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"Research Note"

UNIT SKIN FRICTION FROM THE EXTENDED DYNAMIC CONE PENETROMETER (*EDCP*) TEST SUPPLEMENTED BY MEASUREMENT OF TORQUE WITHIN TESTING WELLS*

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Abstract– The Extended Dynamic Cone Penetration (*EDCP*) test supplemented by measurement of torque (EDCP-*T*) may be used to obtain a direct measurement of unit skin friction (f_s) between the cone section and the surrounding soil. The test is performed after completion of the *EDCP* test. In order to perform the EDCP-*T*, the *EDCP* device is rotated after driving the rod and maximum torque is measured using a calibrated torque wrench that is connected to the top of the *EDCP*. The EDCP-*T* test results at 3 sites are presented. The results show that the unit skin friction values obtained from the EDCP-*T* generally correlate well with normalized blows for 30 cm penetration of the *EDCP* tip ($N_{EDCP(n)}$). The results may be valuable for preliminary estimation of unit skin friction of the driven piles.

Keywords– Penetration, driven piles, rod friction, geotechnical properties, coarse grained, fine grained

1. INTRODUCTION

Scala (1959) originally developed the Dynamic Cone Penetrometer *(DCP)* in Australia [1]. Some relationships have been developed between *DCP* and *CBR* results (e.g., [2]) and elastic modulus (E) (e.g., [3] and [4]). The Dynamic Cone Penetrometer *(DCP)* has been described by ASTM 6951-03 [5]. The typical *DCP* consists of an 8-kg hammer that drops over a height of 575 mm. In this research, a *DCP* with an added torquemeter and the ability to determine the unit skin friction (Extended Dynamic Cone Penetrometer or *EDCP*) is used (Fig. 1). This device could be used within testing wells, throughout the soil profile. The number of blows for 30 cm of penetration ($N_{EDCP(n)}$) is recorded as an in situ measure of soil strength.

To calculate pile capacity, the end bearing and the shaft resistance must be determined. Shaft resistance is the side friction along the entire length of the pile and is determined by multiplying the total pile surface area by unit skin friction, where unit skin friction is defined as the frictional resistance per unit area [6, 7].

A series of tests were performed to investigate the value of unit skin friction of the cone section obtained from rotation of the *EDCP* steel rods. Skin friction is calculated by recording maximum torque, measured after driving the *EDCP* tip into the ground within the testing well. The tests were conducted at 3 sites on both fine-grained and coarse-grained soils.

Many researchers have determined the unit skin friction from *SPT* and *CPT* test (e.g., [8]). These researchers presented some relation between the *N* value obtained from *SPT* and the unit skin friction. It

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seems logical that while the actual *N* value obtained from *SPT* may be subject to wide variation (i.e., the particular operator, rod length, hammer energy, etc.), the *EDCP* device does not experience such a variation.

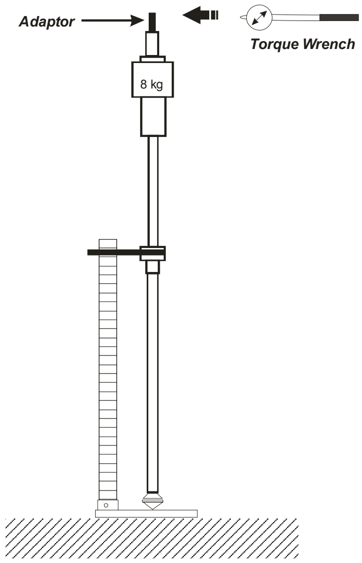

Fig. 1. Structure of Extended Dynamic Cone Penetrometer (*EDCP*) used in the present research

The EDCP-*T* provides a direct measurement of the torque required to rotate the tip after it is driven into the ground. The torque measurement may be used to provide an estimate of the soil-steel unit skin friction using Eq. (1) [6]:

$$f_s = \frac{2T}{\pi d^2 L} \tag{1}$$

where *T*= measured Torque; *d*= outside diameter of rod (for *EDCP* diameter of the cone section); and *L*= length of penetration (for *EDCP* height of the cone section).

EDCP-*T* tests are performed by attaching a small adapter to the top of the handle section of *EDCP* after driving. A common direct-read torque wrench with a capacity of 120 N.m and precision of 1 N.m connected to the assembly was rotated to ensure that all cone section connections were tight.

The N_{EDCP} (number of blow count for 30 cm of penetration) values were converted to the normalized value, $N_{EDCP(n)}$, using Eq. (2) [9]:

$$N_{eque} = \frac{2}{d}\frac{e\tau}{WgH} \tag{2}$$

where N_{eque}= equivalent blow, *d*= diameter of tip (m), e= value of penetration (m) for each step, τ= value of torque (N.m), W= Weight of hammer, H=height of hammer fall (m) and g= acceleration due to gravity.

The N_{eque} values were deducted from N_{EDCP} (i.e. $N_{EDCP(n)} = N_{EDCP}$-N_{eque}).

2. FIELD TESTS

Tests were performed at 3 sites across Iran to evaluate the unit skin friction measured using EDCP-*T* method. The evaluation consisted of directly comparing the corresponding $N_{EDCP(n)}$ values obtained prior to the torque measurement with the EDCP-*T* test f_s values computed by Eq. (1). Table 1 shows a summary of some geotechnical properties of soil at each site with geology descriptions and the soil classifications according to ASTM standard 2487-00 [10]. At each site, EDCP-*T* tests were performed throughout the entire profile to obtain sufficient data.

Table 1. Summary of some geotechnical properties of soil at each site

Site	Description of soil (soil classification)	Water cont. (%)	Unit weight (KN/m^3)	SPT Blows (N)	Angle of friction (degrees)	Effective cohesion (kPa)
Sarshour Hotel in Mashhad[a]	Loose to medium dense, silty sand (SM), silty clay (CL-ML)	4-28	16.5-19	10-30	20-26	0-10
Negin Complex in Rasht[b]	Loose to medium dense, silty sand (SM)	19-30	18-20	12-50	0-33	0-5
Morvarid Complex in Rasht[c]	Stiff to very stiff, sandy silt (ML) to high plasticity silt (MH), high plasticity clay (CH), low plasticity clay (CL)	18-26	18-19	17-50	19-30	10-33

[a]North East of Iran
[b]North of Iran
[c]North of Iran

3. RESULTS

During the initial work, it was observed that there is a unique relationship between the *N* value and the torque measured [6]. These observations suggest that a simple relationship could be developed between $N_{EDCP(n)}$ and f_s. Figures 2 and 3 show the graphical results of the tests at each site. The correlation is somewhat different at each site, which suggests that the correlation is soil specific. Similar observations have been made for the *N* values of *SPT*, where the unit skin friction (the skin friction of standard sampler) is also dependent on the soil type [6]. Each linear correlation shown in Figs. 2 and 3 has the general form of Eq. (3):

$$f_s = \alpha_s N_{EDCP(n)} \tag{3}$$

where α_s = empirical factor; and f_s = unit skin friction (kPa).

Equation (3) has the same form as a number of reported correlations between deep foundation unit skin friction values and *SPT's N* values [11]. The reported f_s correlation values for *SPT* test (α_s) presented in the literature are soil dependent and range between 0.3 and 10.

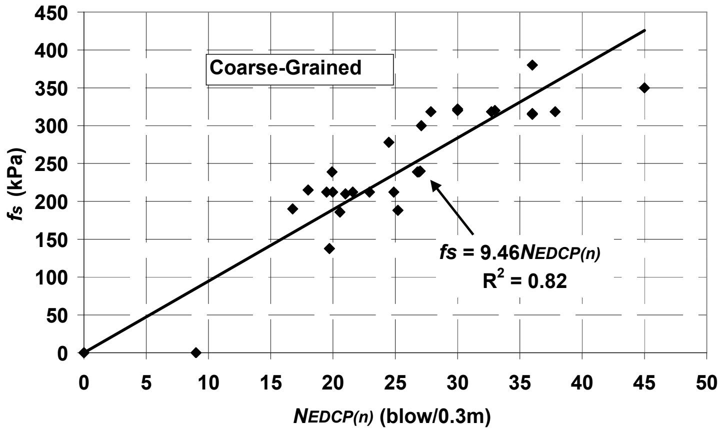

Fig. 2. Unit skin friction versus $N_{EDCP(n)}$ for Coarse-Grained soils

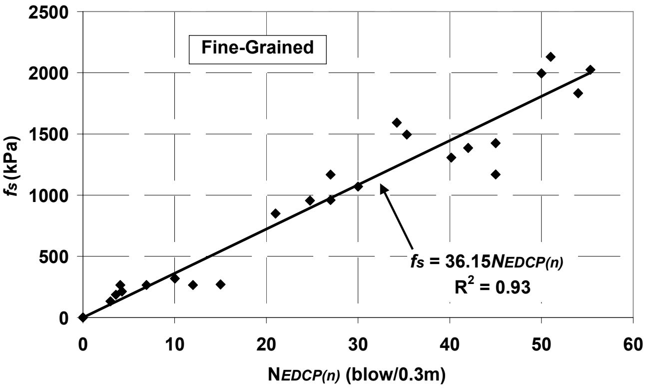

Fig. 3. Unit skin friction versus $N_{EDCP(n)}$ for Fine-Grained soils

The correlation between f_s and N_{60} suggested that *SPT* is largely a skin friction test, something that was noted nearly 30 years ago by Schmertmann [12]. In comparing the average trend lines suggested by the EDCP-*T* data from these sites, the EDCP-*T* unit skin friction values were higher than the f_s correlation provided by Meyerhof [11] and Kelly & Lutenegger [6] for *SPT* tests.

The first possible explanation is that the SPT's *N* values used by Meyerhof [11] were likely obtained in earlier years using either a pin-weight hammer, where the *N* values would be higher as a result of the lower energy levels produced by this type of hammer. In such a condition, the values of α_s are lower.

The second possible explanation is that the SPT's *N* values used by Kelley and Lutenegger [6] were obtained from the standard *SPT* sampler which is a hollow tube section and has not been considered in Eq. (1). In such a condition, the values of f_s are lower than the actual values.

4. CONCLUSION

Application of *EDCP* device with supplemental torque measurement is a novel addition to the widely accepted *DCP* device, normally used by engineers. The EDCP-*T* may prove to be cost effective for the preliminary design of deep foundations since minimal added time and effort are required. The simple procedure of measuring torque after driving provides a direct measurement of f_s to be employed by the design engineers. EDCP-*T* 's f_s data were compared to SPT-*T* obtained from other researchers studies. The results presented in the present research may also help to provide justification for application of *EDCP* for the design of piles, if torque (i.e., f_s) is not directly measured. There is strong evidence that the dynamic penetration measurement of *EDCP* ($N_{DCP(n)}$ value) is directly correlated to the static unit skin friction along the side of the *EDCP* cone for specific soil types (e.g., α_s).

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