Empirical SPT-CPT correlation for soils from Lahore, Pakistan

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Abstract. Standard Penetration Test (SPT) and cone penetration test (CPT) are the most widely used in situ tests to depict the soil stratigraphy and determine the geotechnical engineering of the subsurface soils. The CPT leaps out because of its capability to trace the resistance continuously and due to its accuracy, it is considered to be reliable than the SPT. The outcome of these tests is very important for the design procedures to be implemented for various geotechnical purposes. To effectively utilize all the available data, there is a need of updating the correlation between these two widely used in situ tests. This study implements the statistical linear regression model using a 107 SPT and 49 CPT measurements across the city of Lahore, Pakistan to develop correlations between the the uncorrected SPT blow counts (N) and cone resistance (qc) for various soils. The developed correlation is compared in terms of qc/N ratios with the previous published studies.
Keywords. Empirical SPT-CPT, correlation, Lahore Pakistan

1. Introduction

Standard Penetration Test (SPT) is the widely used in-situ test in Pakistan and around the world for geotechnical investigations. It is also common practice in Pakistan to design most of the foundations based on SPT-N values and soil physical properties. The SPT-N values is empirically correlated with most of engineering properties of the soil. Despite of the most common and economic mean of subsurface investigation SPT has disadvantage such as potential inconsistency of measured resistances depending on operator inconsistency and possibility of missing delicate changes of soil properties due to the unavoidable discrete record.

On the other hand, Cone Penetration Test (CPT) also leaps out because of its capability to trace the resistance continuously. Currently CPT is also in practice to be used as in situ test for geotechnical investigations and design [1]. Most of the geotechnical engineers are well versed in foundation design using soil parameters correlated to SPT-N value.

It is common at many of the construction projects to use Standard Penetration test for estimation of soil parameters at preliminary design stage, whereas static cone penetration test results are used for final design and construction quality control, or vice versa. For effective utilization of the available database of field performances and property correlated with SPT, it is valuable to correlate static cone tip resistance-qc to SPT N-value. Therefore, in those cases where only SPT results are available, engineers, who are more familiar with CPT interpretations, will translate the SPT blow counts (N-values) into CPT cone resistances (qc-values).

A considerable amount of studies has been taken place over the years to correlate SPT N-value and CPT cone resistance qc. Most of the correlations are based on a constant value of qc/N while some other defined n=qc+fs /N for different soil types. Some researchers suggest n=qc/N as a function of mean grain size [2-5] or the fines content [3, 6-8].

Now the SPT-CPT database is gradually increasing in Pakistan, however, SPT-CPT correlation for the local soil conditions are not published. In this study, empirical SPT-CPT correlations for various local soil conditions are proposed.

2. Data Collection

In this study in-situ tests (SPT & CPT) data of Orange Line Metro Train Project, Lahore has been used. Orange Line Metro Train is a rapid transit line built as part of Lahore Metro, Pakistan. This orange metro line is 27.1 km in length, out of which 25.4 km is elevated, while 1.72 km is constructed bellow the ground surface, and transition zone between elevated and underground sections is 0.7 km. The location plan of the area under study is given in Figure 1.

To delineate the subsurface soil a total of 109 SPT and 49 CPT tests were conducted along the project route. The SPT was performed at one-meter interval ranging up to a maximum depth of 50 m and CPT soundings were recorded at each 10 cm interval up to 20 m depth below NSL. Sieve analysis tests were performed on the samples collected in SPT sampler while the CPT data were interpreted in term of Soil Behavior Type (SBT) as proposed by Lunne et al. and Robertson et al. [9, 10]. Sieve Analysis and SBT shows that four types of soil exist along the project route, which are Lean Clay, silty Clay, Clayey Silt and Silty Sand.

In CPT reading is collected for every .01m while performing SPT at each meter only one SPT – N value was collected for 0.5m. Therefore, CPT results have been averaged for 0.5m at every meter depth to make it compatible to SPT results. While choosing the level for CPT tip resistance, the first thing considered was the depth at which SPT was performed. The correlation between SPT N-value and CPT tip resistance was then established for each 0.5m up to the maximum depth of CPT sounding (20 m)

Five hundred and thirty-eight (538) data pairs (N and qc) were available to establish correlation from forty-nine (49) CPT soundings and SPT points.

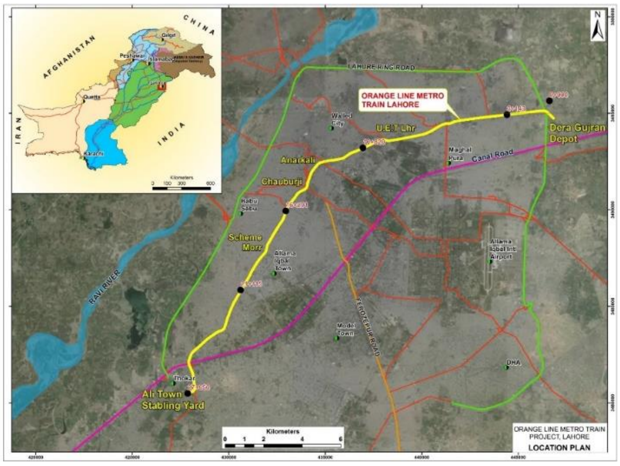

Figure 1. Location Plan of Orange Line Metro Train Project, Lahore, Pakistan [11]

3. Methodology Adopted for Data Processing and proposed correlation

Each type of soil identified along the project route has been separated and correlation was developed. Four soil types have been identified along the project route as Silty Sand, Sandy Silt, Silty Clay and Lean Clay.

Other soil types were regarded infrequent, and if present, they consisted of thin layer. Techniques adopted for calculation of n (qc/N) value is discussed as below:

3.1. Calculation of n ratio

For each soil type as identified along the project route the available data (q_c and N) were combined and n (q_c/N) was calculated, Table 1 summarizes the range of CPT (q_c) and SPT (N) value observed at the project site. The method of arithmetic average is then applied for final calculation of n-value (qc/N) and summary of the result is given in Table 2.

Table 1. Range of SPT-N Value and CPT-q_c

Soil Type	SPT-N Value		CPT q_c Value (MPa)	
	Min	Max.	Min	Max.
Silty Sand	4	50	2.258	20
Sandy Silt	5	37	0.97	17.40
Silty Clay	4	45	0.06	16.95
Lean Clay	5	33	0.164	11

Table 2. Arithmetic Average Method Results

Soil Type	Total No. of Pairs (No. of n_f)	$\sum n_1$ ($n_1=q_c/N$)	$\sum n_1$/(No.of n_f)	n value
Silty Sand	385	159.7	159.70/385	0.41
Sandy Silt	33	11.37	11.37/33	0.34
Silty Clay	85	27.00	27/85	0.32
Lean Clay	33	9.934	9.934/40	0.30

3.2. Proposed correlations

Linear regression is performed to establish a correlation between SPT and CPT. For analysis a line q_c = nN with zero intercept has been adopted using least squares method to establish a linear relation. Correlations were established for all the selected soil cases. the correlations are shown in **Error! Reference source not found.** to Figure 5. The relations along with the correlation coefficients are tabulated in Table 3. Proposed correlations are also compared with the literature and the q_c/N values comparison can be seen in

Table ***4***.

Table 3. Proposed correlations

Soil Type	Correlation Equation	Correlation Coefficient (R^2)
Silty Sand	$q_c = 0.427N$	0.303
Sandy Silt	$q_c = 0.337N$	0.438
Silty Clay	$q_c = 0.319N$	0.604
Lean Clay	$q_c = 0.291N$	0.602

Table 4. Comparison of proposed qc/N values with the literature

Authors	Soil Type	Proposed	This study
De Alencar Velloso (1959) [12]	Clay and silty clay	0.35	-
	Sandy clay and silty sand	0.2	0.43
	Sandy silt	0.35	0.34
Franki Piles (1960) [13]	Silty sand	0.5	0.43
	Sandy clay	0.4	0.34
	Silty clay	0.3	-
	Clays	0.2	0.29
Schmertmann (1970) [14]	Silt, sandy silt and silt-sand mix.	0.2	0.34
	Fine to medium sand, silty sand	0.3-0.4	0.43
	Coarse sand, sand with gravel	0.5-0.6	-
Akca (2003) [13]	Silty sand	0.702	0.43
	Sandy silt	0.58	0.34
Robertson (1986) [15]	Silty sand	0.3-0.4	0.43
Danziger and De Valleso (1995) [16]	Fine to medium sand, Silty sand	0.3-0.42	0.43

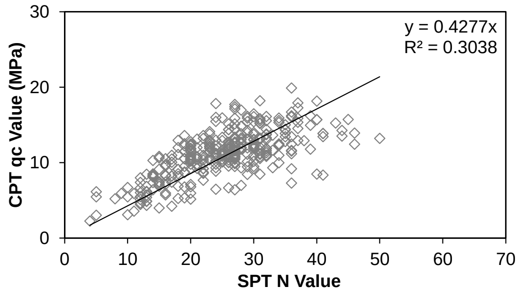

Figure 2. q_c and N relationship for sity sand

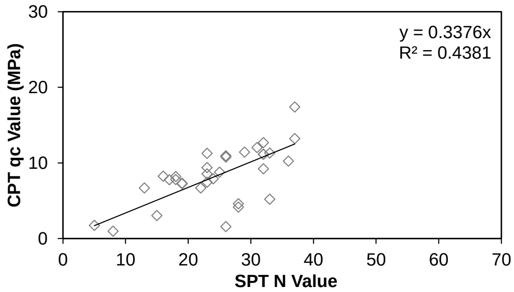

Figure 3. q_c and N relationship for sandy silt

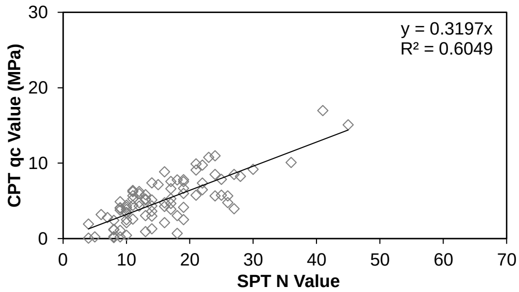

Figure 4. q_c and N relationship for silty clay

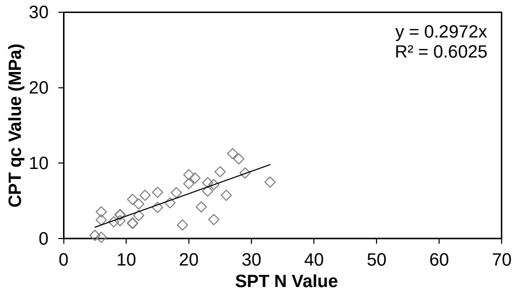

Figure 5. q_c and N relationship for Lean clays

3.3. Discussions

It can be seen in the comparison Table 4 that the results of the current study are within the range of the available correlations in the literature. In fact, the qc/N ratios matches well in most of the cases except those of Akca [13], which are larger comparing with this study. This can be described by the fact that the values proposed by Akca [13] are for the soils which have cemented layers and most of the times showing bands of gypsum and gravel. Presence of stiff bands in those soils could be the reason of difference between the values proposed in current study and those proposed by Acka [13].

4. Conclusions

This paper presents the correlation for different soil types from Lahore Pakistan using arithmetic average method and linear regression. In the studied area, the soil types found are Silty Sand, Sandy Silt, Silty Clay and Lean Clay. The qc/N ratios from the developed correlations have been compared with the previously proposed correlations available in literature. The comparison show that the correlations developed in this research are in good agreement for fine grained soils while it show a little variation for coarse grained soils.

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