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SPT and CPT Correlation of Expansive Clay in Cikarang, Indonesia

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ABSTRACT Several CPT-SPT correlations have been reported worldwide to allow for the estimate of soil physical properties from one set of accessible data to another. Although most correlations are for silty and sandy soils, there is insufficient information on whether these correlations correspond to the silty clay soil conditions in Indonesia. Therefore, this study aims is to validate and enhance the generalized CPT-SPT correlation, with emphasis on Indonesian soil conditions to increase its prediction accuracy. The soil under examination is silty clay layers that cover most of Northern parts of West Java – Indonesia. Known with its expansive clay characteristics, these type of soils are sensitive to volume change as a result of seasonal variations in water content. For this study, data is collected from 8 (eight) locations in Cikarang Area. Each location consists of dedicated SPT and CPT pairs tests at 2 (two) m distance between each other. After analyzed with various statistical regression analysis of data relevant to this type of soil, a simple linear empirical CPT-SPT correlation with a fairly high correlation has been established allowing test findings to be translated and predicted for the relevant soils type. The simple CPT and SPT correlation is in form of n = qc/NSPT = 0.225 (Mpa), with data distribution of n ranges from 0.15 (Mpa) to 0.33 (Mpa). This results shows much lower n values compared to various correlation have been published worldwide. With respect to the clay soil formation, the low of n-value also reflect a lower density and cohesion bonding clay properties.

KEYWORDS SPT; CPT; Correlations; Silty Clay; Expansive Soils.

1 INTRODUCTION

Numerous areas along the northern coast of West Java, Indonesia, possess large surface deposits covered in a clay formation. The majority are classified as expansive soil because it tends to undergo volume change in response to seasonal variations. Buildings or road structures erected on these soil types are usually damaged due to swelling and shrinkage. Suherman (2005) stated that this issue is widespread, at least in the Java region. It is also detected in some section of the Jakarta-Cikampek toll road, the Semarang-Kudus, Semarang-Purwodadi, Wirosari-Cepu, and Ngawi-Caruban highways, among others. However, the earlier mentioned corridor is being transformed into one of the most vital economic districts, with extensive industrial, commercial, and residential growth.

As part of its developments, in-situ testing is becoming more prevalent in conducting geotechnical site evaluations and being perceived as the basis for various civil engineering facilities. The standard penetration test (SPT) and the cone penetration test (CPT) are the most often utilized procedures. SPT and CPT are frequently used for preliminary and extensive soil investigations, including construction quality control, depending on the kind of project. Therefore, it is necessary to correlate the SPT N-value with the CPT tip and friction resistance to maximize the use of each database. By establishing such a correlation, the findings of one test tend to be translated to the results anticipated to be achieved from the other. Studies carried out in numerous countries since 1956 focused on this topic. This study aims to validate and alter the generic CPT-SPT correlation, focusing mainly on silty clay soils in Northwestern Java Indonesia, to increase its predictions accuracy and reliability.

Table 1. CPT – SPT correlations from some literature (Shahri *et al.*, 2014)

Researcher :	Soil Type :	Correlation Proposed:
De Alencar Velloso (1959)	Clay and silty clay	*n=(qc/N)= 0.35*
	Sandy clay and silty sand	*n=(qc/N)=0.2*
	Sandy silt	*n=(qc/N)=0.35*
	Fine Sand	*n=(qc/N)=0.6*
	Sand	*n=(qc/N)=1.00*
Meigh and Nixon (1961)	Coarse sand	*n=(qc/N)=0.2*
	Gravelly sand	*n=(qc/N)=0.3-0.4*
Engineers Franki Piles (1960)	Sand	*n=(qc/N)=1.00*
(From Acka, 2003)	Clayey sand	*n=(qc/N)=0.6*
	Silty sand	*n=(qc/N)=0.5*
	Sandy clay	*n=(qc/N)=0.4*
	Silty clay	*n=(qc/N)=0.3*
	Clays	*n=(qc/N)=0.2*
Schmertmann (1970)	Silt, sandy silt and silt-sand mix.	*n=([qc+fs]/N)=0.2*
	Fine to medium sand, silty sand	*n=([qc+fs]/N)=0.3-0.4*
	Coarse sand, sand with gravel	*n=([qc+fs]/N)=0.5-0.6*
	Sandy gravel and gravel	*n=([qc+fs]/N)=0.8-1.0*
Barata et al., (1978)	Sandy silty clay	*n=(qc/N)*=1.5-2.5*
	Clayey silty sand	*n=(qc/N)*=2.0-3.5*
Ajayi and Balogun (1988)	Lateritic sandy clay	*n=(qc/N)*=4.2*
	Residual sandy clay	*n=(qc/N)*=3.2*
Chang (1988)	Sandy clayey silt	*n=(qc/N)*=2.1*
	Clayey silt, Sandy clayey silt	*n=(qc/N)*=1.8*
Danziger and De Valleso (1995)	Silt, sandy silt and silt-sand	*n=([qc+fs]/N)=0.2*
	Fine to medium sand, silty sand	*n=([qc+fs]/N)=0.3-0.4*
	Coarse sand, sand with gravel	*n=([qc+fs]/N)=0.5-0.6*
	Sandy gravel and gravel	*n=([qc+fs]/N)=0.8-1.0*
	Silty sand	*n=(qc/N)*=7.0*
Danziger et al., (1998)	Sand	*n=(qc/N)*=5.7*
	Silty sand, Silty clay	*n=(qc/N)*=5.0-6.4*
	Clayey silt	*n=(qc/N)*=3.1*
	Clay, silt and sand mixtures	*n=(qc/N)*=1.0-3.5*
	Clayey sand and silty clay	*n=(qc/N)*=4.6-5.3*
	Sandy clay	*n=(qc/N)*=1.8-3.5*
	Clay	*n=(qc/N)*=4.5*
Emrem and Durgunoglu (2000)	Turkey soils	*n=(qc/N)=func (D50)*
Acka (2003)	Sand	*n=(qc/N)=0.77*
	Silty sand	*n=(qc/N)=0.70*
	Sandy silt	*n=(qc/N)=0.58*

Note : q_c in MPa; *q_c in bar / blow 30 cm.

2 PREVIOUS WORKS

Numerous correlations documented correspond with a broad variety of soil types and are not universally applicable, but dependent on soil characteristics and the SPT hammer and testing component. The majority of the empirical correlations assumed a constant value of $n = qc/N$, whereas other studies suggested it is *equivalent to (qc+fs)/N*. Table 1 shows some of the correlations between *n* and *qc* earlier reported in study on various soil types worldwide. Where *qc* is the resistance of the cone tip, *fs* and *N* denotes the frictional resistance and SPT blow count, respectively.

Robertson *et al*. (1983), Kulhawi and Mayne (1990), and Stark and Olson (1995) proposed a more advanced technique. They stated that the *qc/N* ratio as a function of the mean grain size, denoted by the abbreviation '*D50*', is a soil behavior-type index (*Ic*) categorization based on cone penetration tests and pore pressure measurements (CPTu). A possible disadvantage of correlations with *D50* is the reliance on laboratory-derived data on soil grain distribution, which may not be accessible during the first stages of a project or study program. As a result, Jefferies and Davies (1993), and Lunne *et al.* (1997), proposed formulas that solely use CPT data (Akca, 2003; Chin, 1988; Schmertmann, 1970; Fauzi, 2015).

Ismael and Jeragh (1986) compared CPT *QC* and SPT N-values obtained from calcareous desert sands in Kuwait and examined their findings with respect to Schmertmann's analysis (1970) of clean, fine to medium and silty sands. The predicted *n*-values for clean, fine to medium and silty sands were greater than Schmertmann's. Moreover, the test findings in the form of *qc/N* versus mean grain size '*D50*' were compared to Robertson *et al.* (1983) historical data with a high degree of consistency.

For some Brazilian soils, Danziger and de Velloso (1995) postulated a correlation between CPT and SPT, and the values obtained were within Schmertmann's (1970) range.

Several forms of correlations were examined, and it was determined that the linear ones were better suited for practical uses. A broad trend was developed using a pattern similar to that of Robertson's curve with increasing *n*-values and grain size. Lunne *et al.* (1997) referenced Jefferies and Davies (1993), which developed a soil classification chart for predicting N-values using a piezometer attached to CPT. This innovative study examines *QC* by considering pore water pressure (*u*) and overburden stress.

Akca (2003) hypothesized a correlation between SPT and CPT for soils in the United Arab Emirates and indicated that $n = qc/N$ was greater than the values reported in the literature. It further stated that the higher values were due to cementation, densification, and the shelly structure or gravel layers found in the soils of the United Arab Emirates.

Robin (2012) carried out a test within 6 km of the study location and stated that the data distribution of *qc/NSPT* (Mpa) ranges from 0.14 to 0.34. Meanwhile, Shahri *et al.* (2014) revealed a correlation between *QC* and N-value for various layers, particularly in clayey soils with significant clay content detected in southwest Sweden. A linear and power correlation was employed to predict *QC* using N-value.

3 GEOLOGY OF STUDY AREA

According to Bemmelen (1949), the geography of the study area is concerned as the Plain of Batavia, which encompasses the northern half of West Java between Serang or Rangkas-Bitung and Cirebon. This zone is approximately 175 km long and 40 km wide, formed by an alluvial lowland plain in the north and mountainous terrain in the south. It is predominantly composed of alluvial river deposits and lahar (mud flows) from the hinterland's volcanoes, with rare exposures of gently folded marine tertiary material. Field observations suggested that the study area is located in the transition zone between the low coastal flood plain and the mountainous area of northwestern Java.

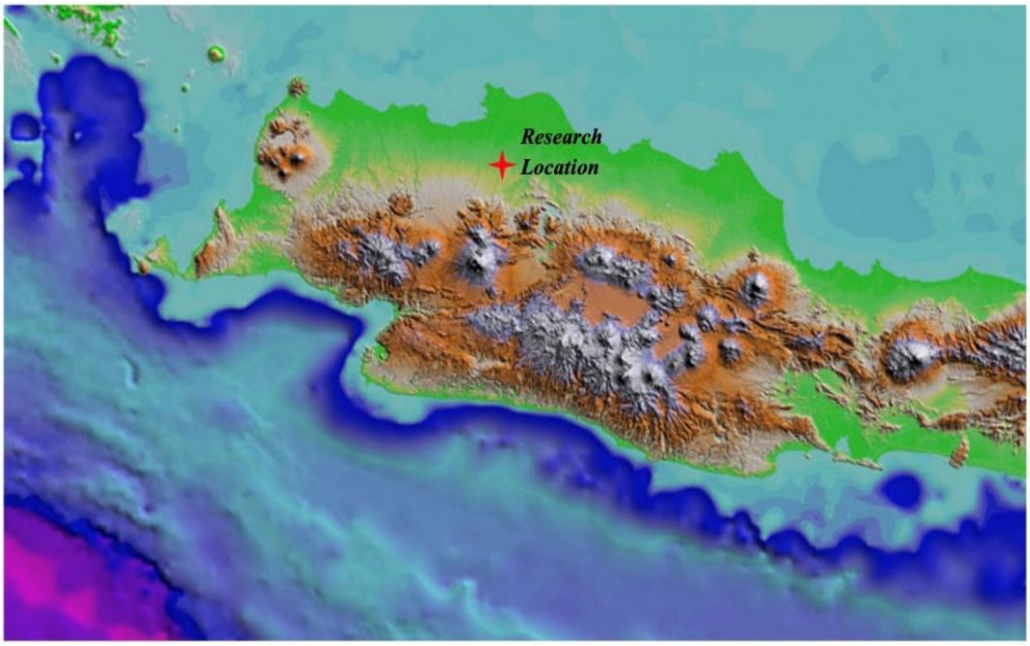

Figure 1. SRTM DEM of West Java, (Clements, 2008)

Robert Hall (2009) stated that most Java Island were considered part of the Woyla Terranes in the early Tertiary, approximately 65.5 million years ago. In the mid-Eocene, about 40 million years ago, there was lifting, subsidence, and sedimentation along the edge of the larger Sundaland due to the subduction of the India-Australia and Eurasia plates. Correspondingly, this subduction action resulted in forming a depressed complex band of hills, volcanoes, and mountainous terrain in the Bogor and Bandung zones of West Java. Clement and Hall (2008) reported that rows of mountains and volcanoes were actively created about 14 million years ago from the mid-Eocene to the Middle Miocene. These activities ceased in the mid-Miocene epoch but resumed towards the end approximately five million years ago and were relocated 50 km north.

Extensive weathering usually occurs in the central belt zone, under a severe tropical environment, consisting of a series of mountains and volcanoes known as the Bandung and Bogor zones. Tropical rain degraded the cones of volcanoes, mountains, plateaus, and any other remnants of subduction zones. This also resulted in residual soils transported by rainwater and rivers. In addition, these sedimentary sediments tend to gravitate toward northern Java's low coastal plains. This indicates sedimentation continues to be considered in the basins of Sunda and Asri, located in North West Java. These sediments started to fold and rise due to renewed subductive activity towards the end of the Miocene. This led to the elevation of a former coastal sedimentation region, approximately 50 m above sea level. These bending and lifting actions, along with tropical rains and erosion, resulted in wavy low undulating hills.

In accordance with the aforementioned analyses, the outcome of 100-meter-deep drilling shows that the study area is structured from alluvial sediment materials. According to Geology Map by Ratman and Gafoer (1998), this sediment was formed during the quaternary periods (>2.5 ma) as deposition of volcanic lava and mud flows of hinterland mountains such as Mount Salak, Gede, and Pangrango, including the coastal plain. These soft-grained sediments accumulated into shale in the Java Sea basins for thousands to millions of years.

Occasionally, volcanic ash tends to settle and is deposited on these sediments. Leaching is restricted in areas with poor drainage conditions, thereby triggering the accumulation of magnesium, calcium, sodium, and iron cations in the system. A combination of volcanic ash and shale progressively changes into clay shale containing montmorillonite. One of the clay mineral concentrations in soils contributes to its expansive feature and is a reason for worry due to its engineering challenges that must be addressed in modern days.

4 DATA COLLECTION AND PROCESS

This study was carried out using existing SPT-CPT pairs collected in Cibatu Village, Cikarang, West Java, Indonesia, which is known for having expansive soil difficulties. Data used consisted of 37 pairs of CPT-SPT with a 2 m distance between each.

4.1 Standard Penetration Test (SPT)

SPT is a commonly performed in-situ approach, which used to determine the density and consistency of sandy and clay or silt layers, respectively. This test is generally carried out simultaneously with drilling and soil sampling. In this study, SPT was executed based on a depth interval of 2 m in accordance with the ASTM D 1586. Visual identification was carried out as soon as the sample was removed from the split poon sampler as an interpretation of SPT data is strictly achievable for suitable soil types.

In total, 37 drilling and SPT tests were carried out, and based on the acquired data, the interpretation of the approximate soil layering or stratigraphy is shown in Figure 3. Generally, the SPT results show that soil consistency becomes harder with depth. The hard layers (SPT > 50) were detected at various depths from 8 m (BH 36) to 32 m (BH 44). However, the SPT value tends to decrease with depth. This results in a value of 30 ~ 40, which means the soil is firmly consistent. Virtually every test point displayed similar behavior. It is also notable that some of them failed to acquire SPT > 50 consistently down to a depth of 60 m (BH 42) or 90 m (BH 39). These results are closely related to the process of soil formation in previous studies. The settlement of various sediment materials with different thickness and period also triggered the consistency of the soil with depth.For analysis purposes, NSPT data were corrected according to SNI 4153:2008 to consider the effective vertical stress (N_1) and energy efficiency (N_{60}). However, the correction factor applied is shown in Table 2. Laboratory analyses on undisturbed samples show that soil's unit weight varies from 1.66 to 1.89 tons/m^3, with an average value of 1.775 tons/m^3. Generally, no groundwater table was found except a small quantity traped in the sandy soil lenses. Figure 4 shows the results of the calculated NSPT corrections.

Figure 4(a) shows the distribution of NSPT within the five drill points studied. Although the degree of proliferation was not clearly defined, the graph shows that it tends to increase with depth. This is related to the vertical overburden stress and the density of the soil, which tends to be denser at the bottom. It also depends on variations in soil type, such as the content of sand, silt, and clay, mineralogy, presence or absence of cementation, chemical bonding etc. Figure 4(b) shows that the value of the corrected NSPT, $(N_1)_{60}$, ranges from 7 to 27 with an average of 15.7 strokes. This implies that its equivalence to the vertical stress of 1 kg/cm^2 and the hammer energy efficiency, the N value does not diverge significantly. This minute N value is closely related to the soil type dominated by clay deposits. Meanwhile, the almost uniform value of $(N_1)_{60}$ versus depth reflects the uniformity of soil stratigraphy.

4.2 Cone Penetration Test (CPT)

CPT is widely used in a more simple soil investigation programme. The test is conducted by penetrating a cone through the soil layer to determine the ground resistance toward it, *QC* (endpoint resistance), and the blanket friction, *fs* (blanket resistance). With the measurements above, it is possible to determine the shear strength and layering of soils, as well as design parameters. In this study, the CPT test was carried out using a Begemann type cone and rigs with 2.5 tons capacity. The reading was taken at an interval of 20 cm, even though the naming of test points was similar to its drilling, it was carried out within 2 m of the SPT, as shown in Figures 5a and b.

Figure 2. Outcrop clay shale layer at Cikarang, West Java

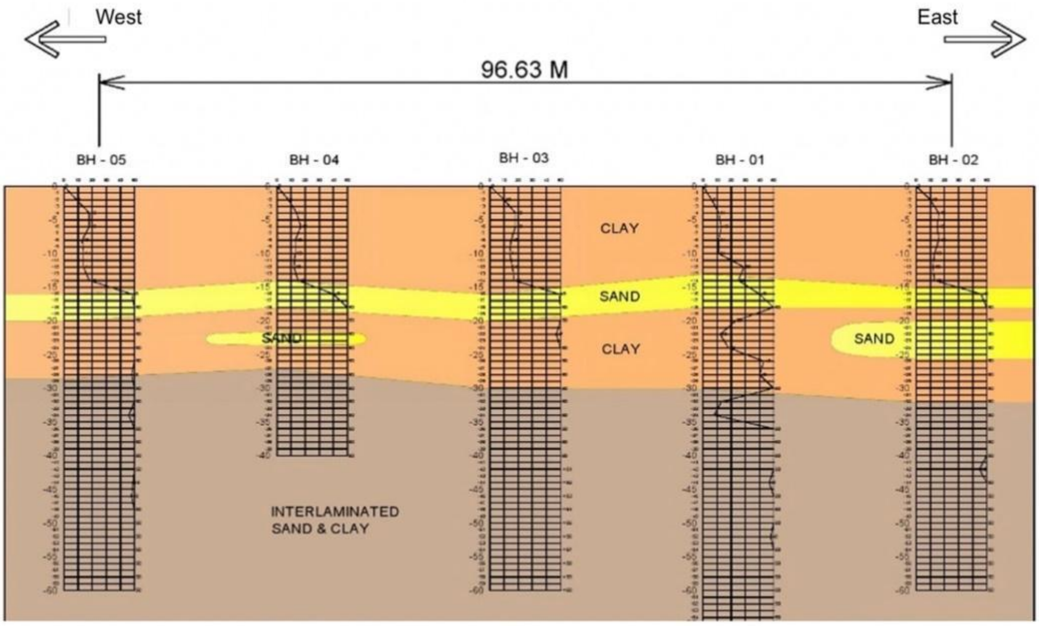

Figure 3. Interpretation of soil stratigraphy-based drilling bore log and NSPT

Table 2. NSPT correction factors

Correction Factors	Site data	Value taken
Effective vertical stress		$2.2/[1.2+(\sigma'_{vo}/P_a)]$
Energy efficiency	Automatic Trip Hammer	1.0
Drill diameter	D = 85 mm	1.0
Rod length	Var. 3.5~53.5 m	0.8 ~ 1,0
Sampler spoon	Standard	1.0

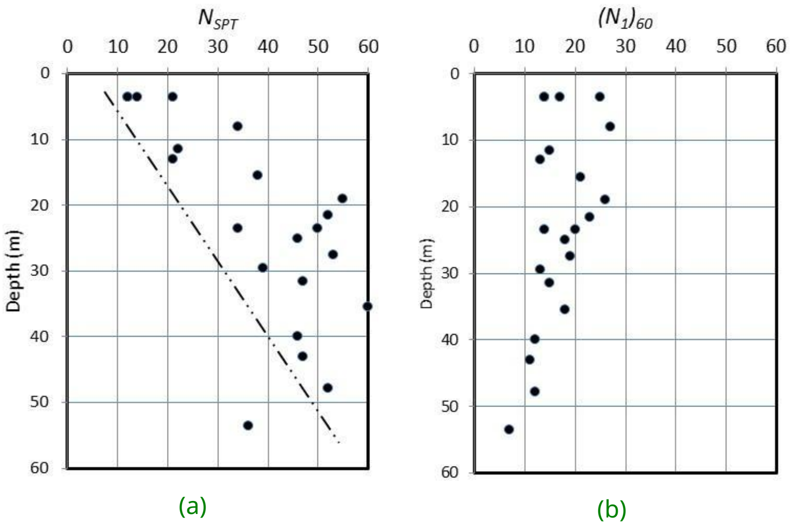

Figure 4. N_{SPT} results vs depth (a) and $(N_1)_{60}$ vs depth (b)

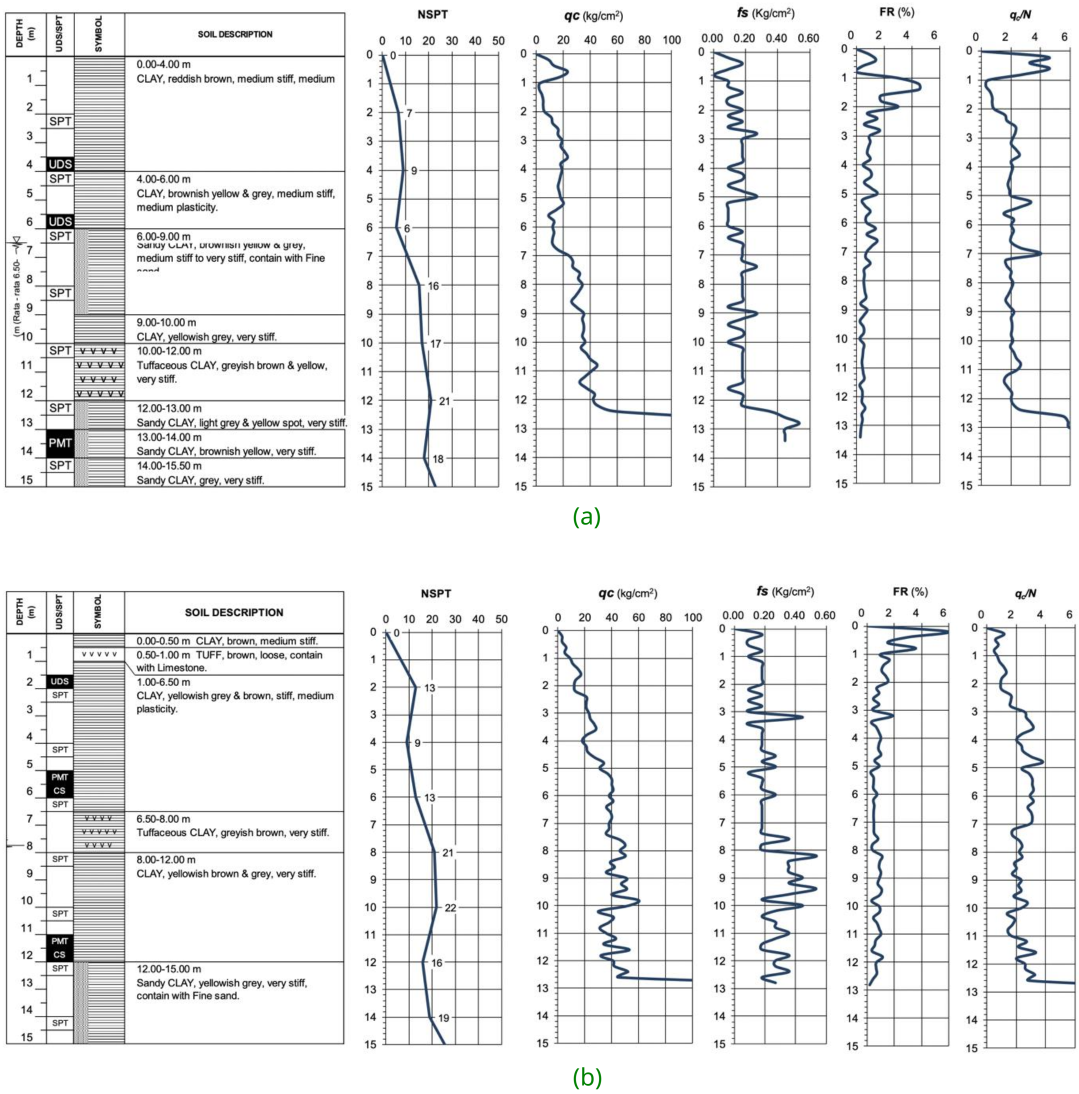

Figure 5. NSPT and CPT BH #7 OC (a) and NSPT and CPT BH #13 OC (b)

5 DATA ANALYSIS AND RESULTS

The magnitude and the variation of (n) = qc/NSPT with respect to depth are illustrated simultaneously with the test results shown in Figures 5a and b. At BH 7 OC, for depth d = 0.0 ~ 2.5 m, n slowly increases from 0 to 2. Furthermore, at d = 2.5 ~ 12.4 m, n is within the range of 1.5 ~ 2.7, these are similar to the study carried out by Barata *et al.* (1979) on sandy, silty clay, and clayey silty sand.

At BH 13, for d = 0.0 ~ 3.0 m, n gradually increases from 0 to 2, while at d = 3.0 ~ 7.0 m, the variation of n is slightly wider between 2.0 ~ 3.8, and at d = 7.0 ~ 12.4 m, the variation of n is between 1.2 ~ 2.4. For BH 26, at d = 0.0 ~ 4.0 m, the range of n variations seems to be between 2.0 ~ 4.0, which narrows down to d = 4.0 ~ 7.4 m where n is within the range of 1.0 ~ 2.18. At BH 26, the CPT test only reaches a depth of 3.0 m, as it encounters a sandstone layer lens, thereby making it difficult to analyze. However, for depths of 0.5 to 3 m, the value of n is stretched between 1.2 to 5.8.

At Cibatu, $n = qc/NSPT$ varied at a certain value, and different characteristics were observed. In BH 2A, the n values consistently increase and correspond to its depth, which was obtained as 10 at the end of the CPT test, d = 13.5 m. A similar incident occurred at BH 6, and it is closely related to the degree of clay shale weathering at the active zone, possibly reflected by *QC*.

This indicates the higher the *QC* value, the lower the weathering rate of the clay shale. At BH 2A, the weathering is estimated to have occurred at a depth of 7 m, while at BH 6A, it only reached 6 m. For BH 4, the bore log shows a layer of clayed sand soil at 10 m depth, with n values varying from 1.58 ~ 4.0, except at some points where the n value was 6.36.

Three statistical analyses were performed: (i) Least-squares linear correlation with an intercept at the origin, $qc = a + b.NSPT$ (ii) Least-squares linear correlation $qc = n.NSPT$ and (iii) Least square power correlation, qc = $c.NSPT^{d}$. Figure 6 shows the plotting of CPT against the SPT at a similar depth where both tests were carried out as well as the linear regression trendline and coefficient of determination, $R^2 = 0.65$.

$$n = qc/NSPT = 0.225 \text{ (Mpa)} \quad (1)$$

with:

$$\text{upper limit : } n = qc/NSPT = 0.33 \text{ (Mpa)} \quad (2)$$

$$\text{lower limit : } n = qc/NSPT = 0.15 \text{ (Mpa)} \quad (3)$$

This trend was generated by ignoring 4 (four) data situated far from the general trend. These were obtained from BH 2A, BH 4, BH6 taken at Cicau Village. The excessive value of CPT at this location reflects the sturdiness of the unexposed or unweathered clay shale. However, assuming the analysis was only made using data from Cibatu, a higher confidence level of R^2= 0.79 tends to be achieved.

6 DISCUSSION

The results are consistent with Robin (2012), which was carried out within 6 km of the study locations. Robin stated that the data distribution of *qc/NSPT* (Mpa) ranges from 0.14 to 0.34. Although the result of the upper boundary differs slightly, n = 0.38, this analysis was made by disregarding 2 data, namely BH 7, d = 12 m and BH 13, d = 16 m. At those depths, the cone penetration almost reaches its final reading, resulting in a high *QC* value of 12 MPa and 16.4 MPa.

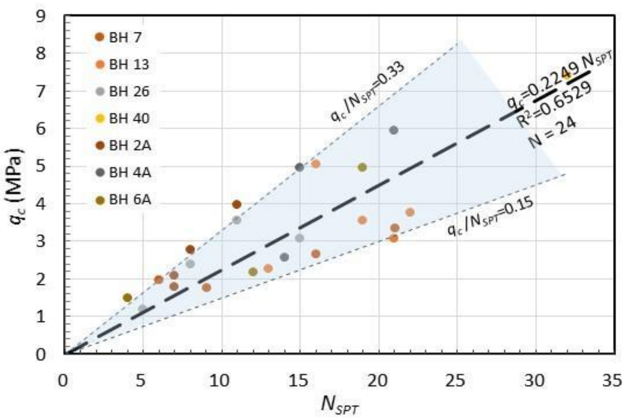

Figure 6. Variations of ratio *qc* vs *NSPT*

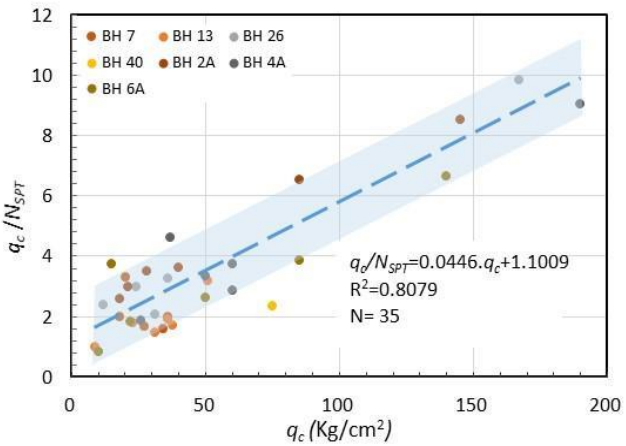

Figure 7. Variations of ration *qc/N* versus *qc*

Referring to Table 1, concerning silty and sandy clay, the results obtained are lower than Danzinger and Velloso (1995), which recommended *qc/NSPT* = 0.35 (Mpa) for soils in Brazil. Akca (2003) recommended *qc/NSPT* = 0.3 ~ 0.45 (Mpa) for those in the United Arab Emirates. This dissimilarity is influenced by differences in soil formation, both micro (minerals constituent) and stress history, which ultimately affects its behavior against CPT's cone penetration and spoon sample of SPT's test.

Based on the expansive clays studied, the low value of *n* might be due to the soil structure that is "open" compared to its original structure and experiences weathering. Its original structure is formed by its chemical bonding, thereby causing the stiffness of clay shale to become too high for a standard cone of CPT with 2.5 tons of pressure to be inserted. All tests experienced this phenomenon at Cicau locations. The CPT penetration tends to reach the depth of active zones. Consequently, up to the active zone depth, the soil structure is more 'exposed' as an effect of water content fluctuations, which swell and shrink, thereby losing its overburden pressure, causing it to be more 'opened' and the density lesser.

The earlier analysis does not include the skin friction and fs contributions. A similar correlation of *n = (qc + fs)/NSPT* was proposed by Schmertmann (1970) and Danzinger and De Valleso (1995), particularly for sandy soil. The data collected was used to carry out a certain analysis involving friction and fs contribution resulting in *n* = 0.34, which is almost similar if the skin resistance is disregarded. As shown on the test reported, the friction ratio is 1 ~ 4% of *QC*.

Robertson *et al.* (1983) stated that the *qc/NSPT* ratio is strongly influenced by the soil grain size (D_{50}), as shown in Figure 7. The penetration resistance ratio of *qc/NSPT* increases in accordance with a higher resistance, which D50 represents. This study did not follow the approach mentioned above because the mean grain size of clay is less than 0.002 mm. Since *QC* is a parameter of soil resistance, the ratio *qc/NSPT* needs to be proportional to the cone resistance *QC*.

Figure 7 shows the distribution of test data on expansive clay soil studied based on this hypothesis. It appears that this study acquired a *qc/NSPT* ratio that is directly proportional to the value of the cone resistance, *QC* resulting in a reliable coefficient of determination, R^2 =0.81. The equivalent NSPT value of the soil layer could be predicted from the CPT cone resistance, *QC*.

Comparing SPT and CPT data, it is evident that the CPT cone is unable to penetrate the firm clay layer with SPT > 15 ~ 25. The predicted depth of the active zones from water content is 12 m. Notably, the aforementioned maximum CPT cone penetration tends to be associated with the depth of the active zone. This is based on the consideration of soil layers that the CPT cone can penetrate. It includes the clay layers which have been weathered through dry and wet cycles. This phenomenon is evident in BH 7, BH 13, BH 2A, and BH 6A, except in BH 40, where the soil type encountered at a depth of 3 m is sandstone.

This led to an important finding because almost every commercial and industrial building, such as housing, factories, and low-rise offices in the Cikarang area, is always designed based on CPT test data. It is also important to note that the depth acknowledged through this analysis is most likely from the active zone acquired. The soils undergo swelling and shrinkage at this depth as the water content increases or decreases. The piles' designed length must be elongated underneath the active zone to avoid its detrimental effects. This is even more crucial to developing areas preceded by land grading. The CPT test was carried out at shallow depths because the active zone had not reached a stable depth. But over time, it tends to increase due to weathering. This factor must be considered in the future CPT test basis foundation design.

7 CONCLUSION

In conclusion, this study examined the correlations between SPT and CPT on Indonesian's expansive clay with dedicated 8 boreholes and CPT measurements of 2 m from one to another. Different types of correlations were tentatively tested, and the result showed that simple linear correlation *QC = n.NSPT* provides the best and most reasonable coefficients compared to the other functions. As shown on Figure 6 as well as Eqs. (1), (2) and (3), the correlation between SPT and CPT for Indonesia expansive clay is *n = qc/NSPT* = 0.225 (Mpa) with upper limit *n* = 0,33 (Mpa) and lower limit *n* = 0.15 (Mpa). These *n* values are relatively low compared to other studies reported around the globe. With respect to the clay soil, the low *n* values also reflect a decrease in density and cohesion bonding of expansive soil in the country.

The proposed correlation can radily be used to estimate and predict the NSPT soil parameter of known CPT's cone resistance, *QC* parameter or vice versa for correspond soils types and characteristics. Addition of more future SPT, CPT and Soil data will increase the accuracy of the proposed correlations.

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