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DEVELOPMENT OF RELATIONSHIP BETWEEN SPT AND DCPT BASED ON THE RELATIVE DENSITY OF SOILS (A CASE STUDY FROM THE KINGDOM OF SAUDI ARABIA)

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ABSTRACT

In-situ penetration tests such as standard penetration tests (SPT) and dynamic cone penetration tests (DCPT) have been widely used in geotechnical engineering for site investigation studies to identify the strength characteristics of investigated soil deposits. Both tests are performed by dropping a hammer from a certain fall height and measuring a penetration depth per blow for the relevant depths. SPT is typically performed at depth intervals of about 1.50m and it has a wide range of well-known defined relationships for parameter acquisition of the soils. DCPT, on the other hand, is a rapid and inexpensive alternative for the penetration tests and obtains continuous data for the investigated soil depths. Considering the advantage of DCPT in providing continuous data compared to SPT, developing correlations between SPT and DCPT can provide a relatively more comprehensive data set to perform data collection for geotechnical design. In this study, a site-specific correlation was developed with comprehensive SPT and DCPT results from renewable energy fields in the Kingdom of Saudi Arabia (KSA). Furthermore, a site-specific relative density class is derived from the SPT and DCPT results, in contrast to the relative density classes given in the literature. The relationship obtained for SPT and DCPT was found to be consistent with similar studies in the literature. The derived relationship can be used to obtain equivalent mechanical and physical soil properties for similar lithological conditions.

Keywords: SPT, DCPT, site investigation, relative density.

LITERATURE REVIEW FOR SPT AND DCPT CORRELATIONS

The SPT and DCPT relationship has been investigated and reported by many researchers. Evaluation of the SPT and DCPT relationship may give reasonable results in the cases where DCPT is being used to verify or support SPT data in an investigation (Lutenegger, 2021). Well-known reported correlations between SPT and DCPT are given in Table 1. DCP term refers to penetration blow count for DCPT, while SPT-N refers to the blow count number for SPT.

Table 1 Reported correlations for SPT and DCPT

DCP/SPT-N	References
2.0	Meyerhof (1956)
0.5-0.9	Gawad (1976)
0.8-3.5	Goel (1982)
1.00-1.15	Muromachi & Kobayashi (1982)
1.6	Rao et al. (1982)
0.50-0.67	Chang & Wong (1986)
0.50-0.66	McGrath et al. (1989)
0.83-1.10	Cabrera & Carcole (2007)
0.6-2.0	MacRobert (2017)

SPT AND DCPT RELATIONSHIPS FOR EQUIVALENT RELATIVE DENSITY

Look (2014) presented the intervals for DCP blow counts per relative density by considering that the Dynamic Cone Penetrometer (DCP) corresponds to the 1/3 of the energy of the SPT. Table 2 and Table 3 shows the comparison of SPT and relative density and DCP and relative density classes with predicted internal friction angle (Ø) intervals.

Table 2 Reported correlations for SPT and DCPT

Density	SPT-N (Blows/300mm)	Ø (°)
Very Loose	<4	Ø=15°-29°
Loose	4-10	Ø=29°-30°
Medium Dense	10-30	Ø=30°-36°
Dense	30-50	Ø=36°-41°
Very Dense	>50	Ø>45°

Table 3 Reported correlations for SPT and DCPT

Density	DCP (Blows/100mm)	Ø (°)
Very Loose	0-1	Ø<30°
Loose	1-3	Ø=30°-35°
Medium Dense	3-8	Ø=35°-40°
Dense	8-15	Ø=40°-45°
Very Dense	>15	Ø>45°

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As can be seen in Table 2 and Table 3, if only number of blows is compared, DCPT estimates higher ranges for Ø for all density classes of coarse-grained layers compared to SPT. Considering this conservative approach for DCPT's Ø predictions, it is thought that DCP density ranges and so predicted Ø should be re-derived. Simplified and new relationship for DCP ranges per density and predicted Ø is proposed for the study (See Table 4).

Table 4 Proposed density and predicted Ø transformations between SPT-N and DCP

SPT-N Range	DCP Range	Density and Predicted Ø (°)
0-10	3-8	Very Loose to Loose (Ø<30°)
10-30	8-15	Medium Dense (Ø=30°-35°)
30-50	15-25	Dense to Very Dense (Ø=35°-40°)

Therefore, the proposed relative density-based DCP ranges were matched with the SPT-N ranges in the table above and a correlation between the two test results was attempted to be obtained in the light of the data matching these ranges. Figure 1 shows the correlation curve of the relative density based SPT-N and DCP values from Look (2014) and the proposed relative density based SPT-N and DCP correlation curve derived from Look (2014). The accuracy of the derivation will be tested later in this study by processing the data in this manner and obtaining high regression values by reaching a large dataset.

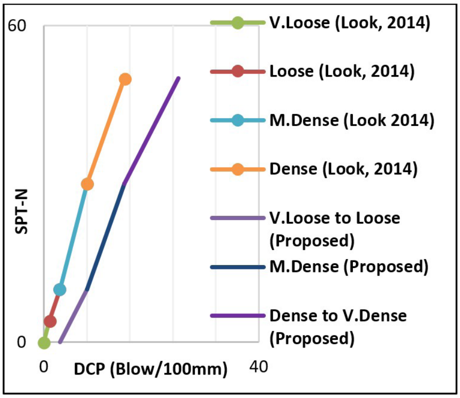

Figure 1 *Comparison of relative density based SPT-N and DCP curves*

DATA EVALUATION

The SPT and DCPT data from 6 renewable energy sites in the Kingdom of Saudi Arabia were evaluated in this context. Groundwater was not encountered during the soil investigations in the sites. Soil lithology was found as silty sand with completely weathered sandstone and siltstone formations. Summary information of the project sites is presented in Table 5. In the selection of SPT and DCPT data to be correlated, the fact that the boreholes (BH) and DCPT locations are adjacent to each other constituted the first stage for data extraction. With ArcGIS mapping program, buffers of the diameter given in the table were defined for each borehole in the sites and therefore the number of adjacent boreholes and DCPT locations was determined. In total, 369 SPT and DCPT datasets from 842 BHs and 441 DCPTs were found to be adjacent to each other.

Table 5 Summary Table of the Project Sites

Site	BH	DCPT	Buffer (m)	Adjacent Quantity
1	205	174	250	98
2	173	47	300	35
3	63	56	250	48
4	145	47	400	138
5	82	47	350	33
6	174	70	350	17
Total	842	441	-	369

SITE-1 RESULTS

Of the 98 adjacent SPT and DCPT datasets at Project site-1, 17 data sets were found that fit the proposed approach mentioned above. The density characteristics for the evaluated measurements are given as following;

- 2 points of measurement are in the range of very loose-loose state.
- 10 points of measurement are in the range of medium dense state.
- 5 points of measurement are in the range of dense to very dense state.

The proposed relationship between SPT-N and DCP blow counts is presented in Eq.1 for Project Site-1. The SPT-N and DCP graph for Project Site-1 is presented in Figure 2.

$$\text{SPT-N} = 1.654\ \text{DCP} + 0.99 \qquad R^2 = 0.61 \qquad (1)$$

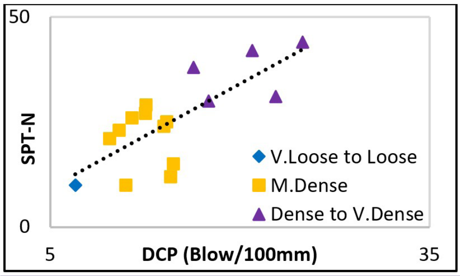

Figure 2 *SPT-N and DCP Relationship, Site-1*

SITE-2 RESULTS

Of the 35 adjacent SPT and DCPT datasets at Project site-2, 19 data sets were found that fit the proposed approach mentioned above. The density characteristics for the evaluated measurements are given as following;

- 9 points of measurement are in the range of very loose-loose state.
- 7 points of measurement are in the range of medium dense state.
- 3 points of measurement are in the range of dense to very dense state.

The proposed relationship between SPT-N and DCP blow counts is presented in Eq.2 for Project Site-2. The SPT-N and DCP graph is presented in Figure 3.

SPT-N = 2.02 DCP - 6.76 $\quad\quad$ R^2 = 0.82 $\quad\quad$ (2)

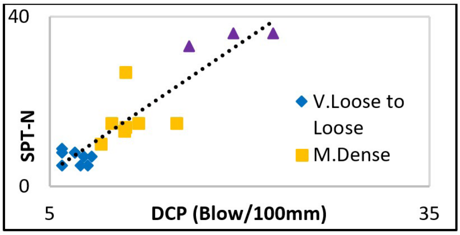

Figure 3 *SPT-N and DCP Relationship, Site-2*

SITE-3 RESULTS

Of the 48 adjacent SPT and DCPT datasets at Project site-3, 22 data sets were found that fit the proposed approach mentioned above. The density characteristics for the evaluated measurements are given as following;

- 14 points of measurement are in the range of very loose-loose state.
- 8 points of measurement are in the range of medium dense state.

The proposed relationship between SPT-N and DCP blow counts is presented in Eq.3 for Project Site-3. The SPT-N and DCP graph is presented in Figure 4.

SPT-N = 1.61 DCP - 2.94 $\quad\quad$ R^2 = 0.79 $\quad\quad$ (3)

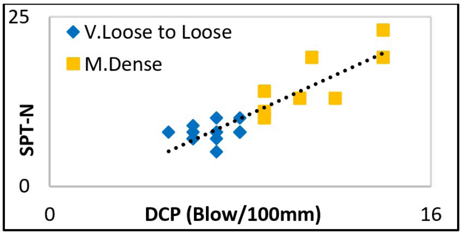

Figure 4 *SPT-N and DCP Relationship, Site-3*

SITE-4 RESULTS

Of the 138 adjacent SPT and DCPT datasets at Project site-4, 58 data sets were found that fit the proposed approach mentioned above. The density characteristics for the evaluated measurements are given as following;

- 21 points of measurement are in the range of very loose-loose state.
- 17 points of measurement are in the range of medium dense state.
- 20 points of measurement are in the range of dense to very dense state.

The proposed relationship between SPT-N and DCP blow counts is presented in Eq.4 for Project Site-4. The SPT-N and DCP graph is presented in Figure 5.

SPT-N = 2.27 DCP - 5.02 $\quad\quad$ R^2 = 0.83 $\quad\quad$ (4)

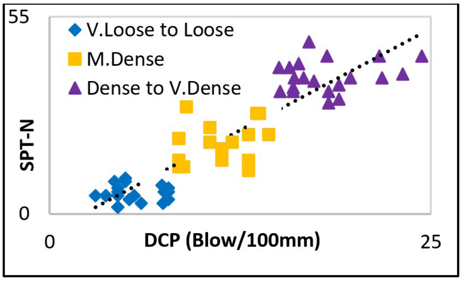

Figure 5 *SPT-N and DCP Relationship, Site-4*

SITE-5 RESULTS

Of the 33 adjacent SPT and DCPT datasets at Project site-5, 19 data sets were found that fit the proposed approach mentioned above. The density characteristics for the evaluated measurements are given as following;

- 15 points of measurement are in the range of medium dense state.
- 4 points of measurement are in the range of dense to very dense state.

The proposed relationship between SPT-N and DCP blow counts is presented in Eq.5 for Project Site-5. The SPT-N and DCP graph is presented in Figure 6.

SPT-N = 2.21 DCP - 6.03 $\quad\quad$ R^2 = 0.64 $\quad\quad$ (5)

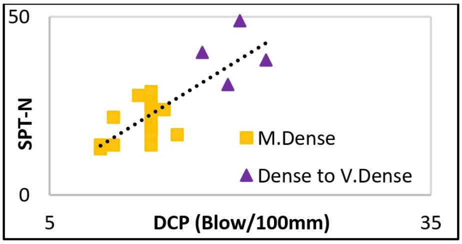

Figure 6 *SPT-N and DCP Relationship, Site-5*

SITE-6 RESULTS

Of the 17 adjacent SPT and DCPT datasets at Project site-6, 13 data sets were found that fit the proposed approach mentioned above. The density characteristics for the evaluated measurements are given as following;

- 11 points of measurement are in the range of medium dense state.
- 2 points of measurement are in the range of dense to very dense state.

The proposed relationship between SPT-N and DCP blow counts is presented in Eq.6 for Project Site-6. The SPT-N and DCP graph is presented in Figure 7.

SPT-N = 2.68 DCP - 13.19 R^2 = 0.67 (6)

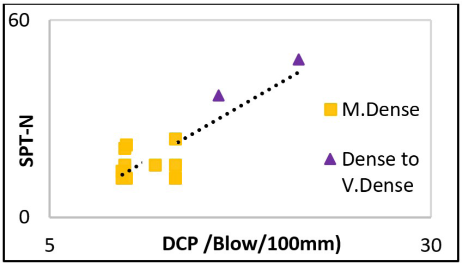

Figure 7 *SPT-N and DCP Relationship, Site-6*

RESULTS FOR ALL SITES

The proposed relationship between SPTN and DCP blow counts is presented in Eq.7 for all sites. The simplified expression of SPT-N and DCP relationship is presented in Figure 8. The density characteristics for the evaluated measurements are given as following;

- 46 points of measurement are in the range of very loose-loose state.
- 68 points of measurement are in the range of medium dense state.
- 34 points of measurement are in the range of dense to very dense state.

SPT-N = 2.20 DCP - 6.14 R^2 = 0.78 (7)

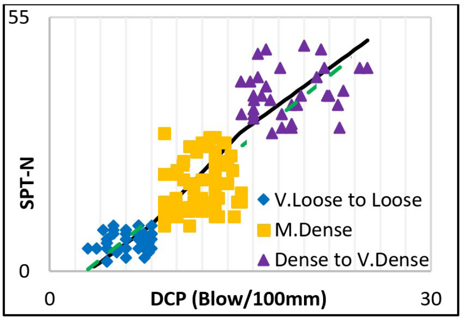

Figure 8 *SPT-N and DCP Relationship for All Sites*

COMPARISON DCP/SPT-N RATIO WITH THE LITERATURE

DCP/SPT-N ratio measurements are calculated for this study to check the consistency with the previous studies as presented in Table 1. The ratio varies between 0.30 to 2.48 with an average value of 0.75 (See Figure 9). The calculated ratio is compatible with the studies of Gawad (1976) and MacRobert (2017).

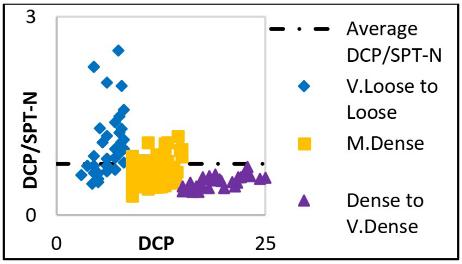

Figure 9 *DCP/SPT-N Ratio measurements for all sites*

RESULTS AND CONCLUSIONS

The aim of this study is to find a correlation between SPT and DCPT tests performed at energy sites in Saudi Arabia, therefore allowing future ground investigation with only DCPT without SPT at sites with similar ground conditions. The reason for this purpose is that DCPT is faster, cheaper and provides continuous data compared to SPT.

As a first step of the study, equivalent measurement ranges for SPT-N and DCP is compared for the same density classes of coarse-grained soils. After obtaining an idealized curve for SPT-N and DCP correlation, the site measurements are compared to check the consistency of the results if they fit the density-based distribution. Following assumptions were considered in the study;

- Depths with SPT-N blow values less than 50 (SPT-N<50) and DCP blow values less than 25 (DCP<25) are considered.
- Adjacent SPT and DCPT tests performed at the similar lithological conditions were used for correlation.
- The depth ranges of DCPT are compatible with SPT testing.
- If multiple DCPT measurements were taken for the equivalent depth of SPT N, the average of the DCP blow number was used in the correlation.

Within the scope of the study 6 project sites including 148 SPT and DCPT investigation points were considered. The results for each site were compared with the obtained density-based curve. Regarding to the compiled results, the general trend of proposed line as addressed in Figure 1 is compatible with obtained curve shown in Figure 8.

Among the 369 adjacent BH and DCPT points in the 6 sites used in the study, 273 points meet the SPT-N<50 and DCP<25 conditions at the same time. SPT-N was estimated from the DCPT data in the field using the Density based relationship presented in the study and the error between this estimate and the actual SPT-N values measured in the field was found by statistical evaluation of Mean Average Error (MAE). The MAE value of the 148 data used to determine the correlation and fitting the density-based breakdown (i.e. DCP:3-8 and SPT-N:0-10, DCP:8-15 and SPT-N:10-30, DCP:15-25 and SPT-N:30-50) was found to be 4.54, while the average measured SPT-N value was 19.41. According to these data, the relative error rate measured for each data was 23%.

This study can be used as a baseline for future studies, and it is aimed to reduce the errors of the proposed relation by enhancing the data sets at sites with similar ground conditions. Nevertheless, it should be emphasized that caution should be noted in the use of the correlation.

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