Evaluation of tip resistance variation with standard penetration index in Trinidad

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ABSTRACT
Most of empirical correlations used by engineers to estimate geotechnical parameters are based upon standard penetration index N. However, with the increasing use of CPTu testing in major projects, comparison between CPTu results and N_{SPT} is becoming more and more crucial. Several publications were submitted over the last decades, but few regard such correlations in Caribbean soils. During last decade, LVM carried out several geotechnical site investigations using both CPTu and SPT tests simultaneously in this area. Comparison of some selected results will be presented in this paper. First, gathered data will be compared to acknowledged correlations between tip resistance value (q_c) of piezocone tests and standard penetration index (N_{SPT}). Further, specific algorithms relating CPTu and N_{SPT} data will be suggested for the investigated soils. Statistical treatment of the field data and accuracy of the algorithm will be also presented.

RÉSUMÉ
La plupart des corrélations utilisées par les ingénieurs pour estimer les propriétés géotechniques des sols se basent sur l'indice de pénétration standard N_{SPT}. Cependant, dans la mesure où le pénétromètre statique (piézocône) est de plus en plus utilisé dans les projets d'envergure, une comparaison fiable entre les résultats obtenus avec celui-ci et l'indice de pénétration standard N_{SPT} devient cruciale. Plusieurs publications font état de cette relation, mais peu concernent les sols rencontrés dans les Caraïbes. La firme LVM a réalisé plusieurs campagnes d'investigation dans ces pays au cours des dernières années, en utilisant les deux procédés. Les résultats de quelques-unes de ces études sont présentés ici. Tout d'abord, les données obtenues sont comparées aux corrélations reconnues qui relient la résistance en pointe (q_c) et l'indice de pénétration standard (N_{SPT}). Par la suite, une relation spécifique entre ces deux termes est proposée pour les sols à l'étude. Une analyse statistique des données de terrain et de la fiabilité de l'équation proposée sont également présentées.

1 INTRODUCTION

Nowadays, cone penetration testing (CPT) and/or standard penetration testing (SPT) are deployed during geotechnical campaigns for major projects. Both methods are standardized (CPT ASTM D 3441-05, Standard Test Method for Mechanical Cone Penetration Tests of Soil; SPT ASTM D 1586-08, Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils). Design calculation methods are related to one or another investigation method in handbooks. However, when both tests are not run in parallel on one same site, correlations between the two are crucial for the geotechnical engineer.
Several publications in the last decades have compared cone resistance q_c, obtained with piezocone testing, to standard penetration index N_{SPT}. Few regard the use of piezocone instrument in the Caribbean for geotechnical purposes, and none present relations between N_{SPT} and q_c in the soils encountered in Trinidad.
The existing correlations are re-examined in this paper by using the collected data from various soundings carried out in Trinidad Island. Some alternative correlations are proposed for the specific soils encountered on Trinidad Island.

It should be mentioned that local geotechnical firms in Trinidad are not presently equipped to carry out CPT tests. Therefore, the correlations between q_c, N_{SPT} and grain size distribution become valuable, if proved accurate.

2 SHORT LITERATURE REVIEW OF EXISTING CORRELATIONS

Robertson & al. (1983), Kulhawy & Mayne (1990), Jefferies & Davis (1993), and Bustamante & Gianeselli (1993) to name only them present various relationships between the tip resistance q_c and the blow count N_{SPT}. The correlations relate either the direct penetration standard index N (field measured N_{SPT}) or the corrected index N_{60} (N_{SPT} corrected for a 60% energy ratio) and the tip resistance q_c to the mean particle size D_{50} or the fines content (percent passing No. 200 Sieve screen). Of course, these relations suppose that soil behaviour is characterized only by average particle size, which is not completely accurate.
Kulhawy and Mayne (1990) presented a model for evaluating the ratio (q_c/Pa)/N (tip resistance rationalized to atmospheric pressure (Pa = 1.01 bar) over N_{SPT}) to mean particle size D_{50}. Figure 1 is a reproduction of figure 2-30 from Kulhawy & Mayne (1990).

Figure 1 regroups the original correlation between mean particle size suggested by Robertson & al. (1983), as well as additional data from several authors. It clearly appears that ratio (q_c/Pa)/N increases with increasing the mean particle size. However, the dispersion of plots increases for coarser materials (sand and gravel).

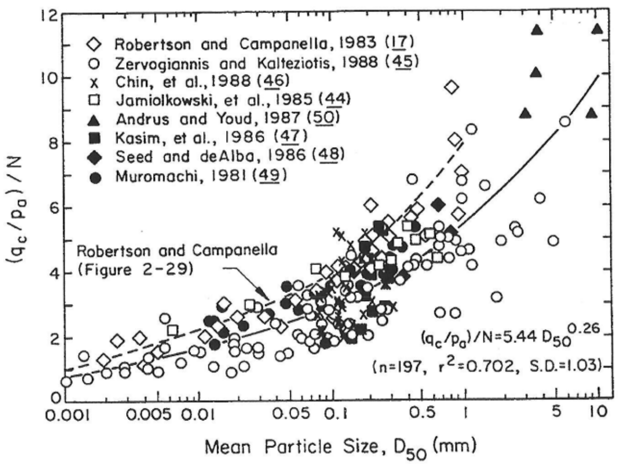

Figure 1. CPT-SPT correlation with grain size (reproduction from Kulhawy & Mayne (1990)).

Another model, still proposed by Kulhawy & Mayne (1990), relates (q_c/Pa)/N_{60} to the fines content (see figure 2).

The same dispersion for sandy and gravelly materials is observed. A general tendency in redaction of (q_c/Pa)/N ratio is noted when the fines content increases.

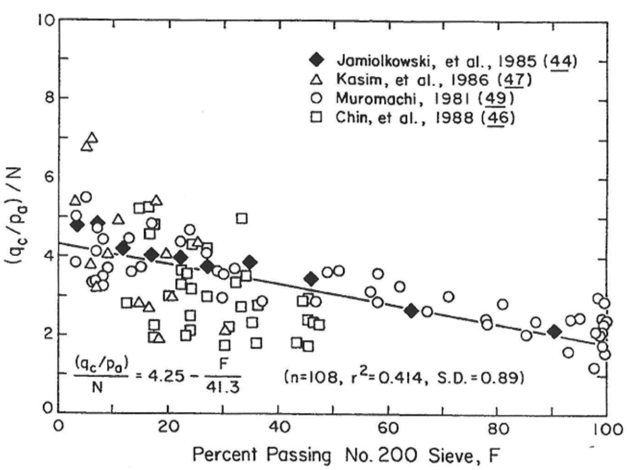

Figure 2. CPT-SPT correlation with fines content (reproduction from Kulhawy & Mayne (1990)).

The data provided by Kulhawy & Mayne do not define if an energy ratio correction was applied to the blow count before plotting (i.e. use of N_{60} instead of in situ N_{SPT} values). The data from Robertson & al (1983) correspond to an energy ratio of about 60% (i.e. use of N_{60}).

3 TRINIDAD GEOLOGICAL CONTEXT

Unlike most islands of the Lesser Antilles which are of volcanic composition, Trinidad originates from sedimentary units and metamorphism. The northern plain is a basin (syncline) and is a low-lying area of river terraces of gravelly sands and clays, alluvial plains (lenticular silty clays and silty sands) and swamp deposits (soft peaty soils and mixture of silt and clay). The Central Range is primarily made up of clays, shale and marls. The central part is predominantly underlain by soft clay and silt deposits, and the southern range area presents clayey highly plastic soils with a high percentage of Montmorillonite (± 40%) (Expansive clays) (Ramana (1993)).

4 DATA GATHERING PROCEDURE

Cone Penetration testing was performed by Fugro Consults inc. with a Vertek-Hogentogler Cone. The apex angle of the cone was 60º and its tip area was 15 cm² for a maximal capacity of 20 t. Excess pore-water pressure generated during the test was recorded (sensor just above the tip - U2) in addition to the usual parameters (tip resistance, side friction, inclination, etc.). Rate of penetration was 20 mm/s. Boreholes was put down using auger-equipped CME-55 drills provided by local contractors (Geotech associates ltd and Trintoplan Consultants ltd). A 63 kg hammer (manual) was used, for a free fall of 760 mm (± 10%). The split-barrel had an outside diameter of 51 mm ("B" calibre).

All in situ testing (CPT or SPT) were performed following the ASTM standard. Soundings were considered comparable when performed within a distance of ± 5.0 m.

5 DATABASE PRESENTATION

Data collected at 12 locations all over the Island of Trinidad have been analysed and used for this study. Table 1 presents the general specificity of each site.

The following items were compiled for each point (sample):

- Standard penetration index N_{SPT} (in blows/300 mm of penetration; blowcount accuracy of ± 2);
- Mean tip resistance value (q_c) over the length of penetration for the considered sample;
- Standard deviation of measured tip resistance over the length of penetration for the considered sample;
- Mean normalized cone resistance (Qt) over the length of penetration for the considered sample (for classification purpose only);
- Mean friction ratio (R_f) over the length of penetration for the considered sample (for classification purpose only);
- Robertson classification (Robertson & al. (1983));
- Fines content (FC) as the percent passing No. 200 sieve (percentage of silt and clay) when lab test were carried out;

Table 1. Trinidad complete database.

Site reference	Location	General soil description	Number of comparative points	Available lab test
1	North range, western area	Alluvial plain	11	2
28	North range, western area	Alluvial plain	7	0
44	North range, western area	Alluvial plain	16	3
56	North range, western area	Alluvial plain	15	4
93	North range, western area	Swamp	18	3
324	North range, central	Terrace	22	4
384	North range, central	Terrace	22	4
418	North range, eastern area	Terrace	22	3
464	North range eastern area	Terrace	20	1
529	South range western area	Sedimentary basin	7	1
615	Middle range western area	Sedimentary basin	19	4
671	Middle range western area	Swamp	14	1
12 sites	-	-	Total : 193	Total : 30

Overlapped samples (samples recovered at the interface of two layers) were not considered in the compilation. Once these items properly tabled, for each comparative points, the corrected penetration index N_{60} was calculated with a 92% energy ratio and the Robertson classification was also established.

In order to eliminate possible inaccurate points, standard deviation (S.D.) and mean ratio (S.D. / q_c) were plotted (figure 3). Only samples for which the standard deviation is less than 20 bars and represent less than 40% of the mean tip resistance are considered in the following study. Table 2 presents the remaining population for each soil class.

Table 2. Population of soil classes.

Soil class (Robertson (1990))	Population	Population with available lab test	Mean S.D.	S.D./qc (mean value)
1 (sensitive fine grained)	1	1	-	-
3 (clay)	34	2	1.4 bars	0.1
4 (silty clay to clay)	16	2	4.2 bars	0.1
5 (clayey silt to silty clay)	29	10	2.4 bars	0.1
6 (sandy silt to clayey silt)	48	11	12.1 bars	0.1
7 (silty sand to sandy silt)	9	4	24.7 bars	0.3
-	Total : 137	Total : 30	-	-

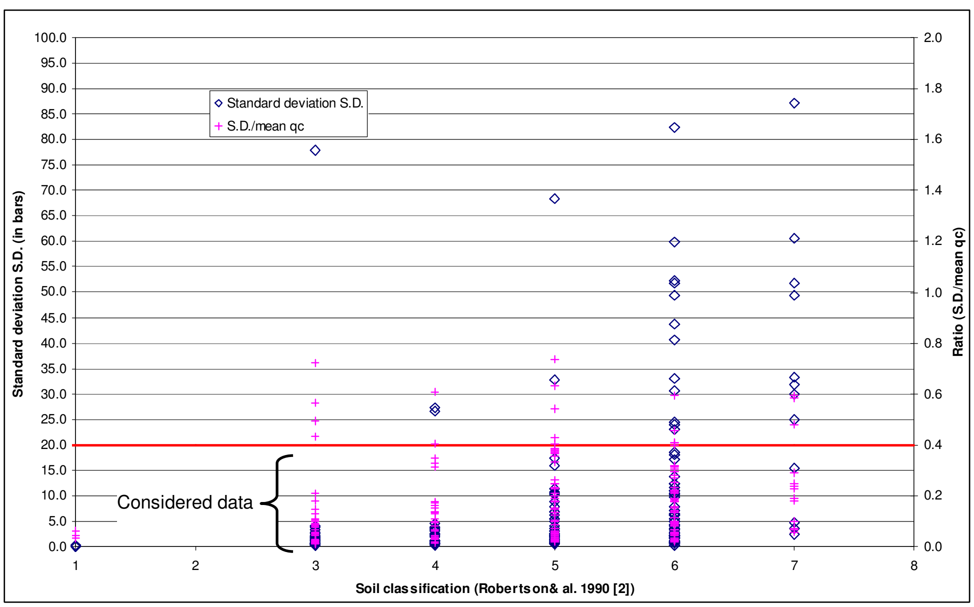

Figure 3. Standard deviation (S.D.) sorted by soil classes.

6 CORRELATION WITH MEAN PARTICLE SIZE

The equation, proposed by Kulhawy & Mayne (1990) for CPT-SPT correlation as a function of grain size, offers a correlation coefficient (R^2) of 0.702 for a population of 197 samples (figure 1).

In order to carry out a comparison, the data obtained from Trinidad were inserted in a similar plot. Results are shown on figure 4 along with the data from Kulhawy & Mayne (1990).

The general tendency of an increase in $(q_c/Pa)/N$ ratio can be observed with increase in mean particle size. However, dispersion seems to appear in silty soils containing sand and gravel.

As shown in figure 4, the existing Kulhawy & Mayne (1990) equation does not represent adequately the gathered existing data from Trinidad. Dispersion is noted for the data from Trinidad. Despite of this dispersion, a new tendency equitation is proposed in figure 4 attempting to relate the CPT-SPT data from Trinidad soils. The data dispersion is such that the available population (30 cases) shows a very low correlation coefficient (R^2) of about 0.1. For fine-grained soils, a comparison was also made with q_t (tip resistance corrected for excess pore-pressure U_2), but the variation is negligible (less than 1% of q_c value).

In situ blow counts (N_{SPT}) were used for the plotting. The verification with a corrected standard penetration index N_{60} provides the same results.

Additional testing should be performed to confirm a valuable correlation with mean particle size.

7 CORRELATION WITH FINES CONTENT

As shown in figure 2, Kulhawy & Mayne(1990) were presented a correlation for CPT-SPT data as a function of fines content. The equation, presented by Kulhawy & Mayne (1990) on figure 2 for $(q_c/Pa)/N_{60}$ a function of fines content shows a correlation coefficient (R^2) of 0.41 over a population of 108 samples.

Similarly, figure 5 shows the variation of $(q_c/Pa)/N_{60}$ as a function of fines content for data gathered in Trinidad as well as the existing correlation from Kulhawy & Mayne (1990). These plots allow a comparison between the existing and proposed regression equations.

As shown in figure 5, the correlation proposed by Kulhawy & Mayne (1990) does not give a proper representation of the variation of $(q_c/Pa)/N_{60}$ ratios as measured in Trinidad.

However, the same general tendency is noted. In the both cases, the decrease of $(q_c/Pa)/N_{60}$ ratio is obvious with increase in fines content. Moreover, the data dispersion decreases when fines content exceeds 50%.

For fine-grained soils, comparison was also made with q_t (tip resistance corrected for excess pore-pressure U_2), and it was found that the variation is negligible (less than 1% of q_c value).

A new regression equation is proposed in figure 5 for Trinidad soils. This equation shows a correlation coefficient (R^2) of 0.22.

In situ blow counts (N_{SPT}) were used for the plotting. The verification with a corrected standard penetration index N_{60} provides the similar results.

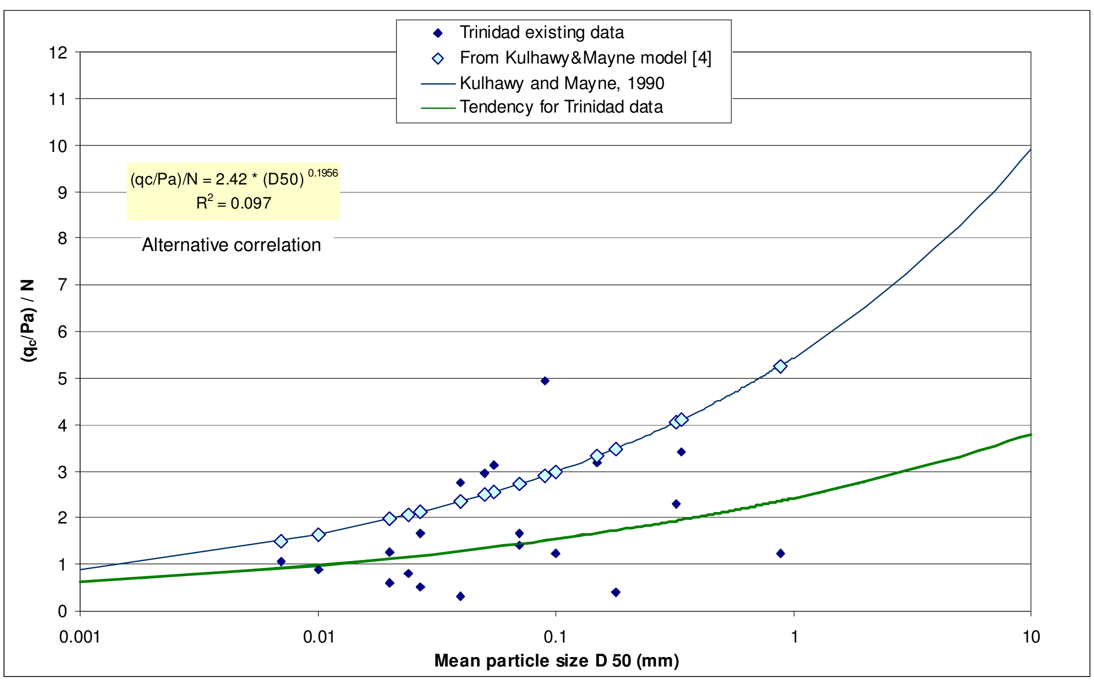

Figure 4. Variation of $(q_c/Pa)/N$ as a function of mean particle size.

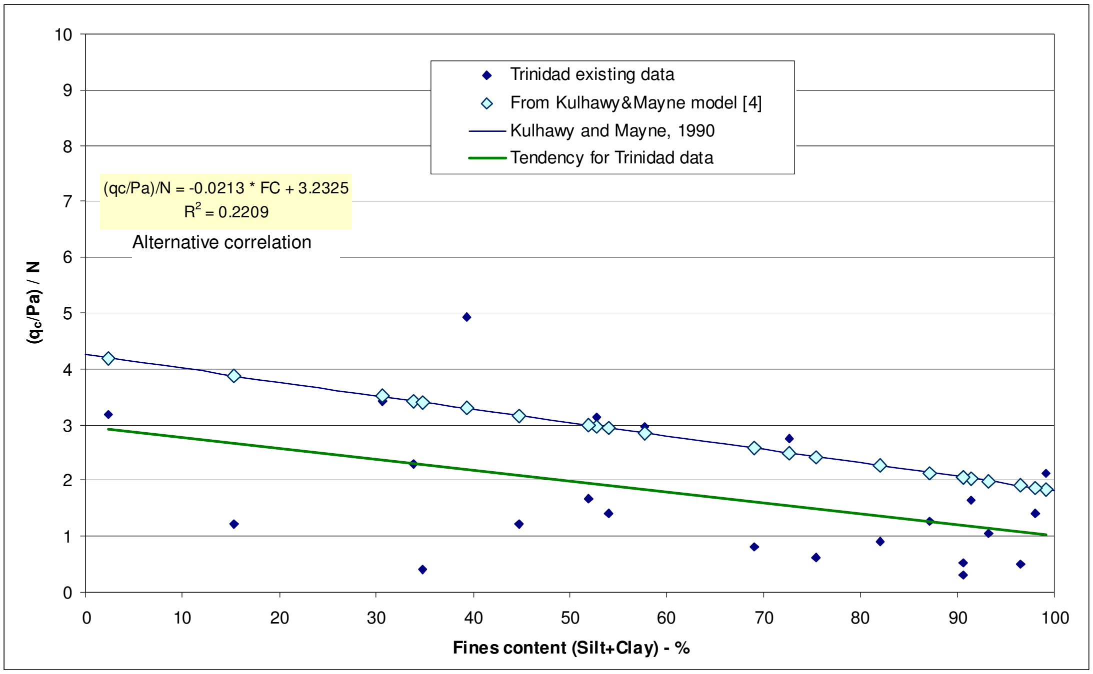

Figure 5. Variation of $(qc/Pa)/N_{60}$ as a function of fines content.

8 CORRELATION CONSIDERING SOIL CLASSES

It was shown in previous section that the correlation suggested by Kulhawy & Mayne (1990) to relate $(q_c/Pa)/N_{60}$ ratio and the fines contents does not fit those of soils present in Trinidad (30 cases plotted data in figure 5). It is very likely that other existing $(q_c/Pa)/N$ correlations not be applicable to Trinidad soils either.

One other pertinent approach is to separate data in several groups according to their soils classes and then looking for the $(q_c/Pa)/N_{60}$ ratio in each group.

This approach was used by Lunne & al. (1997) for 7 soil classes. The soil classification defined by Robertson (1990) was used for this purpose. The established ratios in this reference are shown in Table 3.

Table 3. Existing and proposed ratios of $(q_c/Pa)/N_{60}$ for various classes of soils (after Lunne& al. (1997), table 6-2).

Soil class (Robertson (1990))	Lunne & al. (1997)	*Population (total 193)*	Trinidad (q_c/Pa) / N_{60}
1 (sensitive fine grained)	2	*1*	insufficient data
3 (clay)	1	*34*	0.6
4 (silty clay to clay)	1.5	*16*	1.3
5 (clayey silt to silty clay)	2	*29*	1.7
6 (sandy silt to clayey silt)	2.5	*48*	2.9
7 (silty sand to sandy silt)	3	*9*	6.4

The data from Trinidad were compiled with the same approach in order to identify the best applicable ratio for Trinidad soils. Table 3 shows a revised series of $(q_c/Pa)/N_{60}$ ratios for Trinidad for the same soil classification.

Except for soils of class 7, the proposed ratios for Trinidad soils are close to those established by Lunne & al. (1997).

9 CONCLUSION

The existing correlations were re-examined by using the collected data from site investigations carried out in Trinidad.

Several approaches were tested on a population of 193 data samples from 12 different sites, for both cohesive and granular soils.

The compiled data showed that the existing correlations between tip resistance (q_c) and standard penetration index (N_{SPT} or N_{60}) are note quite applicable for soils on Trinidad Island. Data dispersion was noted for coarser soils.

Alternate correlations were proposed for the specific soils encountered on Trinidad Island. The same general tendency was noted for $(q_c/Pa)/N_{60}$ ratio as a function of mean grain size or fines content in the both existing and proposed correlations.

Finally, data from Trinidad were compiled in groups according to their soils classes and a series of best applicable $(q_c/Pa)/N_{60}$ ratios were suggested for Trinidad soils. The proposed ratios for Trinidad soils were generally close to those proposed by other authors.

Additional investigations are required in order to refine the proposed correlations for Trinidad soils.

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