collection at the site.

At each site, both SPT and DCPT tests were conducted at adjacent boreholes (0.5 m apart) to ensure consistent soil conditions. The tests were performed following standard procedures as outlined in ASTM D1586 for SPT and German (DIN) Standard for DCPT.

- SPT Equipment: Standard 63.5 kg hammer with 760 mm drop height, using a split-spoon sampler.
- DCPT Equipment: 10 kg hammer with 500 mm drop height and a 60° steel cone of 20 mm base diameter.

The SPT was typically performed at 1.5 m intervals within boreholes, while the DCPT was recorded at 0.1 m depth increments. A total of approximately 40 paired data points were compiled from all sites.

3.3 Data Processing and Normalization

3.3.1 Geotechnical Characteristics

Laboratory test results from selected sites indicated the following average soil properties:

- Moisture content (w): 13%–21% for sand; 12%–40% for lean clay.
- Liquid limit (LL): 31%–58% for clays; 22%–37% for silts clay and clayey sand.
- Plasticity index (PI): 10%–29% for cohesive soils.
- Bulk unit weight (γ): 15.71–21.36 kN/m³.

For this study, soil classification was performed using results from borehole logs, grain size analyses, and Atterberg limits tests following the Unified Soil Classification System (USCS). The soils in Phnom Penh were generally classified into three main groups:

- Cohesive soils (CL and CH): Medium to high plasticity clays, predominant in central and low-lying areas.
- Cohesionless soils (SM, SC, and SP): Silty sand and sands, typically found at intermediate to greater depths.
- Mixed soils (CL-ML): Transitional layers containing both silty and clayey components.

These classifications were used to differentiate soil behavior in the correlation analysis between SPT and DCPT results.

3.3.2 SPT Data Correction

The raw SPT-N values were corrected for hammer energy, borehole diameter, rod length, and sampler type to obtain the normalized SPT-N_{60} values using the standard correction equation:

$$N_{60} = \frac{N\eta_H\eta_B\eta_s\eta_R}{60}$$

where:

- N_{60} = standard penetration number corrected for field condition (Blow)
- η_H = hammer effieciency (%)
- η_B = borehole diameter correction factor
- η_S = sampler correction factor
- η_R = rod length correction factor

For this study, typical energy efficiency of **60%** was assumed for the SPT system, consistent with local practice.

Table 1. Variations of η_H, [3]

Country	Hammer type	Hammer release	η_H (%)
Japan	Donut	Free fall	78
	Donut	Rope and pulley	67
United State	Safety	Rope and pulley	60
	Donut	Rope and pulley	45
Argentina	Doute	Rope and pulley	45
China	Donute	Free fall	60
	Donute	Rope and pulley	50

Table 2. Variation of η_B

Diameter (mm)	η_B
60 - 120	1
150	1.05
200	1.15

Table 3. Variation of η_S

Variable	η_S
Standard sampler	1.0
With liner for dense sand and clay	0.8
With liner for loose sand	0.9

Table 4. Variation of η_R

Rod length (m)	η_S
> 10	1.0
6 - 10	0.95
4 - 6	0.85
0 - 4	0.75

3.4 Data Pairing and Classification

SPT and DCP data were collected from 5 different hole at different site in Phnom Penh capital city. The SPT and DCPT data were paired based on equivalent depth intervals (±0.25 m). Each data pair was classified according to soil type, determined from borehole logs and laboratory testing. The dataset was divided into three main categories:

1. Medium stiff to very stiff lean clay (CL)
2. Medium dense to dense Sand (Poorly Graded SAND, SP)
3. All Soil Types (Mixed soils)

This classification allowed separate correlation analysis for different soil groups, improving reliability and reducing variability caused by differing soil behaviors.

4. RESULTS AND DISCUSSION

Finally, based on the established correlations, conversion charts and nomograms were prepared to allow quick estimation of SPT-N_{60} values from DCPT results in the field. These charts were designed for practical use by local engineers in Phnom Penh to support preliminary foundation design when only DCPT data are available (Fig. 3, 4, and 5).

The relationship between SPT-N_{60} and DCPT-N_{10} was analyzed using regression analysis. Both linearm and Power-type regression models were evaluated base on the best fit correlation:

For **Medium stiff to very stiff lean clay (CL):**

1. Linear model: $N_{60} = 0.703 \times N_{10} - 1.2636$
2. Power model: $N_{60} = 0.4083(N_{10})^{1.1388}$

For **Medium Dense to Dense Sand (SP):**

1. Linear model: $N_{60} = 0.9731 \times N_{10} - 3.3293$
2. Power model**:** $N_{60} = 0.3894(N_{10})^{1.2317}$

For **all soil types:**

1. Linear model: $N_{60} = 0.8282 \times N_{10} - 2.3398$
2. Power model**:** $N_{60} = 0.3737(N_{10})^{1.2317}$

Where:

N_{60} = standard penetration number corrected for field condition (Blow).

N_{10} = Number of DCP hammer blow for 10cm penetration.

The strength of each correlation was evaluated using the coefficient of determination (R^2). Separate regression analyses were conducted for each soil category to obtain representative equations.

The developed correlation between SPT-N_{60} and DCPT-N_{10} values for Phnom Penh subsoils showing that a strong relationship exists between both parameters. Using regression analysis were obtained with an associated coefficient of determination in the rank of $R^2 = 0.80$ to 0.85.

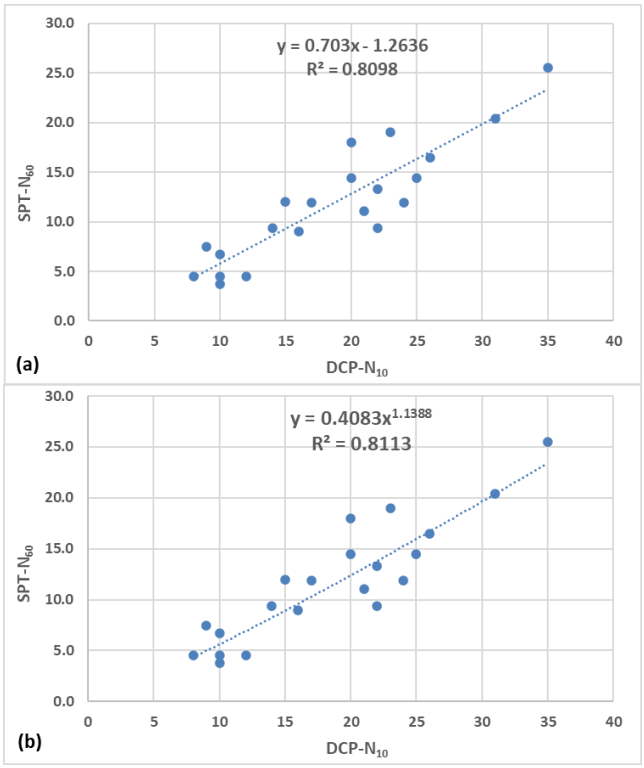


Fig. 3. Plot of SPT-N_{60} versus DCP-N_{10} for Medium Stiff to very Stiff Lean Clay (CL). (a): Linear model, (b): Power model.

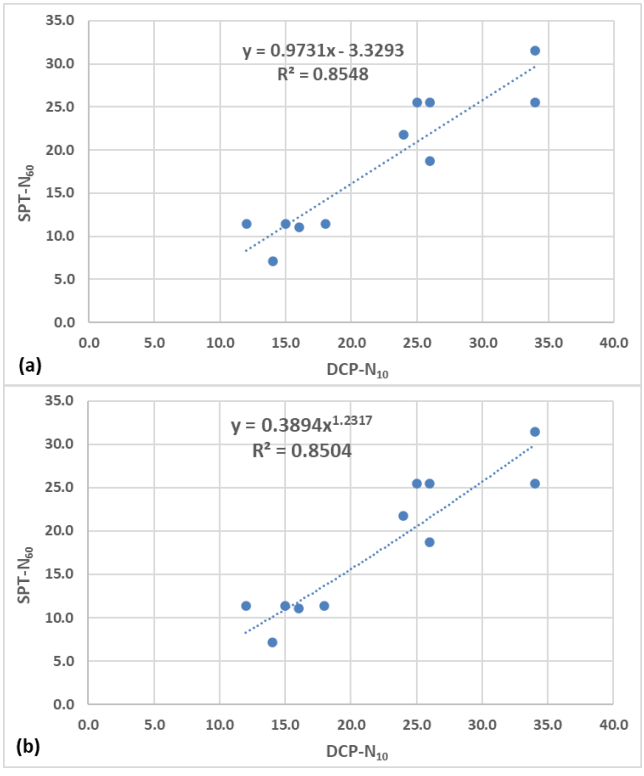


Fig. 4. Plot of SPT-N_{60} versus DCP-N_{10} for Medium to Dense Sand (SP). (a): Linear model, (b): Power model.

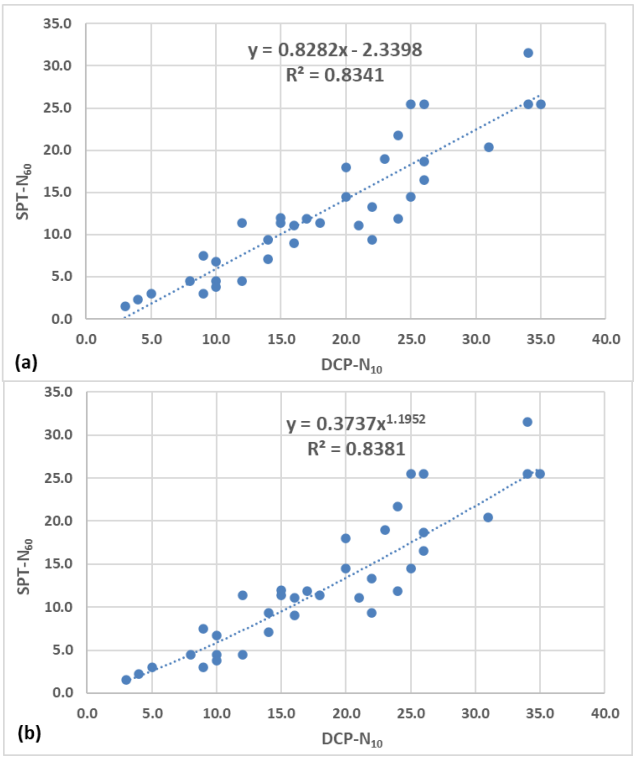


Fig. 5. Plot of SPT-N_{60} versus DCP-N_{10} for all soil types. (a): Linear model, (b): Power model.

5. CONCLUSIONS AND RECOMMENDATION

In this study, SPT and DCPT tests are carried out side by side on several sites in Phnom Penh and a site-specific correlation is developed between SPT-N_{60} and DCPT-N_{10} for Phnom Penh soils. It has been shown that a strong correlation exists between the parameters considered with an associated coefficient of determination in the rank of $R^2 = 0.80$ to 0.85.

These correlations will be of benefit for site investigations where the number of boreholes drilled to obtain SPT-N values can be reduced and supplemented with DCP tests thus saving cost. For sites where budget is limited and the foundation is expected to be shallow, the DCP test can provide basic information for foundation design.

Due to the limitations and simplified assumptions in DCPT-based correlations for estimating allowable bearing capacity, it is recommended to use SPT-based methods for bearing capacity evaluation. This can be achieved by first converting DCPT values into equivalent SPT values using the established correlations, and then applying SPT-based approaches for bearing capacity evaluation.

Validation on the proposed empirical correlations shall be conducted for further research.

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