ORIGINAL RESEARCH

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Use of CPT and DCP based correlations in characterization of subgrade of a highway in Southern Ethiopia Region

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Abstract

Background: Necessity of highway infrastructure development has been renowned all over the globe. Key success for highway projects mainly depends on the characterization of subgrade soil intended for thousands of kilometers. In practice, any one of the soil test data may not provide exact characterization of subgrade and at least minimum two tests can be used to develop design values of subgrade for a highway pavement. Also, there is a need to have relationship between two to three soil parameters so as to understand evidently about the soil characteristics and their behavior.

Methods: Two test data such as CPT and DCP are utilized to develop statistical correlations for better site characterization. Ordinary least squares and the simple arithmetic mean methods are obtained for scatter plots of data pairs and different trends are fitted to the data. Correlation agreements between CPT and DCP for various combinations are plotted for 40 data sets.

Results: Liquid limit values ranged from 22 to 56 %, while plastic limits are ranging in between 16 and 43 %. Plasticity index values are varying from minimum 1 % to maximum of 29 %, indicating low to medium swelling potential. Based on the American Association of State Highways and Transportation Officials soil classification system, soil along the chosen highway alignment includes A-2-4, A-4, A-2-5, A-2-7, A-1(a), A-1(b), A-7-6 and A-6. Similarly, according to Unified Soil Classification System, the dominant soils along the highway stretched are placed into inorganic silts or organic clays (MH or OH), inorganic clays (CL), inorganic silts or organic silts (ML and OL), and combinations of the two (CL-ML). Deliberation of sleeve friction measurements resulted minor improvement in correlations and these may be considered trivial. According to Roberson's chart, the distribution of CPT and DCP data obtained along the highway route encompasses four zones. Zone 4 (i.e., silt mixtures: clayey silt to silty clay), zone 5 (sand mixtures: silty sand to sandy silt), zone 6 (sands: clean sand to silty sand), and zone 8 (very stiff sand to clayey sand), with some scattered data points are located in zone 9 (very stiff, fine-grained).

Conclusions: The correlations developed in this study indicates that, CPT ($q_c + f_s$) and DCP (q_c) correlations are very much enhanced compared to other combinations studied in terms of higher coefficient of correlation and least transformation uncertainty. The CPT and DCP data obtained along the highway route is superimposed in Roberson's chart to characterize the subgrade soil swiftly.

Keywords: Subgrade, Southern Ethiopia, Sleeve friction, Frictional resistance, CPT, DCP

Background

Geotechnical site characterization plays vital role in selection of pavement layers such as surface course, base course, subbase and subgrade. For most of the highway projects, cone penetration test (CPT) and dynamic cone penetrometers (DCP) are extensively used worldwide. These tests provide continuous and uninterrupted stratigraphic data with the improved resolution along the depth of penetration. The data obtained from these tests are less disruptive as compared to the data obtained from drilling operations. The CPT and DCP data has got a strong theoretical acceptance [19]. Soil samples cannot be retrieved during the operation of these tests. Visual inspection to promote the soil classification of subgrade is the only drawback in these tests. However, these tests are expedient, repeatable, and economical [30].

Most valid and acceptable information can be obtained about the subgrade or stratigraphy of a particular location, if combination of testing approaches are employed during the geotechnical site investigations [32]. The transformation error from measured to evaluated value of soil property can be significantly reduced with the use of two to three test methods at the site [6, 8, 22]. In the recent past, CPT has been considered as one of the combination tests in soil investigation in Ethiopia mainly to have a data that can cross verify the data obtained from other test so as to develop confirmed design. The CPT can thereby maximize geotechnical characterization of a subgrade at an affordable price. It can be distinguished that the DCP has gained popularity in road projects mainly due to its economy and simplicity to operate and also its superiority to provide repeatable results to assess soil property rapidly. A perfectly performing soil testing method is only an impossible fantasy as there is always adjustment between one parameter to another. It is a fact that, both CPT and DCP are well recognized approaches with a rich performance history in the different parts of the globe. The theoretical acceptance and recognition of CPT and DCP test data by the scientific community, gave a light further to develop correlation between CPT and DCP in this study. In addition, there are also number of correlations between standard penetration test (SPT), light dynamic probing test (DPL), and CPT [15, 17, 21, 31, 35]. However, there are no many such correlations available in the literature in the case of DCP relating to CPT.

There are many factors that influence correlations developed at different conditions: such as geology prevailing at the site, normalization and general treatment of data, degree of control of soil variability effects, the range of soil strength/stiffness and methods of determining correlations. Most of the correlations developed between the geotechnical parameters by the investigators may not meet all those criteria and preferred to develop simplified expressions or correlations as close to the accuracy by considering possible environmental factors [34].

Now a days, classification of soil types using CPT are interconnected directly to soil classification charts [7, 9, 12, 15, 20, 24, 27–29, 34]. Many number of probabilistic soil classification approaches are available in the literature [5, 16, 18, 36]. Among the available soil classification charts, Robertson's soil classification chart has gained popularity because it accounts past observations and also engineering experience and judgment by the experienced professionals. The soil is based on two parameters such as: the normalized friction ratio, $F_R = \left[\frac{100f_s}{(q_t - \sigma_{vo})} \right]$, and the normalized tip resistance, $Q_t = [(q_t - \sigma_{vo}) / \sigma'_{vo}]$, obtained from penetration test data, where f_s , q_t , σ_{vo} , and σ'_{vo} are

Table 1 Description of zones in Robertson's soil classification chart (after [29])

Zone	Soil description
1	Sensitive, fine grained
2	Organic soils (peats)
3	Clays (clay to silty clay)
4	Silt mixtures (clayey silt to silty clay)
5	Sand mixtures (silty sand to sandy silt)
6	Sands (clean sand to silty sand)
7	Gravelly sand to sand
8	Very stiff sand to clayey sand
9	Very stiff, fine grained

the sleeve friction, corrected tip resistance, vertical total stress, and vertical effective stress, respectively. The chart is divided into nine zones corresponding to nine different soil types, as presented in Table 1. For the known ratios of F_R and Q_c , the soil zone would be identified.

This paper integrates the soil domains collected along the highway path selected (Modjo to Hawassa in the area of southern Ethiopia) and developing the correlation between CPT and DCP. Two penetrometer test data was collected within the interval of 1 m to avoid the subgrade inconsistency and classification of soil domains using Robertson's soil profiling is also discussed.

Site description and geology

The highway considered in this study links between Modjo and Hawassa in the area of southern Ethiopia. Most part of the highway selected is passing through Oromia region in Ethiopia and is a part of the major Mombasa—Nairobi—Addis Ababa highway. This highway has significant economic importance due to the connectivity with neighboring countries. In contemporary, it has a two lane, two—way carriage way stretching around total length of 209 km. The data was collected upto 25 km of the highway which was being rehabilitated into dual carriage way. The selected highway route has a flat terrain topography with no undulations. The geographical co-ordinates are $8^{\circ} 39' N$, $39^{\circ} 5' E$ for Modjo, and $7^{\circ} 3' N$, $38^{\circ} 28' E$ for Hawassa.

Methods

Penetrometers and testing

Numerous penetrometers are in practice worldwide for investigation and characterization of subgrade. There are many developments in geotechnical instrumentation which are noticed in both the penetrometers, but more have been made on the dutch cone penetrometer (DCPT). CPT has also got many improvements, which increases its capability to handle diverse ground conditions [4], accurately identifying soil types [3, 23, 29], and gives better estimates of relevant geotechnical soil parameters. The CPT equipment used in this study has the following accessories: anvil and driving rod, a 10 kg rammer, height of fall of 50 cm, 11 sounding rods, lifting device for sounding rods, and couplings all in a box casing weighing approximately 71 kg. The cone tip angle of the penetrometer used in this study is 60° and rods are 20 mm in diameter. Both qualitative

and quantitative interpretation of the CPT readings in this study followed the guidelines of DIN: 4094—Part 2 [10].

The DCP used in this study has the following accessories: a steel rod with a cone at one end with a base diameter of 20 mm and apex angle of 60°. It is driven into the subgrade by a sliding hammer weighing 8 kg from a height of 575 mm. Two people are usually required to penetrate the equipment into soil. However, the manpower can be reduced to one person by using an electronic device to record the data. According to ASTM D 6951 method, apex angle 60° is better than 30° and became more popular in the recent past due to its durability in high-strength materials.

Statistical tool

In common practice, statistical tools can be used for analysis, interpretation, presentation, and organization of data sets. Among the available tools, descriptive statistics summarizes the data from mean or standard deviation, and inferential statistics, which draws conclusions from data that are subject to random variation (e.g., observational errors, sampling variation). In this study, ordinary least squares and the simple arithmetic mean methods are used to obtain the scatter plots of data pairs and different trends fitted to the data.

The best fit agreement between chosen alternatives was determined using Eq. 1 [11]. For a linear regression, the coefficient of correlation (r) can be determined using Eq. 2, and is checked for significance by comparing the critical values as recommended in the Pearson product—moment correlation table. The standard error of estimate (S_e) was determined using Eq. 3.

$$R^2 = \frac{\sum(\hat{Y}_i - \bar{Y})^2}{\sum(Y_i - \bar{Y})^2} \quad (1)$$

$$R^2 = r^2 \quad (2)$$

$$S_e = \sqrt{\frac{\sum(Y_i - \hat{Y}_i)^2}{z - 1}} \quad (3)$$

where, R^2 is coefficient of determination, r is coefficient of correlation, Y_i is the i th value of a data set, $\bar{Y}$ is mean of the data set and $\hat{Y}_i$ is the i th fitted value, z is the number of data points, and S_e is the standard error of estimate. The degree of uncertainty persuaded, while measuring a parameter can be transformed to a desired property [1, 26] using regression analysis. The magnitude of transformation uncertainty can be expressed by an indicator z . The coefficient of variation (COV) of the transformation uncertainty from parameter X to Y can be determined by the ratio between S_e and the mean as indicated by Eq. 4.

$$COV_{X \rightarrow Y} = \frac{S_e}{\bar{Y}} \quad (4)$$

where $X \rightarrow Y$ transform from parameter X to Y and $\bar{Y}$ is the mean of parameter Y .

Fig. 1 In situ soil profile at chainage 8 + 450 RHS

Fig. 2 Gradation analysis of test samples along the selected highway

Results and discussion

Field observations

In this study, around 40 test points were chosen along the highway. Typical geotechnical characteristics of existing subgrade obtained from testing are presented in Table 2. In situ soil profile at chainage 8 + 450 RHS is shown in Fig. 1. Designation of the trend of gradation analysis, around six selected test points are presented in Fig. 2. From this figure, it can be seen that the percentage passing through sieve No. 200 is about 20 %

at chainage 13 + 900 LHS and 79 % at the chainage 4 + 00 LHS and it can be seen that most of the soil is in the form of fine grained textures.

Atterberg limits such as liquid limit and plastic limits are also presented in Table 2. From this table, it can be noticed that, liquid limit values ranged from 22 to 56 %, while plastic limit values are ranging in between 16 and 43 %. Plasticity index values are varying from minimum 1 % to maximum of 29 %, indicating low to medium swell potential (Fig. 3). The soil domains in Fig. 3 are modified according to the Casagrande's plasticity chart considering A—line classification system. Laboratory analyses of consistency limits with gradation analysis places the soil, in a quite wide range of soil types. Based on the American Association of State Highways and Transportation Officials (AASHTO) soil classification systems, soil along the proposed alignment includes A-2-4, A-4, A-2-5, A-2-7, A-1(a), A-1(b), A-7-6 and A-6. According to Unified Soil Classification System (USCS), the dominant soils along the highway stretch considered are positioned into inorganic silts or organic clays (MH or OH), inorganic clays (CL), inorganic silts or organic silts (ML & OL), and combinations of the two (CL-ML).

The estimated natural moisture content (NMC) of existing subgrade is ranging from 11.2 to 16.9 %, while liquidity index is ranging from -1.5 to -0.3 . In general, the range of liquidity index can be from -1.0 to $+1.0$ [25]. From the compaction test results, it can be seen that the value of maximum dry density (MDD) for soil is ranging from 1.07 gm/cc (10.7 kN/m^3) at Ch.9 + 600 LHS to 2.10 gm/cc (21.0 kN/m^3) at Ch. 3 + 300 RHS; and the optimum moisture content (OMC) is ranging between 7.8 and 25 % at Ch. 13 + 500 LHS and Ch.6 + 000 RHS, respectively.

Correlation agreements between CPT and DCP

It is necessitated to develop the relationship between CPT and DCP, with various combinations of sleeve frictions encompassing the selected highway route. This need has arisen from the necessity that to achieve reliable and consistent geotechnical analysis, CPT and/or DCP are essential. In this exploration, around 40 data pairs were gathered and plots are developed using various combinations and are presented in Figs. 4, 5, 6 and 7.

Method of least squares tool was used to obtain the best fit relationship between CPT (q_c) and DCP (q_c) and the best fit line is showed in Fig. 4. It can be seen from the figure that by considering all the data points the following expression is obtained.

$$DCP(q_c) = 1.1209 CPT(q_c) + 0.2296 \quad (5)$$

Equation 5 has high correlation of $r = 1.305$ and $S_e = 0.9026$. The transformation uncertainty between CPT (q_c) and DCP (q_c) ($COV_{trans CPT(q_c) \rightarrow DCP(q_c)}$) is therefore determined to be 30.73 %. Subsequently, filtering the data set, the new expression is obtained (Eq. 6) with $r = 1.331$ and $S_e = 1.011$, which sorts ($COV_{trans CPT(q_c) \rightarrow DCP(q_c)}$) descent to 25.15 %.

$$DCP(q_c) = 1.2894 CPT(q_c) - 0.1977 \quad (6)$$

In most of the circumstances, the magnitudes of sleeve friction are significant and could not be simply overlooked. Because in summing up the values, sleeve friction values improve correlation between the normalized parameters. A statistical correlation

Table 2 Geotechnical characteristics of subgrade along the highway route alignment

S.no	Test points	Chainage along the alignment	Natural moisture content (NMC) (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Liquidity index	Optimum moisture content (OMC) (%)	Maximum dry density (MDD), gm/cc	Sieve sizes (mm)				AASHTO classification	Unified soil classification system (USCS)
										4.75	2	0.425	0.075		
1	Test point. 1	Ch..3 + 050 LHS	20.5	55	26	29	-0.2	20.0	1.63	98	87	78	63	A-7-6	MH or OH
2	Test point. 2	Ch..3 + 100 LHS	16.2	44	25	19	-0.5	15.0	1.76	72	95	90	57	A-7-6	CL
3	Test point. 3	Ch..3 + 150 RHS	11.5	29	20	9	-0.9	10.0	1.96	98	80	70	48	A-2-4	ML & OL
4	Test point. 4	Ch..3 + 250 RHS	20.9	45	29	16	-0.5	21.0	1.56	99	86	77	62	A-7-6	CL
5	Test point. 5	Ch..3 + 300 RHS	17.2	34	25	9	-0.9	16.0	2.10	100	80	65	45	A-4	CL
6	Test point. 6	Ch..4 + 000 LHS	23.5	46	31	15	-0.5	22.5	1.51	97	94	88	79	A-7-5	CL
7	Test point. 7	Ch..4 + 400 LHS	13.2	29	19	10	-0.6	11.2	1.80	100	78	61	39	A-4	CL-ML
8	Test point. 8	Ch..4 + 750 LHS	19.6	41	24	17	-0.3	19.0	1.69	87	98	88	73	A-7-6	CL
9	Test point. 9	Ch..5 + 000 RHS	16	32	21	11	-0.5	14.5	1.90	83	92	78	53	A-6	ML & OL
10	Test point. 10	Ch..5 + 250 RHS	14.2	26	18	8	-0.5	14.0	1.78	80	92	73	45	A-4	ML & OL
11	Test point. 11	Ch..5 + 500 LHS	18.2	25	22	3	-1.3	17.5	1.60	56	96	80	32	A-2-4	ML & OL
12	Test point. 12	Ch..5 + 750 LHS	15.8	31	25	6	-1.5	15.0	1.98	100	72	60	32	A-4	ML & OL
13	Test point. 13	Ch..6 + 000 RHS	17.6	35	27	8	-1.2	17.0	1.56	97	84	72	53	A-4	ML & OL
14	Test point. 14	Ch..6 + 250 RHS	12.6	29	27	2	-7.2	11.0	1.90	37	97	92	26	A-2-4	ML & OL

Table 2 continued

S. no	Test points	Chainage along the alignment	Natural moisture content (NMC) (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Liquidity index	Optimum moisture content (OMC) (%)	Maximum dry density (MDD), gm/cc	Sieve sizes (mm)				AASHTO classification	Unified soil classification system (USCS)
										4.75	2	0.425	0.075		
15	Test point. 15	Ch.6 + 000 RHS	25.8	36	30	6	-0.7	25.0	1.54	86	95	90	71	A-4	CL
16	Test point. 16	Ch.6 + 500 LHS	15.2	41	29	12	-1.2	14.0	1.40	89	93	71	53	A-7-6	CL
17	Test point. 17	Ch.6 + 750 RHS	19	35	32	3	-4.3	17.0	1.32	100	86	85	71	A-1b	CL
18	Test point. 18	Ch.7 + 150 LHS	17	34	33	1	-16.0	16.2	1.40	100	76	47	23	A-2-4	CL
19	Test point. 19	Ch.7 + 450 LHS	13	23	21	2	-4.0	12.0	1.85	97	81	80	58	A-1b	ML & OL
20	Test point. 20	Ch.7 + 800 LHS	16.8	33	28	5	-2.2	16.1	1.50	77	93	66	36	A-4	ML & OL
21	Test point. 21	Ch.8 + 150 RHS	16.8	38	30	8	-1.7	17.0	1.39	88	88	69	49	A-4	CL
22	Test point. 22	Ch.8 + 450 RHS	17.5	47	39	8	-2.7	16.2	1.45	87	90	84	61	A-2-5	CL
23	Test point. 23	Ch.8 + 900 RHS	20	40	30	10	-1.0	19.0	1.67	72	99	86	57	A-4	CL
24	Test point. 24	Ch.9 + 200 RHS	14	49	37	12	-1.9	12.6	1.90	89	86	85	60	A-2-7	CL
25	Test point. 25	Ch.9 + 250 LHS	12	38	35	3	-7.7	10.0	1.65	92	88	65	45	A-1b	CL
26	Test point. 26	Ch.9 + 600 LHS	21	56	43	13	-1.7	19.5	1.07	100	67	75	42	A-2-7	CL
27	Test point. 27	Ch.9 + 850 LHS	17	31	25	6	-1.3	15.0	1.64	100	76	68	42	A-2-4	ML & OL
28	Test point. 28	Ch.10 + 000 RHS	17	36	26	10	-0.9	16.4	1.28	98	66	75	39	A-4	CL

Table 2 continued

S. no	Test points	Chainage along the alignment	Natural moisture content (NMC) (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Liquidity index	Optimum moisture content (OMC) (%)	Maximum dry density (MDD), gm/cc	Sieve sizes (mm)				AASHTO classification	Unified soil classification system (USCS)
										4.75	2	0.425	0.075		
29	Test point. 29	Ch..10 + 400 RHS	15.1	27	19	8	-0.5	13.8	1.90	84	72	85	41	A-2-4	ML & OL
30	Test point. 30	Ch..10 + 650 RHS	16.5	25	18	7	-0.2	15.8	1.76	90	69	76	35	A-2-4	ML & OL
31	Test point. 31	Ch..10 + 900 RHS	14	28	21	7	-1.0	13.2	1.96	91	68	76	35	A-2-4	ML & OL
32	Test point. 32	Ch..11 + 100 LHS	12.4	29	19	10	-0.7	11.3	1.91	94	60	75	29	A-2-4	ML & OL
33	Test point. 33	Ch..11 + 250 LHS	13.4	28	21	7	-1.1	11.6	1.83	98	66	70	34	A-2-4	ML & OL
34	Test point. 34	Ch..11 + 600 LHS	14	29	24	5	-2.0	11.8	1.84	92	55	75	22	A-1b	ML & OL
35	Test point. 35	Ch..11 + 850 LHS	13.1	27	18	9	-0.5	10.5	1.94	98	62	65	25	A-2-4	ML & OL
36	Test point. 36	Ch..12 + 800 RHS	14	29	24	5	-2.0	11.6	1.84	98	68	57	23	A-1b	ML & OL
37	Test point. 37	Ch..12 + 950 RHS	9.5	25	22	3	-4.2	8.0	1.97	100	43	95	38	A-1a	ML & OL
38	Test point. 38	Ch..13 + 000 LHS	19	22	16	6	0.5	17.6	1.78	100	53	75	28	A-1a	ML & OL
39	Test point. 39	Ch..13 + 500 LHS	9	23	18	5	-1.8	7.8	2.07	96	85	39	20	A-1a	ML & OL
40	Test point. 40	Ch..13 + 900 LHS	9.5	25	19	6	-1.6	8.2	2.00	97	49	74	20	A-1a	ML & OL

Fig. 3 Classification of soil domains along the highway considered in the study

Fig. 4 Statistical correlation between CPT (q_c) and DCP (q_c)

between CPT ($q_c + f_s$) and DCP ($q_c + f_s$) is presented in Fig. 5. From Fig. 5, the following expression (Eq. 7) can be obtained with a moderate correlation of $r = 1.3585$ and $S_e = 0.9956$ as compared to CPT (q_c) and DCP (q_c) with transformation uncertainty of 28.64 %.

$$DCP (q_c + f_s) = 1.1667 CPT (q_c + f_s) - 0.1119 \quad (7)$$

Subsequently, sorting out the data set, a new correlation is obtained (Eq. 8) with $r = 1.3239$ and $S_e = 1.039$, which forms $(COV_{trans CPT (q_c + f_s) \rightarrow DCP (q_c + f_s)})$ descent to 26.55 %.

$$DCP (q_c + f_s) = 1.2346 CPT (q_c + f_s) - 0.107 \quad (8)$$

In addition, the relationships between CPT (q_c) vs DCP ($q_c + f_s$) and CPT ($q_c + f_s$) vs DCP (q_c) are furnished in Figs. 6 and 7. A statistical correlation between CPT (q_c) and DCP ($q_c + f_s$) is presented in Fig. 6. From this figure, the following best fit (Eq. 9) is obtained with a high correlation of $r = 1.4295$ and $S_e = 1.1297$. The transformation uncertainty between CPT (q_c) and DCP ($q_c + f_s$) $(COV_{trans CPT (q_c) \rightarrow DCP (q_c + f_s)})$ is therefore determined to be 30.12 %.

$$DCP (q_c + f_s) = 1.1817 CPT (q_c) + 0.2173 \quad (9)$$

Afterwards, filtering the data set, a new expression (Eq. 10) was obtained with $r = 1.3377$ and $S_e = 1.1257$, which makes $(COV_{trans CPT (q_c) \rightarrow DCP (q_c + f_s)})$ descent to 29.93 %.

$$DCP(q_c + f_s) = 1.1847CPT(q_c) + 0.1776 \quad (10)$$

Likewise, a statistical correlation (Eq. 11) between CPT ($q_c + f_s$) and DCP (q_c) is developed from the data presented in Fig. 7. The correlation presented in Eq. 11 has a high correlation of $r = 1.2411$ and $S_e = 0.794$.

$$DCP(q_c) = 1.1057CPT(q_c + f_s) + 0.139 \quad (11)$$

The transformation uncertainty between CPT ($q_c + f_s$) and DCP (q_c) ($COV_{transCPT(q_c+f_s) \rightarrow DCP(q_c)}$) is therefore determined as 22.18 %. After filtering the data set, the new expression (Eq. 12) is obtained with $r = 1.2048$ and $S_e = 0.773$, which makes ($COV_{transCPT(q_c+f_s) \rightarrow DCP(q_c)}$) descent up to 21.78 %.

$$DCP(q_c) = 1.1029CPT(q_c + f_s) + 0.1187 \quad (12)$$

Robertson's soil profiling

Soil profiling charts have been amended and improved from a large data base obtained from various geotechnical site characterization studies carried out by the good number of investigators [23, 33]. Previous researches have also illustrated the importance of cone design and the effect of water pressures on the measured penetration resistance and sleeve friction, because of uneven surface at the end [2, 4]. Consequently, cones of slightly different designs, but conforming to the international standard [14] and

reference test procedures [13], will give slightly different values of q_c and f_s , especially in soft clays and silts.

The variation of the logarithm of normalized friction ratio $\ln (F_R)$ and tip resistance $\ln (Q_t)$ using CPT and DCP data points along the selected highway route, based on Robertson's chart is presented in Fig. 8. As it can be observed from the figure that, the soil profile principally encompasses zone 4 (i.e., silt mixtures: clayey silt to silty clay), zone 5 (sand mixtures: silty sand to sandy silt), zone 6 (sands: clean sand to silty sand), and zone 8 (very stiff sand to clayey sand), with some scattered data points located in zone 9 (very stiff, fine-grained).

Summary and conclusion

This paper integrated the geotechnical characterization of a selected highway route. The soils are characterized by organic and inorganic silts, organic and inorganic clays within the depth of subgrade. In contrast, relationships shaped in this study indicates that, CPT ($q_c + f_s$) and DCP (q_c) correlations are very much improved compared to other combinations studied in terms of higher coefficient of correlation and least transformation uncertainty. Deliberation of sleeve friction measurements resulted in minor improvement in of correlations and these may be considered insignificant. According to Roberson's chart, the distribution of the CPT and DCP data obtained along the highway route encompasses four zones. Zone 4 (i.e., silt mixtures: clayey silt to silty clay), zone 5 (sand mixtures: silty sand to sandy silt), zone 6 (sands: clean sand to silty sand), and

zone 8 (very stiff sand to clayey sand), with some scattered data points are located in the zone 9 (very stiff, fine-grained). Overall, it is seen that the statistical correlations developed from the vast data points can help the site and design engineers to have a clear idea about the stratigraphy of a particular location for taking appropriate planning and design steps of an intended infrastructure project to meet the requirements of sustainability.

Authors' contributions

SPKK collected the raw data and carried out preliminary sort out. DKN was taken care of statistical analysis and developed linear relationships between the parameters. Both authors involved in compilation of whole manuscript write-up and finally read and approved for the submission. Both authors read and approved the final manuscript.

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Acknowledgements

The authors are grateful to the Techniplan S.P.A for their cooperation in providing the raw data.

Competing interests

The authors declare that they have no competing interests.

Received: 7 February 2016 Accepted: 16 August 2016

Published online: 30 August 2016

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