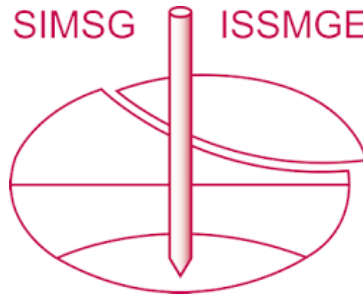


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Equivalent CPT Method for estimation of shear strength parameters for a project site in Kolkata using combination of SPT, DMT and CPT- a case study

Méthode CPT équivalente pour l'estimation des paramètres de résistance au cisaillement pour un site de projet à Kolkata en utilisant une combinaison de SPT, DMT et CPT - une étude de cas

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ABSTRACT: In this paper focus is given to a selected project site for the present study purposes. This particular site is situated at Rajarhat area in Kolkata city of India. The subject site comprises building structures with pile foundation. The soil investigation was carried out by two different approaches i.e., conventional laboratory tests on the collected undisturbed samples, and field tests consisting of Standard Penetration Test (SPT), Cone Penetration Test (CPT) and Marchetti Flat Dilatometer Test (DMT). This paper describes a comparative study of undrained cohesion (C_u) and friction angle (Φ) measured from the laboratory and field tests. Also an attempt is made to establish a site specific correlation between the two basic parameters of DMT and CPT i.e., horizontal stress index (K_D) and normalized cone resistance (Q_t) respectively for providing the subsoil model for the investigation area. It was observed that the values of shear parameters (C_u and Φ) calculated using the new correlation is close to the values obtained from other tests. It was also noted that the variation over the depth of the values of C_u and Φ estimated by new correlation are similar in nature compared to the other tests.

RÉSUMÉ : Dans cet article, l'accent est mis sur un site de projet sélectionné aux fins de la présente étude. Ce site particulier est situé dans la région de Rajarhat dans la ville de Kolkata en Inde. Le site en question comprend des structures de bâtiments avec fondation sur pieux. L'étude du sol a été réalisée par deux approches différentes, à savoir des tests de laboratoire conventionnels sur les échantillons non perturbés collectés et des tests sur le terrain comprenant un test de pénétration standard (SPT), un test de pénétration de cône (CPT) et un test de dilatomètre plat de Marchetti (DMT). Cet article décrit une étude comparative de la cohésion non drainée (C_u) et de l'angle de frottement (Φ) mesurés à partir d'essais en laboratoire et sur le terrain. On tente également d'établir une corrélation spécifique au site entre les deux paramètres de base du DMT et du CPT, à savoir l'indice de contrainte horizontale (K_D) et la résistance normalisée du cône (Q_t) respectivement pour fournir le modèle de sous-sol pour la zone d'étude. Les valeurs des paramètres de cisaillement (C_u et Φ) calculées à l'aide de la nouvelle corrélation sont proches des valeurs obtenues à partir d'autres essais. Il a également été noté que les variations sur la profondeur des valeurs de C_u et Φ estimées par nouvelle corrélation sont de nature similaire par rapport aux autres tests.

KEYWORDS: CPT; DMT; K_D , Q_t ; Correlation.

1 INTRODUCTION.

The Cone Penetration Test (CPT) and Standard Penetration Test (SPT) are commonly used field tests in India for geotechnical investigation purpose. Marchetti Flat Dilatometer (DMT), apart from being one of the renowned and latest in-situ test equipment, entered as a recent member in geotechnical investigation field in India. This equipment was invented by Prof. (Dr.) Silvano Marchetti in 1974 at the L'Aquila University in Italy. Shear strength parameters i.e., undrained cohesion (C_u) and angle of internal friction (Φ) along with some other geotechnical parameters of subsoil can be estimated by the Flat Dilatometer test.

In this regard, a subject area (CA94) was selected at "Rajarhat" which is situated on the eastern part of Kolkata city. The subject area, namely CA94 consists of typical normal Calcutta deposit. This site was dedicated for the construction of building structure. In this present study, the scope of geotechnical investigation included digging boreholes, laboratory test on collected samples, standard penetration test

estimated from the newly developed correlation and compared with the values obtained from field (DMT, CPT, SPT) and laboratory triaxial UU tests.

2 SITE INVESTIGATIONS

2.1 SPT tests and bore logs

In the research site two numbers of bore holes namely BH1 and BH2 as shown in Figure 1, were dug within the projected area of the building up to the depth of 30 m. The undisturbed samples from each borehole were collected from every 3m depth interval inside the borehole. The SPT tests were carried out as per IS Code 2131-1981. The number of blows required for the last 30 cm penetration of the split spoon sampler was recorded as 'N'-value. On the other hand, laboratory tests were carried out on the undisturbed samples. The triaxial tests (UU) were conducted to estimate the undrained cohesion (C_u).

Angle of internal friction ϕ (Φ) was calculated from the correlation as stated in Eq. 1, with the SPT N value (Kumar et al. 2016):

$$\Phi = 27.12 + 0.2857 \times N \text{ (when } N = 4 \text{ to } 50) \quad (1a)$$

$$\Phi = 7 \times N \text{ (when } N < 4) \quad (1b)$$

(SPT), dilatometer test (DMT) and static cone penetration test (CPT).

In this particular paper the shear strength parameters i.e., undrained cohesion (C_u) and angle of internal friction (Φ), are

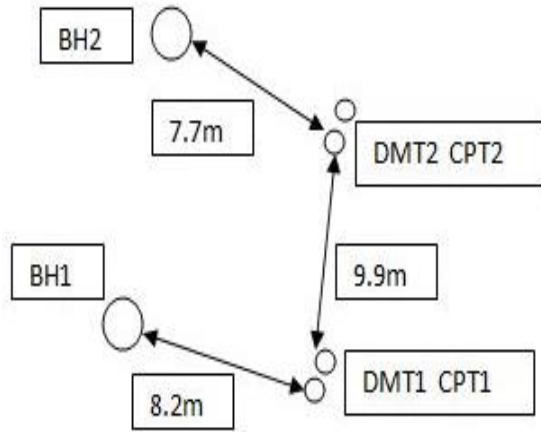


Figure 1. Location plan of study area

2.2 Cone penetration test

The CPT test was carried out at the study area by penetrating the cone (Begemann Bit) vertically to the sub-surface at a constant strain rate ($\approx 2\text{cm/s}$) with aid of Pagani TG 63-150 penetrometer and three consecutive readings (i.e., R_p , R_p+R_L and R_T) were taken on every depth interval ($\approx 20\text{cm}$) upto the depth of 17m below ground level. On the basis of observed readings, the following parameters as given in Eq.2, were estimated for the study purpose (Robertson et al. 1983; Robertson et al. 1988; Kulhawy et al. 1990; Robertson et al. 2009; Motaghedi et al. 2013; Robertson et al. 2014). The tests were carried out in two locations, namely CPT1 and CPT2 as shown in Figure 1.

$$C_u = (q_t - \sigma_v) / N_{kt} \quad (2a)$$

Where:

q_t = corrected cone resistance (q_c) for CPT tests without piezocone

σ_v = total overburden pressure [i.e., $\sum(Z_i \times \gamma_i)$]

Z_i = depth of the i^{th} layer from the ground surface

γ_i = soil unit weight of the i^{th} layer

$\gamma/\gamma_w = 0.27 \times (\log R_f) + 0.36 \times [(\log(q_t/P_a))] + 1.236$

γ_w = Unit weight of water

P_a = Atmospheric pressure

R_f = friction ratio (i.e., $[f_s/q_t] \times 100\%$)

N_{kt} = Cone factor (here it is 14)

Phi (Φ) is calculated from the following equation (Robertson et al. 1983; Motaghedi et al. 2013; Robertson et al. 1988; Robertson et al. 2014)

$$\Phi = \tan^{-1}\{0.1 + 0.38 \log\left(\frac{q_c}{\sigma_{v0}}\right)\} \quad (2b)$$

σ_{v0} Or σ'_v = effective overburden pressure

q_c = corrected cone resistance

Normalized Cone resistance (Q_t):

$$Q_t = (q_c - \sigma_v) / \sigma'_v \quad (2c)$$

Normalized Friction resistance (F_r):

$$F_r = [f_s / (q_c - \sigma_v)] \times 100\% \quad (2d)$$

Soil Behavior type index:

$$(I_c) =$$

$$[(3.47 - \log Q_t)^2 + (\log F_r + 1.22)^2]^{0.5} \quad (2e)$$

2.3 Flat dilatometer test

The Flat Dilatometer Test (DMT) is a pushed-in type test, used to estimate the compressibility characteristics of the soils in very short time with accuracy. The flat dilatometer is made up of a steel blade with size $95\text{mm} \times 200\text{mm} \times 15\text{mm}$, provided with an expandable steel membrane on one face, as shown in Figure 2 and corresponding photographs of the tests are shown in Figure 3. Any non-corrosive gas (here it is Nitrogen gas) pressure is required to expand the membrane. During the test, by taking the pressure readings, three numbers of basic parameters, namely Material Index (I_D) Horizontal Stress Index (K_D) and Dilatometer modulus (E_D) (Marchetti 1980; TC16 2001; Bandyopadhyay et al. 2015), are calculated as given in Eq. 3. This equation simultaneously governs the stiffness and strength properties of soil.

In the study area, undrained cohesion (C_u) and angle of internal friction (Φ) (Marchetti 1980; Marchetti 1997; TC16 2001; Mayne 2006; Halder et al. 2017) were calculated on the basis of Material Index (I_D), Dilatometer Modulus (E_D), Horizontal stress index (K_D), upto the depth of 17m (below ground level) as given in Eq.4 and Eq. 5 respectively for the two numbers of DMT tests locations i.e., DMT1 and DMT2, as shown in Figure 1.

Material Index:

$$(I_D) = [(p_1 - p_0) / (p_0 - u_0)] \quad (3a)$$

Dilatometer Modulus:

$$(E_D) = 34.7 \times (p_1 - p_0) \quad (3b)$$

Horizontal stress index:

$$(K_D) = [(p_0 - u_0) /] \quad (3c)$$

Undrained cohesion (C_u):

$$C_u = 0.22 \times \sigma'_{v0} \times (0.5 \times K_D)^{1.25} \quad (4)$$

Friction Angle (Φ):

$$\Phi = 28^\circ + 14.6^\circ \times \log(K_D) - 2.1^\circ \times (\log K_D)^2 \quad (5)$$

Where, p_0 and p_1 are corrected first and second readings corresponding to two pressure readings i.e., lift-off pressure (A) and final pressure (B) readings of DMT. The pre-insertion pore pressure is u_0 and σ'_{v0} is effective overburden pressure calculated at each depth.

3 RESULTS

3.1 Soil profile

It was observed from the laboratory test results that the sub-soil mainly comprises silty clay upto the depth of 17m below the ground level, as shown in Figure 4.

In the DMT and CPT tests, the indication of soil type can be assessed from the material index (I_D) (Marchetti 1980; Marchetti 1997; TC 16, 2001; Mayne 2006) and soil behavior type index (I_c) (Robertson et al. 1983; Robertson et al. 1988; Robertson 2009; Kulhawy & Mayne 1990; Robertson & Cabal 2014) respectively. In the study area, it was observed that the values were lying in the range given by Eq. 6 and Eq. 7, indicating the type as silt/clay soil upto the depth of 17m.

$$0.06 < I_D < 0.83 \quad (6)$$

$$2.26 < I_c < 3.58$$

(7)

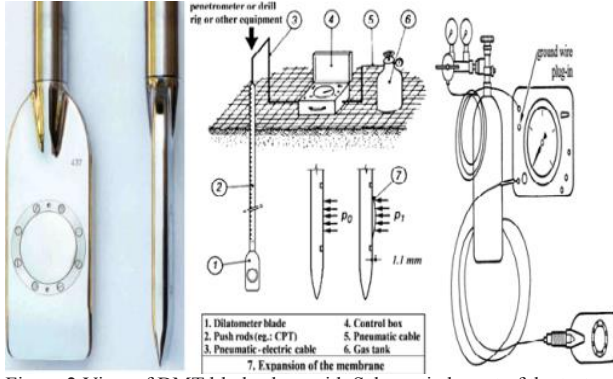


Figure 2. View of DMT blade along with Schematic layout of the test



Figure 3. Few Photographs of the tests

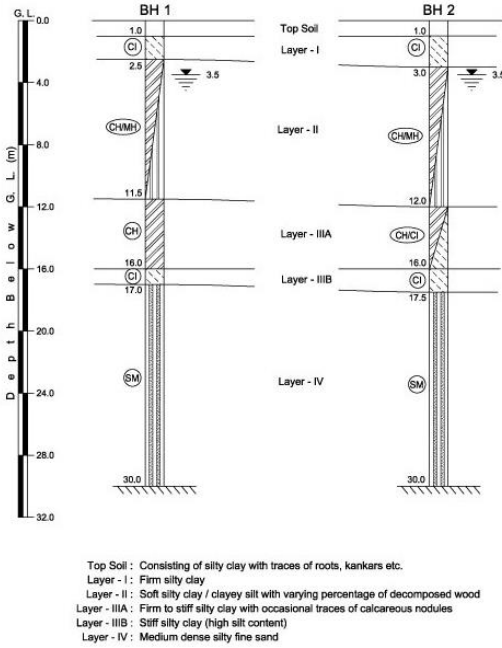


Figure 4. Soil profile of the site from soil boring method

3.2 K_D and Q_t

The K_D and Q_t are the parameters which provide soil strength and stiffness properties from DMT and CPT tests respectively. Both of these parameters are normalized and dimensionless variables.

Good quality data were taken for this study. The overall values of K_D and Q_t values were calculated from the one meter depth-wise averaged values for the individual test point.

The estimated average values of K_D and Q_t were then plotted for the individual location along with overall site and these are plotted in Figure 5, Figure 6 and Figure 7 respectively. Based on these plots, a site specific correlation between K_D and Q_t has

been established as given in Eq.8, to determine shear strength parameters in terms of the normalised cone resistance (Q_t), (Jamiołkowski et al. 1988; Mayne 2002; Mayne 2006; Robertson 2009).

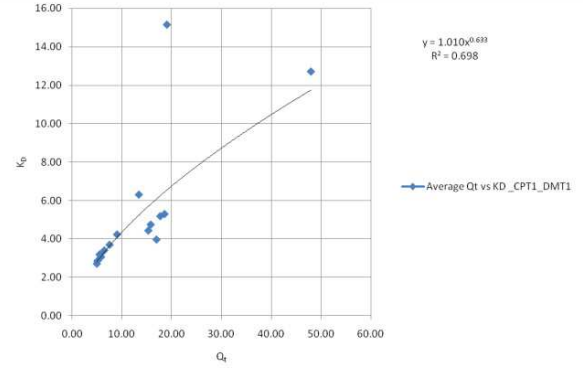


Figure 5. Average K_D vs Average Q_t plot for the position CPT1_DMT1

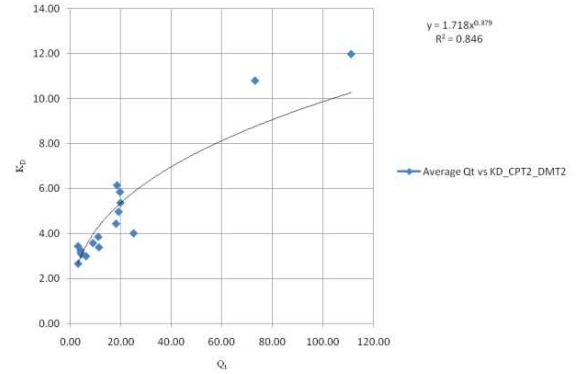


Figure 6. Average K_D vs. Average Q_t plot for the position CPT2_DMT2

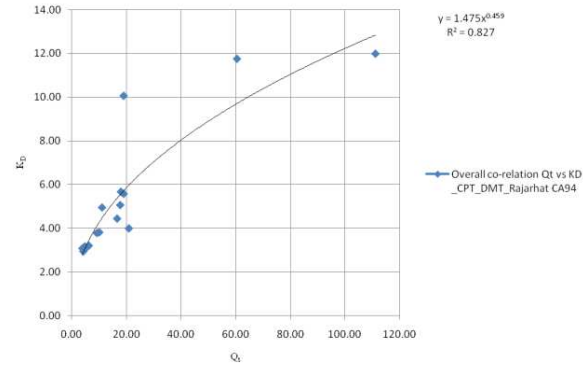


Figure 7. Overall K_D vs. Q_t plot for the site Rajarhat CA94

$$K_D = 1.475 \times Q_t^{0.459} \quad (8)$$

3.3 Undrained cohesion (C_u)

The newly developed correlation (as given in Eq.8) is further used to determine the undrained cohesion for the two locations namely CPT1_DMT1 and CPT2_DMT2. The term K_D in Eq.4, (Marchetti 1980; Marchetti 1997; TC 16 2001) is substituted for the term normalized cone resistance Q_t to estimate undrained cohesion, as given in Eq.9. The undrained cohesion (C_u) for the two test points are then estimated in terms of Q_t from Eq. 9 and compared with those obtained from the laboratory triaxial (UU) tests and field tests e.g., CPT, DMT etc., as shown in Figure 8a and Figure 8b. The summarized values are given in Table 1.

Undrained cohesion (C_u):

$$C_u = \left[0.22 \times \sigma'_{v0} \times \left[0.5 \times 1.475 \times Q_t^{0.459} \right]^{1.25} \right] \quad (9)$$

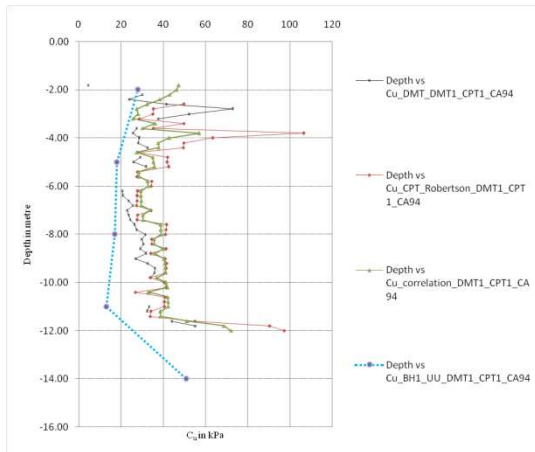


Figure.8a. Variation of undrained cohesion with depth at the location DMT1_CPT1

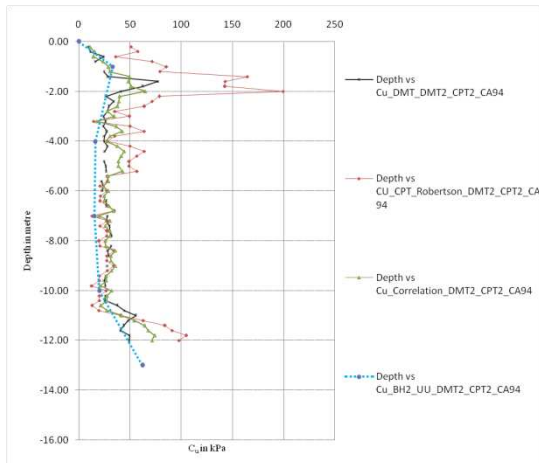


Figure.8b. Variation of undrained cohesion with depth at the location DMT2_CPT2

Table 1. Comparison of undrained cohesion (C_u) in kN/m^2

Test location	type	Values		unit
		Maximum	minimum	
DMT1_CPT1	UU	51	13	kN/m^2
	CPT	97	27	kN/m^2
	DMT	73	4	kN/m^2
	correlation	72	26	kN/m^2
DMT2_CPT2	UU	62	15	kN/m^2
	CPT	98	13	kN/m^2
	DMT	77	9	kN/m^2
	correlation	74	11	kN/m^2

3.4 Angle of internal friction (Φ)

For the estimation purpose of angle of internal friction (Φ), the horizontal stress index (K_D) from the correlated equation, i.e., Eq.8, is substituted for K_D in the equation (i.e., Eq.5) which was originally proposed by Marchetti for DMT tests (Marchetti 1980; Marchetti 1997; TC 16 2001). Thereafter, the values of angle of internal friction (Φ) are calculated from the modified equation, as presented in Eq.10, and compared with the values estimated from DMT, CPT and SPT tests. These are plotted in Figure 9a and Figure 9b. Summarised values are given in Table 2.

$$\Phi = 28^\circ + 14.6^\circ \times \log(1.475 \times Q_t^{0.459}) - 2.1^\circ \times \{\log(1.475 \times Q_t^{0.459})\}^2 \quad (10)$$

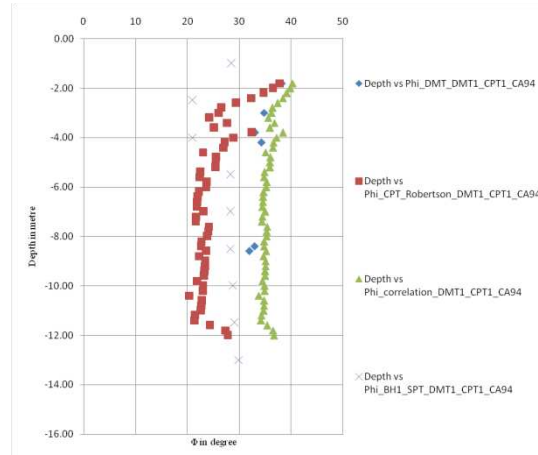


Figure.9a. Variation of Φ with depth at the location DMT1_CPT1

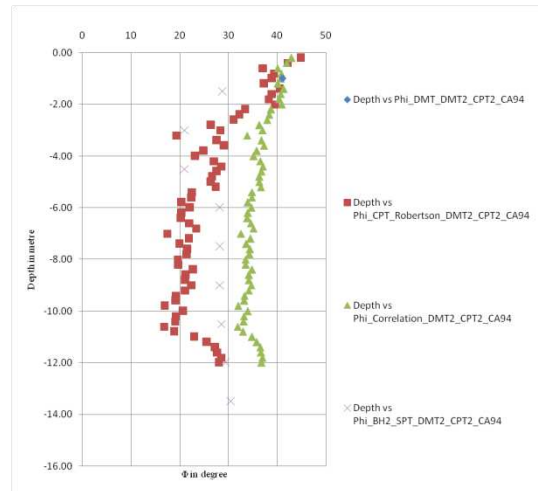


Figure.9b. Variation of Φ with depth at the location DMT2_CPT2

Table 2. Comparison of angle of internal friction (Φ) in degree

Test location	type	Values		unit
		Maximum	minimum	
DMT1_CPT1	SPT	30	21	Degree
	CPT	38	20	Degree
	DMT	38	32	Degree
	correlation	40	34	Degree
DMT2_CPT2	SPT	31	21	Degree
	CPT	45	17	Degree
	DMT	41	41	Degree
	correlation	43	32	Degree

4 DISCUSSIONS

In this present study an effort is made to formulate a site specific correlation between horizontal stress index, K_D and normalised cone resistance, Q_t to obtain the basic soil shear strength parameters C_u and Φ from field tests.

It is observed that the variation of undrained cohesion (C_u) with depth is similar in nature for all the tests along with the values estimated from the correlation.

In the present study, the undrained cohesion is estimated upto the depth of 12 m which predominantly consists of soft silty clay/clayey silt as shown in Figure 4. The value of undrained cohesion are found from laboratory triaxial tests and is found to vary between 13 to 51 kN/m^2 for the borehole BH1 near to DMT1_CPT1 test location and 15 kN/m^2 to 62 kN/m^2 for the bore hole BH2 near to DMT2_CPT2 test location respectively. The estimated values of undrained cohesion vary

between 27 to 97kN/m² and 13 to 98kN/m² for the CPT tests attests points DMT1_CPT1 and DMT2_CPT2 locations respectively. On the other hand, in two DMT tests corresponding to DMT1_CPT1 and DMT2_CPT2 test locations, the estimated undrained cohesion are obtained in the range of 4 to 73kN/m² and 9 to 77kN/m² respectively.

In this regard, the estimated value of undrained cohesion from the correlated equation are in the range of 26 to 72kN/m² and 11 to 74kN/m² for the DMT1_CPT1 and DMT2_CPT2 test locations respectively.

The values of undrained cohesion estimated from CPT tests, are found to be on the higher side upto Layer I as shown in Figure 4 for both CPT tests locations. Although, the values of undrained cohesion estimated from DMT tests, CPT tests and correlation depict more or less similar and consistent results compared to the values calculated from laboratory Triaxial UU tests. It is also observed that graphical representation of undrained cohesion along depth is more or less similar for all the cases.

In this study the angle of internal friction is also calculated from the SPT, CPT, DMT field tests and in addition from correlated equation. The values estimated from SPT tests are in the range of 21° to 30° and 21° to 31° for the BH1 and BH2 borehole locations respectively. On the other hand, the value of angle of internal friction varies between 20° to 38° and 17° to 45° for the CPT1 and CPT2 tests respectively. The values obtained are in the range of 32° to 38° for DMT1 test and 41° from DMT2 test respectively. In addition, the values of internal friction calculated from correlation vary between 34° to 40° and 32° to 43° for the said two test locations, i.e., DMT1_CPT1 and DMT2_CPT2 respectively. In view of the values of angle of internal friction, it is perceived that the values estimated from correlation equation are more or less close to the values obtained from DMT tests for both the test locations.

5 CONCLUSIONS

- From the present investigation, it is observed that along the depth, the variation of undrained cohesion (C_u) is more or less consistent for all the cases.
- Estimated values of angle of internal friction from correlated equation are found to be more or less equal to the values obtained from DMT tests and also it is showing similar type of variation along depth with regard to other tests.
- Estimated values of undrained cohesion from CPT tests are found to be on the higher side in comparison with the laboratory Triaxial (UU) and field DMT tests in the depth range of Layer I for both the test points.
- It is also found that the correlation depicts reasonable assessment of shear parameters compared to other tests.
- Hence, it is concluded that the present correlation relating K_D and Q_t may be used for the determination of C_u and Φ with more or less similar sub-soil profile.
- Further research may be carried out on the correlation between horizontal stress index (K_D) and normalised cone resistance (Q_t) by carrying out field tests for some other test sites.

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