



# CPT and SPT as Complementary Tests for the Formulation of Geotechnical Design Profiles

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**Abstract.** Standard Penetration Test (SPT) is the most commonly used field test in any geotechnical investigation campaign. Although SPT provides quite useful information on the nature and type of the subsurface strata, owing to its inherent operating mechanism, SPT incorporates several limitations. During the dynamic impact of the SPT hammer during the testing/sampling, there is a tendency of the breakage of the cementation and disturbance of the structure in the partially-cemented soils. Breakage of cementation and similar disturbance to the soil structure may mask some of the essential information required for the choice of geotechnical design parameters for the in-situ strata. Such partially-cemented soils are prevalent in the semi-arid regions of the world such as eastern Saudi Arabia. Cone Penetration Test (CPT) is another penetration-based field test employed, usually, deployed as a secondary test for the geotechnical explorations. Due to the pseudo-static penetration mechanism of the cone during CPT testing, this test is capable of quite closely recording the information pertinent to the undisturbed structure of the soil. Therefore, CPT can be classed as an essential complementary test to SPT for the development of the representative in-situ design subsurface profile. This paper discusses several case studies from eastern Saudi Arabia, in which the precise interpretation of the CPT provided the essential complementary information that augmented the results from the SPT in developing the accurate and field representative subsurface design profiles.

## 1 Introduction

In any routine geotechnical investigation campaign, number of field testing techniques are used. All these techniques have their corresponding pros and cons. Standard penetration test (SPT) is being widely utilized to delineate nature and type of subsurface strata. Many geotechnical design parameters of the soils are associated with the standard penetration test (SPT) and huge database of SPT correlations is available to assess these design parameters. Cone Penetration Test (CPT) is another penetration-based field test employed, usually, as a secondary test for the geotechnical explorations. CPT has several advantages over SPT including continuous profiling, relatively quick performance and

less/no disturbance affects associated with boreholes. On contrary, its limitations include non retrieval of samples and limited penetration in very dense and hard materials. The combined results of both of these tests however, could provide quite essential information about the subsurface strata, which each one of these in isolation may not be able to reveal.

SPT and CPT have been correlated in literature as  $n = q_c/N_{60}$  where  $q_c$  is CPT cone bearing resistance and  $N_{60}$  is corrected SPT N-value. SPT and CPT correlations are generally used for subsurface strata classification and translation of SPT blow counts (N-values) into CPT cone resistances ( $q_c$ -values) and vice versa. The primary objective of conversion of one parameter into the other is to use the available data base of correlations in literature depending upon the local experience, field observations, design methodologies and preferences.

De Alencar Velloso (1959) were among the first who determined ratios of SPT N values and cone tip resistance for different soil types and introduced 0.35 MPa for clay and silty clay, 0.2 MPa for sandy clay and silty clay, 0.35 MPa for sandy silt, 0.6 MPa for fine grained sand, and 1.0 MPa for sand. Meigh and Nixon (1961) considered the effect of grain size in correlation proposed by De Alencar Velloso (1959) and recommended n-values as 0.2 MPa for coarse grained sand and 0.3–0.4 MPa for gravelly sand. Schmertmann (1970) recommended 0.2 MPa for silt, sandy silt, and slightly cohesive silt-sand mixture, 0.3–0.4 MPa for clean, fine to medium sand and slightly silty sand, 0.5–0.6 MPa for sandy gravel and gravel. Meyerhof (1965) suggested the relationship as  $n = (q_c/N) = 0.4$  MPa. Robertson et al. (1983) used the available data base in literature in combination with his filed testing in the province of British Columbia in Canada and developed  $D_{50}$  based  $N_{60}$  and CPT correlation. Robertson et al. (1986) later normalized cone tip resistance ( $q_c/Pa$ ) and presented a CPT-SPT correlation for different soil types. Kulhawy and Mayne (1990) extended the Robertson et al. (1983) correlation based on their additional data and developed a mathematical expression for their updated SPT-CPT correlation based on fines content. Lunne et al. (1997) modified the CPT-SPT correlation by Robertson et al. (1986) by using Soil Behavior Index ( $I_c$ ).

Ismael and Jeragh (1986) made a correlation on calcareous desert sands in Kuwait and compared it with the value of Schmertmann (1970) for clean, fine to medium sands and slightly silty sands. Their average value ranges from 4.2 to 5.6 which was higher than what Schmertmann suggested for clean, fine to medium sands and slightly silty sands. N. Akca (2003) carried out study on United Arab Emirates soils (Sand, Silty Sand, Sandy Silt) and results of  $q_c/N_{60}$  ratio are generally higher than literature values. The deviation of the  $q_c/N_{60}$  ratio in both of these studies from the ones available in the literature was attributed to cementation, densification, gravels/shells and calcareous nature of soils.

Table 1 represents the summary of correlative works which have been done in the past to develop correlations between SPT N-values and CPT cone bearing resistances,  $q_c$ .

The soils found in eastern Saudi Arabia, especially in coastal areas are generally cemented and calcareous in nature with shallow water tables. Therefore, it would be useful to study the correlations between SPT N-values and CPT cone bearing resistances ( $q_c$ ) for local soils to get an insight into subsurface strata behaviour/response in both tests.

**Table 1.**  $q_c/N_{60}$  ratios available in literature ( $q_c$  in MPa).

Soil Type	De Alencar Velloso (1959)	Schmertmann (1970)	Engineers Franki Piles (1960)	Meigh and Nixon (1961)	Meyerhof (1965)	Robertson et al. (1986)	Danziger and De Valleso (1995)	Acka (2003)	Ismael and Jeragh (1986)
Sand	0.6–1.0	0.3–0.6	1.0	0.20	–	0.3–0.6	0.3–0.6	0.77	4.2 to 5.6*
Silty Sand	0.2	0.3–0.4	0.5	–	0.4	0.3–0.4	0.3–0.4	0.7	–
Sandy Silt	0.35	0.2	0.4	–	–	–	0.2	0.58	–

\*  $q_c$  in  $\text{kgf/cm}^2$ .

## 2 Sites and Investigation Description

The data set used in this study consists of Cone Penetration Test (CPT) soundings and standard penetration test (SPT) profiles from three (03) different sites in eastern Saudi Arabia. All data used in this study are from the coastal areas of eastern Saudi Arabia. Location map of the sites is shown in Fig. 1. Data set from each site consists of five (05) boreholes and five (05) CPTs. CPTs at each site were carried out at about 3.0 to 5.0 m distance from the SPT boreholes.

A total of fifteen (15) boreholes with SPTs were drilled at the site locations. All the boreholes were drilled using straight rotary drill rigs. Standard Penetration Tests (SPTs) were performed using automatic hammers at 0.75 m depth intervals. These tests were performed generally in accordance with ASTM D-1586 using a split spoon sampler of 35 mm inner dia. and 50 mm outer diameter.

CPT soundings were also performed at fifteen (15) locations in the vicinity of boreholes. CPTs were performed using Geomil electric cone penetrometer. In order to perform the CPT, ten (10) tons capacity wheel mounted hydraulic rig was used. The tests were performed in accordance with procedures described in ASTM designations D5778. A calibrated electric cone is pushed into the ground by hydraulic pressure. The electric cone connected to a microprocessor and a laptop computer passed signals thru a cable regarding the tip resistance, side friction as well as pore water pressure measured by the cone. All data is automatically recorded in the laptop and later processed and printed using patented software.



**Fig. 1.** Vicinity Map showing location of three (03) investigated sites

### 2.1 Subsurface Strata Conditions

A particular feature, typical for the western and southern Gulf coast, is the flat and wide spreading coastal Sabkha. Penetrating up to 10 km inland they cover areas of more than 100 km<sup>2</sup>. “Sabkha” is the Arabic term for flat salt-crusted desert. Sabkha is a saline (generally coastal) deposit consisting of saturated, loose silty sand and possibly clay. Sabkhas are salt bearing arid climate sediments (Saudi Building Code 303). In general, Sabkha sediments are characterized by high void ratios and low dry densities. Accordingly, upon wetting Sabkha soil is renowned for being highly compressible material with low bearing resistance, and hence considered among the poorest of foundation materials.

Soil layers consisting of Poorly Graded SAND (SP)/Poorly Graded SAND with Silt (SP-SM)/Silty Sand (SM)/Silt (ML) have been predominantly found at borehole locations in the study areas. Very loose/loose layers encountered in boreholes and CPTs are classified as sabkha layers. Being very near to shoreline, the Sabkha layers found at the study sites are directly connected to sea water and exhibit characteristics of “coastal Sabkha”.

The groundwater table was encountered in the boreholes at shallower depths varying from 1.50 to 7.0 m below existing grade level. As the groundwater table is connected to sea, it has very high dissolved salt content and may experience seasonal/tidal fluctuations.

### 3 SPT and CPT Data Analysis

For all the boreholes of the three investigated sites, SPT-N values were normalized to  $N_{60}$  after applying the energy and other essential corrections. The tip resistance ( $q_c$ ) values were also logged from the CPT profiles corresponding to the depths at which SPTs were performed. It is also necessary to normalize the cone resistance for pore pressure.

From the fifteen (15) SPT boreholes and CPTs, the number of data pairs ( $N_{60}$  and  $q_c$ ) available for comparison are about one hundred and fifty (150). However, just to explain the process, the data points for sands where sieve analysis information was also available have been selected and tabulated in Table 2.

**Table 2.**  $q_c/N_{60}$  field data points.

Depth	Fines content (%)	$D_{50}$ (mm)	$N_{\text{field}}$	$N_{60}$	$q_c$ (MPa)	$n = q_c/N_{60}$ (MPa)
7.50	6.60	0.28	23	32	17.56	0.55
15.0	23.40	0.10	32	47	12.83	0.28
0.75	1.70	0.28	7	7	9.01	1.27
9.0	10.20	0.22	17	22	4.34	0.20
3.0	7.40	0.35	7	7	26.94	3.80
3.75	8.20	0.28	8	8	7.70	0.95
1.50	10.50	0.25	9	9	4.30	0.47
4.50	5.60	0.26	22	25	15	0.59

Finally for all these boreholes,  $q_c/N_{60}$  ratios were plotted against depth below the ground surface and are shown in Figs. 2, 3 and 4. The soil samples recovered from SPT split-spoon samplers were classified through laboratory-based particle size distribution and the plasticity tests. Based on the type of soils classified from the SPT samples, a range of  $q_c/N_{60}$  ratios, based on the correlations available in the literature, were assigned to these soils and plotted on the same figures (Figs. 2, 3 and 4). Most commonly adopted relationships developed by Schmertmann (1970) and Robertson et al. (1986) have been used to assign the range of  $q_c/N_{60}$  ratios to the corresponding soils in these plots.

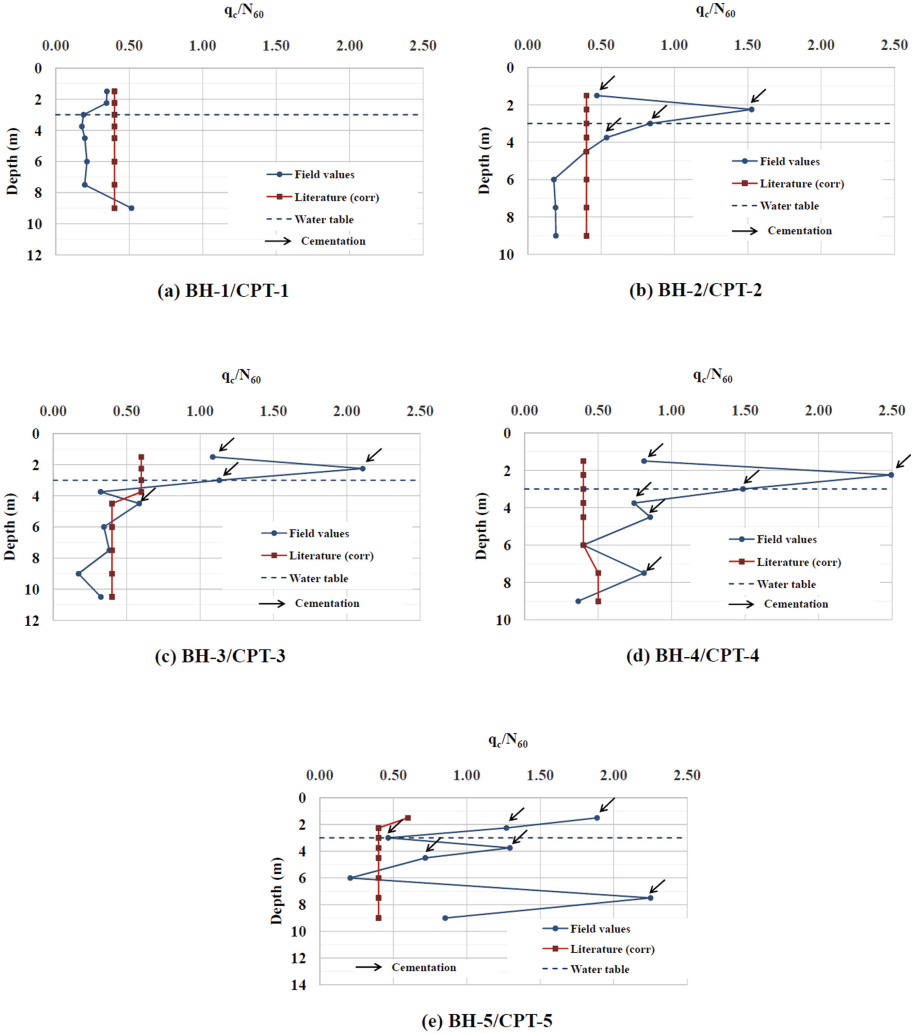
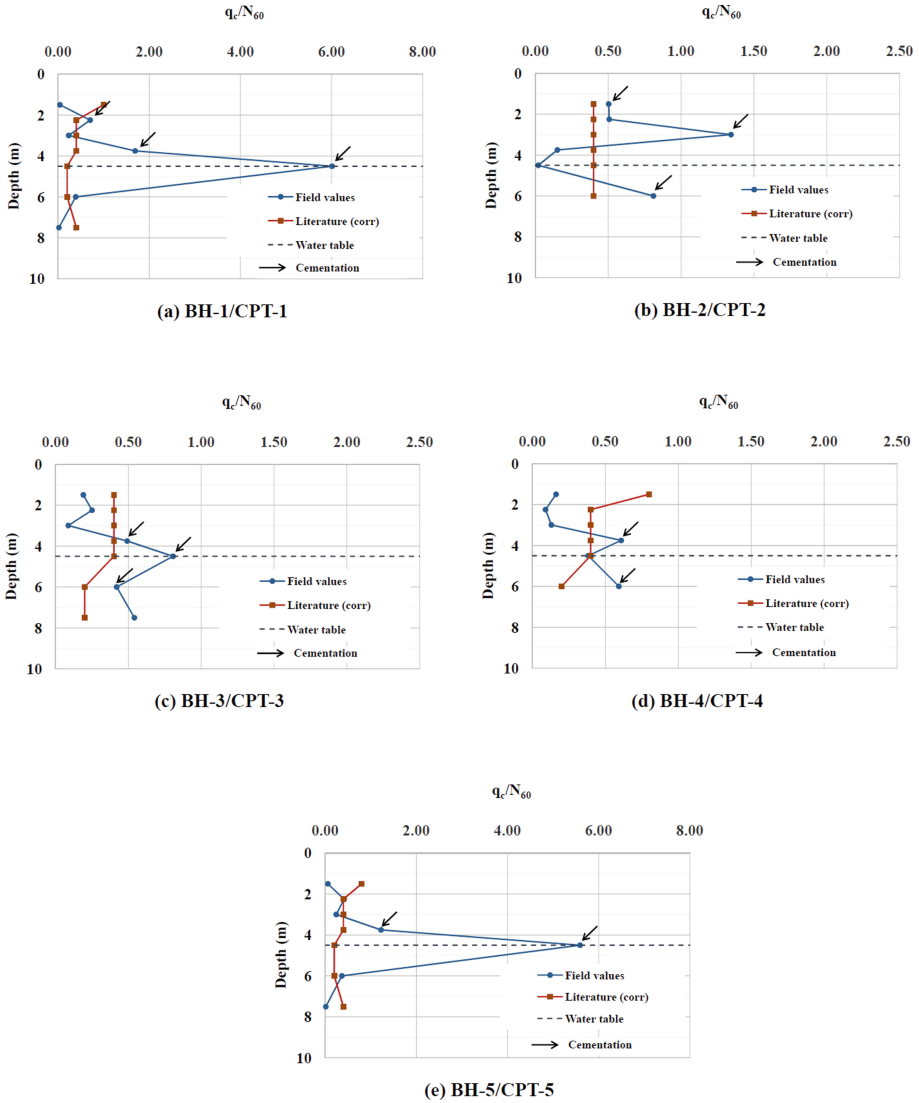


Fig. 2. Comparison of field  $q_c/N_{60}$  ratios with literature values for Site 1

### 4 Results and Discussions

A comparison of the  $q_c/N_{60}$  ratios in Figs. 2, 3 and 4 with the literature-based ratios (Table 1) reveals that there is a general agreement between these values at most of the depth horizons with some exceptions especially above the water table. At these exceptional locations, actual (field) ratios have been found to be quite higher than the ones generally available in the literature. Moreover, almost all the places having a general disagreement between the field and literature-based ratios lie above the water table. As discussed in the site description section, the investigated sites are typified by the shallow water tables and very high dissolved salt content. The high salt content of these waters owes



**Fig. 3.** Comparison of field  $q_c/N_{60}$  ratios with literature values for Site 2

either to the presence of percolated seawater or to the Sabkha brines. Due to several factors including fluctuation of the water table with tidal variation, ambient temperature, relative humidity, and precipitation, the soils above the water table experience continuous cycles of capillary saturation and evaporation. These cycles result in the precipitation and the consequent cementation of different types and amounts of salts in the soil layers above the water table. This cementation process has been confirmed by the undisturbed samples acquired through coring during several investigation campaigns in the area. The

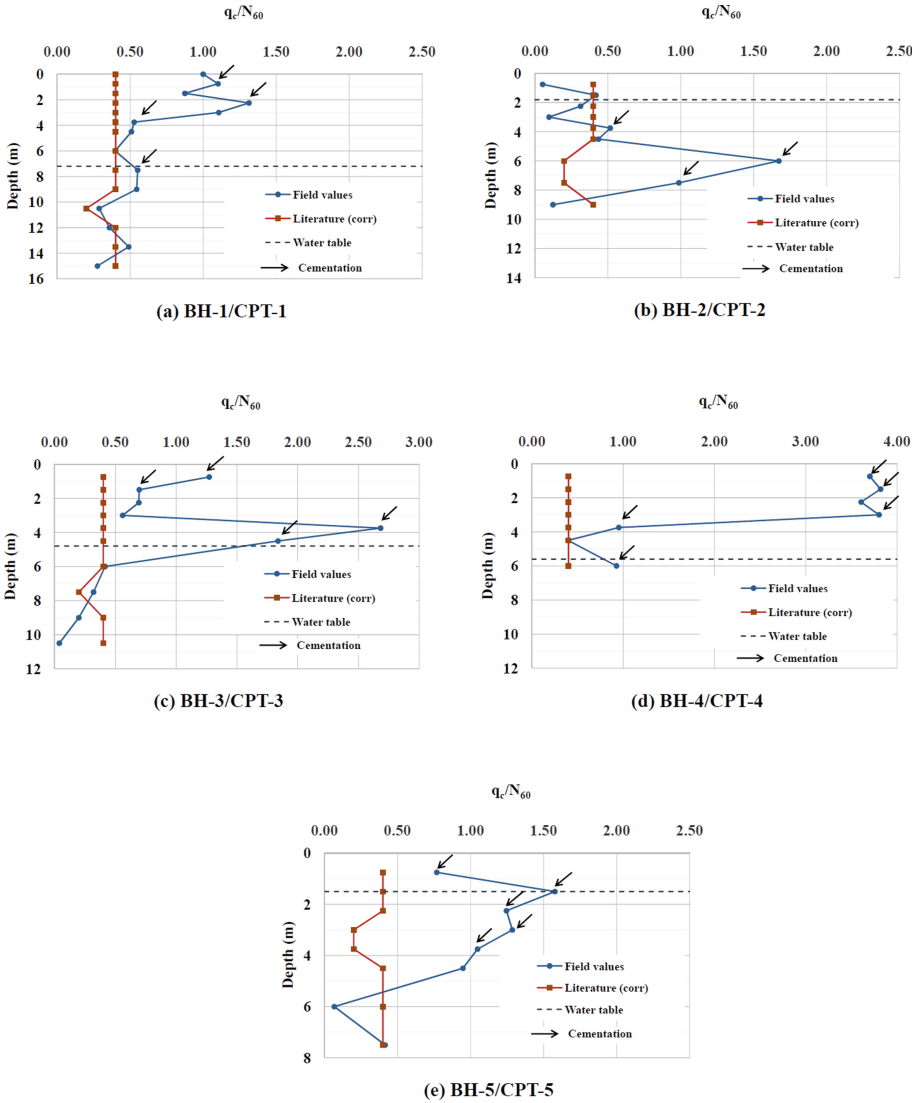


Fig. 4. Comparison of field  $q_c/N_{60}$  ratios with literature values for Site 3

cementation among the soil particles, most probably, results from the precipitation of salts such as calcium carbonate, sodium chloride, potassium chloride, etc.

During any regular field investigation campaign using SPT on a site with cemented subsurface layers, the dynamic impact of SPT hammer results in the breakdown of the cementation among the soil particles. After the breakdown of the cementation, the SPT test proceeds virtually in an ‘uncemented soil,’ and the resulting N-values falsely represent the real/in-situ shear strength and stiffness behavior of these soils. CPT, on the other hand, due to its push-type and pseudo-static rate of penetration mechanism,



provides a true representation of the nature and type of the cemented strata. Therefore, the deviation of the  $q_c/N_{60}$  ratio determined at specific depth horizons in our projects from the ones available in the literature, most probably owes to the presence of the soil cementation at these depths. The degree of deviation of this ratio from the correlations in the previous research could also be a qualitative indicative of the extent of the cementation. In addition to the assessment of the cemented strata above the water table, this ratio could also be helpful in revealing the presence of such layers below the water table. In the seashore areas, presence of coralline or other such cemented deposits even below the water table could also be explored/revealed by the adoption of both SPT and CPT testing regimes. In our case, higher  $q_c/N_{60}$  ratios below the water table at some boreholes are also quite probably indicative of the cemented strata.

The findings of the current study have also been substantiated by similar studies on the calcareous/cemented soils in the Middle East. The ratio  $(q_c/Pa)/N_{60}$ , as determined from field data, for the UAE calcareous fine to medium grained sand was found to be significantly, 40 to 45%, higher than the values predicted using the existing correlations for siliceous sand (Elkateb and Ali 2010). They further highlighted that the existing correlations in literature are developed for siliceous sands and therefore have poor applicability in calcareous soils due to their high compressibility, crushability and presence of shells. Their study also indicated that the ratio  $(q_c/Pa)/N_{60}$  for calcareous sand is higher than that of siliceous sand due to presence of shells in calcareous sands which might have a bigger influence on the CPT tip resistance value compared to the SPT blow counts. Ahmed et al. (2013) also concluded that none of the existing SPT-CPT correlations are applicable to calcareous sands and there is a need for reliable SPT-CPT correlations, encompassing both calcareous and siliceous soils. Moreover, the SPT-CPT correlation should address the anticipated difference in soil crushability/compressibility between the CPT and the SPT in calcareous soils.

## 5 Conclusions

Owing to their push-type and pseudo-static soil penetration methodology, CPT test have been found quite suitable to provide at least a qualitative assessment of the degree of the cementation present in the strata both above and below the water table.

The combined results from both SPT and CPT tests were able to provide quite essential information about the subsurface strata especially in cemented strata, which each one of these in isolation may not be able to reveal.

## 6 Recommendations

For the foundation design purposes, if the breakdown of the cementation among the soil particles is anticipated under the envisaged structure loading, the choice of geotechnical design parameters should conservatively be based on SPT-N values. Use of CPT values for the bearing capacity analysis in such cases could result in unsafe designs. However, in cases where there is a high degree of cementation in the strata and the probability of its persistence during the envisaged structure loading is high, the selection of foundation design parameters should be based on the CPT results. Use of SPT values in the latter case would result in uneconomical foundation designs.

## 7 Limitation

Although, assessment of the cementation in soil layers were carried out from the undisturbed samples acquired at different depths, quality of undisturbed samples may be further improved to refine the  $q_c/N$  ratios.

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