# SPT-CPT CORRELATIONS FOR GRANULAR SOILS

by

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# SPT-CPT correlations for granular soils

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ABSTRACT: With the increasing use of the Cone Penetration Test (CPT), it would be of significant value to establish a reliable correlation between the cone tip resistance, $q_c$, and the Standard Penetration Test (SPT) blow count, N-value. Based on recent data obtained from sand deposits, a historical review on SPT-CPT correlations is presented. For sands, the $q_c/N$ ratio decreases significantly with increasing fine content. This paper suggests that the $q_c/N$ ratio can be better correlated with fine content instead of the mean grain size for granular soils. It is important for geotechnical engineers to be aware of the scatter of the $q_c/N$ ratio caused by the inherent variability of the penetration tests. The SPT N-value used to establish the local correlation should be corrected by the energy level.

## 1 INTRODUCTION

Up to the present, the Standard Penetration Test (SPT) is still one of the most commonly used in-situ tests for site investigation. Many empirical relations have been established between the SPT blow count, N-value, and other engineering properties of soils. Although geotechnical engineers use these correlations in foundation design, continued effort has been made recently for the standardization of the SPT. It is believed that the application of a measured energy correction factor will lead to more repeatability and reliability of the SPT N-value in the future (Campanella and Robertson, 1982; Kovacs and Salomone, 1982).

The Cone Penetration Test (CPT) is becoming increasingly popular for its unequalled ability to delineate soil stratigraphy and measure soil properties rapidly and continuously. Similar to the use of the SPT results, many correlations need to be established for the direct application of CPT results. Before these relations can be set up, it is very valuable to correlate the cone tip resistance, $q_c$, to SPT N-value so that the available data base of the field performances and property correlations with the N-value could be effectively utilized.

The purpose of this paper is to review some of the previous researches on the $q_c/N$ ratio and to present a correlation for granular soil between the $q_c/N$ ratio and its fine content.

## 2 HISTORICAL REVIEW

Compiling a number of studies, Robertson et al. (1983) presented the $q_c/N$ ratio as a function of mean grain size, $D_{50}$ (Fig. 1). This presentation provides a very useful guideline to convert the cone tip resistance to the equivalent N-value for soils with $D_{50}$ varying between 0.001 mm to 1 mm, namely, from clay to gravelly sand. It should be noted that each data point represents the result of one site. Energy correction of the N-value has not been applied to most of their data. Figure 1 indicates that the $q_c/N$ ratio increases with increasing mean grain size. They have also pointed out that the scatter of the $q_c/N$ ratio also increases with increasing mean grain size.

In the last few years, many research efforts have been made to establish more reliable local correlations between SPT and CPT. For example, Moh (1985) has collected many research results on the correlations between $q_c$ and N-value. In his report, the $q_c/N$ ratio for silty sand can vary between 3 and 6 as proposed by different researchers.

It is interesting to note the results presented by Kasim et al. (1986) on naturally and hydraulically filled sand in Alameda, California, USA. In Fig. 1, each data point of their results is based on one energy corrected SPT blow count ($N_{55}$) and its corresponding $q_c$ and $D_{50}$. The Alameda data show that the curve suggested by Robertson et al. (1983) is a good average, but the scatter around this average is significant. For the mean grain size varying between 0.14 mm and 0.28 mm, the $q_c/N$ ratio ranges from 2 to 7. It is also noted that the standard deviation of $D_{50}$ is relatively small, yet the fine content of these sandy materials varies significantly.

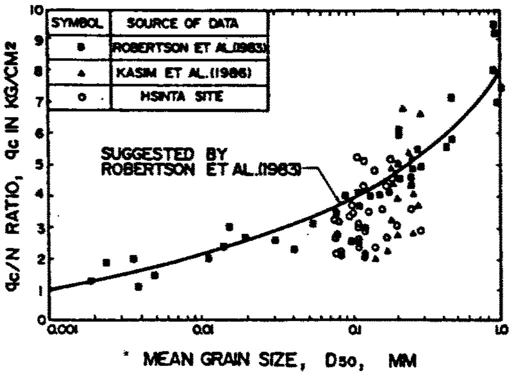


Fig. 1 Variation of $q_c/N$ Ratio with Mean Grain Size

Generally speaking, these available data imply that the correlation suggested by Robertson et al. (1983) provides a good framework to start with, but the direct application of the average curve in engineering practice may lead to significant deviation. This paper, therefore, attempts to establish a more stringent correlationship between $q_c$ and N-value.

## 3 SITE INVESTIGATION

In this research, the site studied is the Hsinta Power Plant in Taiwan. In order to prepare the preliminary design for two generator units, seven boreholes were drilled and eighteen cone penetration tests were conducted. Within the area and depth where the correlation tests were conducted, the subsoil conditions can be subdivided into three layers. The top layer consists of hydraulic sand fill and natural sand with a total thickness of approximately 7 m. Underlying this sand layer is a 13 m clay layer. Immediately below this cohesive deposit is a sand layer which can be as thick as 35 m. The groundwater table is typically at 2.5 m below ground surface. Grain size analyses were carried out on split spoon samples following ASTM Standard D422-63 (1972). According to the Unified Soil Classification System, both the hydraulically filled sand and natural sand are generally classified as SM.

Standard Penetration Tests were conducted by using a rope and cathead assembly to raise and drop the donut type hammer. Many variables which may affect the N-value have been carefully taken into account. The kinetic energy computed from the impact velocity is compared to the theoretical free fall energy. The energy correction factor was then applied to the measured N-value to calculate $N_{55}$ which corresponds to 55% of the standard energy.

Cone penetration soundings were made using a Hogentogler type electronic cone. Tip resistance, skin friction and cone inclination were continuously recorded during penetration. Pore water pressures measured in a few tests indicated that the difference between the uncorrected tip resistance, $q_c$, and the corrected tip resistance, $q_t$ (Jamiolkowski et al., 1985) is within 5%.

A total of 35 data points of sand deposits were selected from this investigation. A summary of these field measurements and laboratory test results are tabulated in Table 1.

## 4 CORRELATION ANALYSIS

Results obtained from Hsinta site were superimposed on Fig. 1. Similar to the Alameda data, these results also show that the curve presented by Robertson et al. (1983) can be best served as a reasonable average, while the direct utilization of this curve may end up with significant deviations. It should be mentioned that data plotted on Fig. 1 are based on SPT N-values corrected by the energy level. If this correction would not have been made, the scatter of the $q_c/N$ ratio is much greater. It is noticed that the $D_{50}$ of Hsinta data has a mean value of 0.13 mm with a standard deviation of 0.05 mm. However, the fine content varies from 13% to almost 50%. This suggests that the large variation of $q_c/N$ for granular soils (except gravelly sands) may be better reflected by the fine content rather than mean grain size. Therefore, Fig. 2 was developed to evaluate the relationship between the $q_c/N$ ratio and the fine content. It clearly illustrates that the

Table 1 Penetration and Grain Size Data of Hsinta Site

| Depth m | $N_{55}$ | $q_c$ kg/cm$^2$ | FR* | FC** | $D_{50}$ mm |
|---|---|---|---|---|---|
| 2.0 | 12.85 | 48.14 | 0.26 | 35 | 0.100 |
| 4.0 | 5.00 | 13.46 | 0.43 | 25 | 0.170 |
| 38.5 | 39.96 | 134.84 | 0.78 | 25 | 0.095 |
| 44.5 | 77.07 | 170.65 | 1.27 | 44 | 0.083 |
| 21.0 | 30.68 | 106.59 | 0.91 | 23 | 0.100 |
| 31.0 | 29.29 | 62.32 | 0.30 | 37 | 0.084 |
| 33.0 | 19.52 | 63.65 | 0.28 | 46 | 0.078 |
| 37.0 | 23.71 | 76.19 | 0.40 | 45 | 0.081 |
| 1.0 | 14.97 | 64.87 | 0.73 | 28 | 0.120 |
| 2.0 | 11.23 | 49.06 | 0.49 | 25 | 0.170 |
| 3.0 | 8.73 | 42.02 | 0.48 | 18 | 0.140 |
| 4.0 | 14.97 | 46.21 | 0.56 | 21 | 0.200 |
| 21.0 | 41.16 | 99.45 | 0.82 | 18 | 0.110 |
| 31.0 | 24.95 | 73.24 | 0.45 | 37 | 0.120 |
| 37.0 | 47.40 | 131.07 | 1.03 | 46 | 0.080 |
| 39.0 | 51.14 | 153.51 | 1.25 | 34 | 0.120 |
| 41.0 | 52.39 | 184.93 | 1.82 | 33 | 0.130 |
| 5.0 | 16.73 | 48.55 | 0.04 | 13 | 0.290 |
| 37.0 | 51.19 | 114.04 | 0.63 | 24 | 0.170 |
| 5.0 | 11.75 | 54.16 | 0.02 | 17 | 0.180 |
| 20.5 | 41.17 | 88.03 | 0.81 | 18 | 0.120 |
| 28.5 | 26.11 | 94.55 | 0.10 | 24 | 0.250 |
| 34.5 | 45.69 | 108.43 | 0.29 | 25 | 0.140 |
| 36.5 | 18.28 | 93.53 | 0.54 | 34 | 0.120 |
| 40.5 | 56.13 | 150.25 | 0.89 | 48 | 0.077 |
| 42.5 | 67.88 | 169.93 | 1.45 | 32 | 0.110 |
| 48.5 | 48.30 | 104.86 | 1.17 | 46 | 0.080 |
| 2.0 | 8.56 | 44.68 | 0.41 | 17 | 0.110 |
| 3.0 | 7.14 | 36.92 | 0.29 | 15 | 0.180 |
| 5.0 | 17.12 | 61.71 | 0.29 | 23 | 0.260 |
| 21.5 | 27.12 | 70.99 | 0.93 | 36 | 0.110 |
| 33.5 | 29.97 | 61.40 | 0.36 | 31 | 0.120 |
| 37.5 | 41.39 | 129.44 | 1.22 | 28 | 0.110 |
| 39.5 | 68.51 | 208.08 | 1.22 | 21 | 0.110 |
| 45.5 | 67.01 | 183.80 | 1.78 | 47 | 0.080 |

* FR: Friction Ratio, %.
** FC: Fine Content, %.

effect of fine content on the $q_c/N$ ratio is signicant and that the ratio increases with decreasing fine content. A simple relationship is established based on the available date:

$$q_c/N_{55} = 4.70 - 0.05 \times \text{Fine Content (\%)}$$

It still should be noted that the data scatter caused by the variability of penetration tests cannot be eliminated. A more sophisticated statistical approach is under investigation so that this effect can be identified and minimized.

From the practical point of view, the use of fine content as the index in the correlation is more convenient. The fine content can be easily estimated by the percentage of materials retained on #200 sieve, but $D_{50}$ can only be obtained by a more tedious sieve analysis.

The disadvantage of using either Fig. 1 or Fig. 2 is that the equivalent N-value cannot be directly calculated from CPT results. A laboratory test is required to estimate the gradation of the soil sample. Hence, many classification charts have been constructed in order to directly convert the $q_c$ to N-value by the use of other measured parameters during cone penetration, for example, skin friction or pore pressure. Based on the friction ratio and corrected tip resistance, Robertson (1986) proposed a simplified soil classification chart with suggested $q_c/N$ ratio for each soil type, as shown in Fig. 3. In this plot, cone bearing, $q_t$, is the measured cone resistance, $q_c$, calibrated by the pore pressure and the net area ratio. Measured data from Hsinta site were plotted on Fig. 3 by using different symbols. Each symbol represents a different $q_c/N$ ratio. Since pore pressure was not measured in Hsinta, uncorrected tip resistance, $q_c$, was used instead of $q_t$. It is believed that the difference between $q_c$ and $q_t$ is not very significant since the excess pore pressure during cone penetration in granular deposits is relatively small. All the Hsinta data plotted on Fig. 3 fall within Zone 8 and Zone 9 of the chart which are described as sand to silty sand and sand, respectively. Notice that solid symbol on Fig. 3 means that the measured $q_c/N$ ratio coincides exactly with suggested value. Only 7 data points (solid symbols in Fig. 3) show the exact match. However, there also has 7 data points with their measured $q_c/N$ ratios equal to only half of the suggested values. This comparison indicates that this general classification

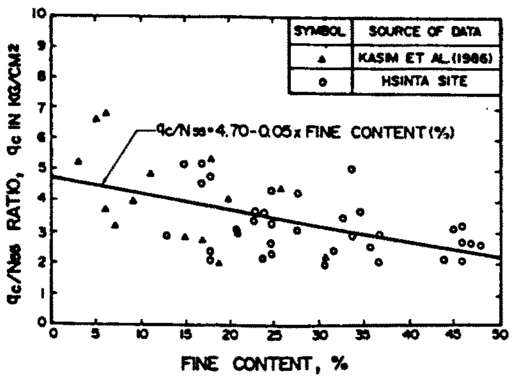


Fig. 2 Variation of $q_c/N$ Ratio with Fine Content of Granular Soils

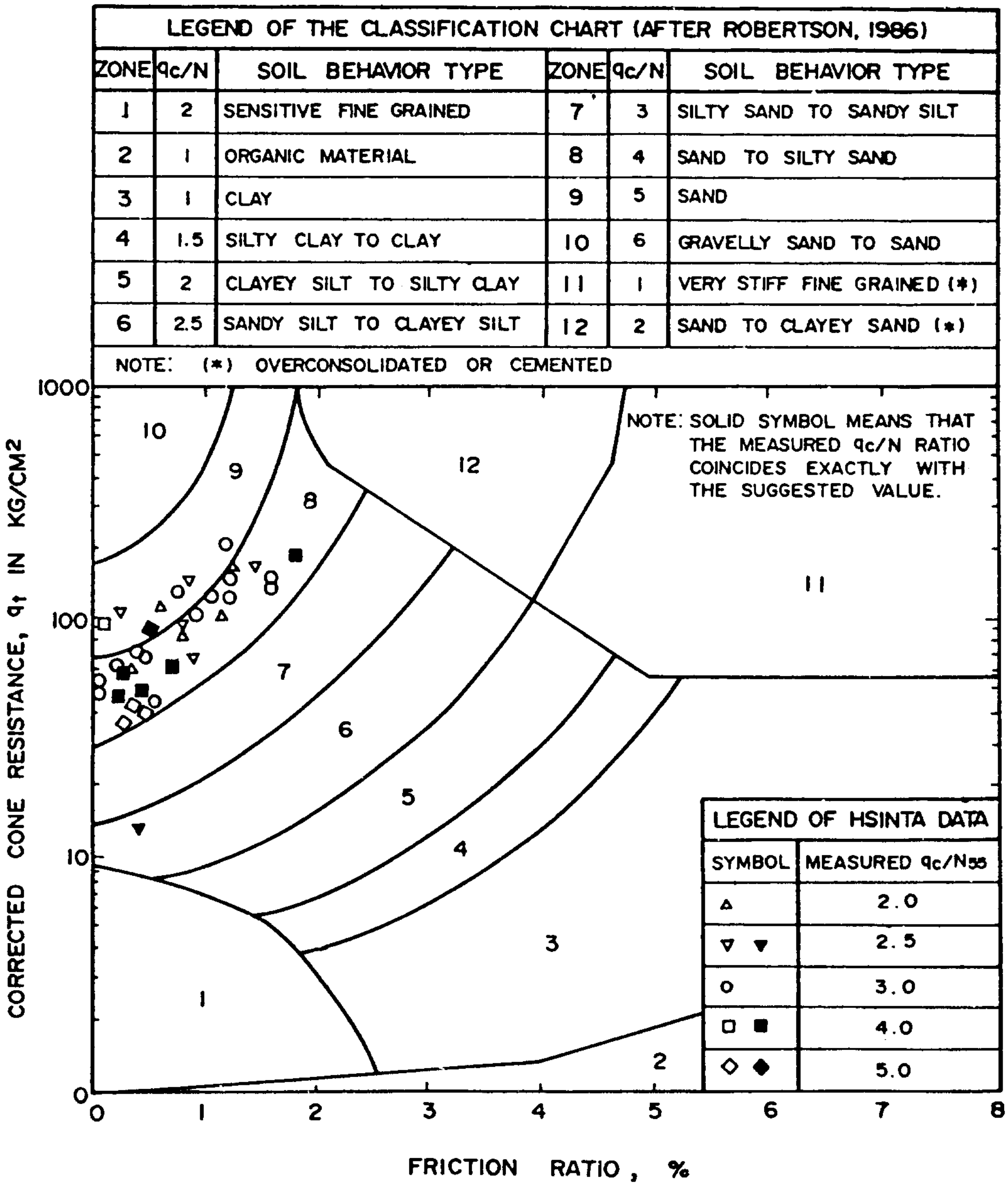


Fig. 3 Comparisons between Suggested and Measured $q_c/N$ Ratio

chart provides a good qualitative description, but the suggested $q_c/N$ ratio has to be used with great care.

## 5 SUMMARY AND CONCLUSIONS

With the increasing use of CPT, it is useful to correlate the cone tip resistance to the SPT blow count so that the available abundant experiences on SPT can be utilized. The focus of this paper is on the SPT-CPT correlations for granular soils.

It is very important for geotechnical engineers to appreciate the variability of these two penetration tests. Therefore, it is suggested that the SPT N-value should be carefully corrected for the energy level. It is also recommended that the cone resistance be corrected for its unequal area and excess pore pressure effects whenever it is possible.

This paper presents the findings of the SPT-CPT correlations for SP and SM materials based upon the data obtained from well-documented and carefully conducted site investigations. It suggests that the relationship between the $q_c/N$ ratio and $D_{50}$ proposed by Robertson et al. (1983) can be regarded as a reasonable average. However, the scatter around this average is very significant even within a small range of $D_{50}$. On the other hand, this study clearly illustrates that the $q_c/N$ ratio is much smaller for sands with higher fine contents than for clean sands. It is believed that the correlation between the $q_c/N$ ratio and fine content for granular soils is more meaningful and more convenient to use. A simple relationship is thus proposed based on the available data. More well conducted site investigations are needed to confirm or improve the correlation presented in this paper.

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