A Preliminary Method to determine DCP Rod Friction Correction in Tropical Soils

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ABSTRACT: The Dynamic Cone Penetrometer (DCP) is a simple, portable and economical equipment that has been used in pavement application for the in-situ measurement of CBR. Recently its application as a site investigation tool where it is referred to as the Dynamic Probing Light (DPL) for simple structures is increasing. However, its widespread acceptance as a reliable site investigation tool in the ranks of the SPT depends on finding a method to measure and account for the rod friction component in the measured DPL values. This study therefore seeks to develop a simple but reliable field method of measurement of rod friction correction to be applied to measured DPL values for use in design. Two variations of the method were investigated. The assumptions underlying the methods are examined, the rod friction variations in the two methods compared and discussed. The preliminary comparison with existing correlations between N_{SPT} and N_{DPL} and the likely influence of the rod correction are discussed.

1 INTRODUCTION

The Dynamic Cone Penetrometer (DCP) is a simple, portable and inexpensive equipment that is used for in-situ investigations. For a long time, this equipment has been used in pavement engineering applications where it is used mainly for the in-situ determination of the California Bearing Ratio (CBR). However, in recent times, in many developing countries, the equipment is being used as a convenient site investigation tool for the design of shallow foundations of light structures including domestic single to two storey structures. When it is used in the latter application, the equipment is classified by the International Symposium of Penetration as the Dynamic Probing Light (DPL). The most common approach to use the DPL as a foundation design tool is to correlate the DPL readings with a foundation design parameter such as the Standard Penetration Test (SPT) N-value. The application of the DPL for design of electrical transmission tower foundations has been well discussed in Ampadu et al (2018).

As a penetrometer, the theoretical input energy (E_{in}) applied to drive the penetrometer into the soil which is equal to the penetration resistance (R_d) is resisted by the sum of the rod resistance (R_f) and the cone resistance (R_c) as shown in Equation 1.

$$R_d = R_c + R_f \qquad \text{Equation 1}$$

In the particular case of the DPL, however, the equipment has been designed in such a way that the cone diameter is slightly larger than the rod diameter. The design therefore assumes that the sides of the rod do not touch the walls of the hole created by the cone and therefore in DPL testing it is assumed that the rod friction is negligible (i.e. R_f=0) and further that all the driving energy is absorbed by the penetrometer. For DCP use in pavements involving shallow penetrations of up to about 1.0m, this assumption of R_f=0 has been found to be valid and so the DCP has been used without any corrections. However, in its application as a site investigation tool as DPL, involving penetrations of up to about 5.0m, it is no longer possible to prevent the rod touching the sides of the excavation or the sides of the excavation caving in onto the rods during the cone penetration. Under such circumstances therefore it is no longer valid to assume that the shaft resistance is zero. The normal test procedure involves determining the number of blows (N_{DPL}) required to produce a penetration of 100mm. The relationship between the penetration resistance and the resistance per 100mm penetration (N_{DPL}) is given in Equation 2.

$$R_d = K_2 N_{DPL} \quad \text{Equation 2}$$

However, in order to obtain a valid correlation between the N_{DPL} and other strength measurements such as the SPT N-values, the value of the rod resistance (N'_{DPL}) need to be determined in order to correct the N_{DPL} values for the rod friction according to Equation 3.

$$N_{DPL} = N''_{DPL} + N'_{DPL} \quad \text{Equation 3}$$

Ampadu et al., (2018) identified the inability to measure shaft friction as one of the key drawbacks to the use of the DPL. MacRobert et al., (2011) reported that the inability to account for the effect of rod friction is one reason militating against the widespread use of the Dynamic Probing Super Heavy (DPSH) among engineers in the Republic of South Africa.

Several attempts including those of Dahlberg and Bergdahl (1974), Bergdahl (1979) and Abuel-Naga (2011) have been made in the past to measure the rod friction. However, in these cases, either the methods are considered not simple enough or they have not been applied in a tropical environment.

This study therefore seeks to develop a simple and practical method to measure the rod friction in the field and so be able to correct the DPL values for the rod friction. The method is based on the procedure proposed by Abuel-Naga (2011) but modified for the equipment design available in the sub region. This paper presents the results of a preliminary test in one location where two variations of the method were performed. A 5.0m deep borehole was drilled and the SPT N-values were obtained as a standard strength parameter. Then two DPL tests were performed at a distance of 1.0m from the borehole. In the first variation, the N_{DPL} values were measured continuously to the depth of 5.0m, followed by the 1.0m cycles of withdrawal and re-penetration with measurement of re-penetration N'_{DPL}. In the second approach the N_{DPL} and N'_{DPL} values were measured in simultaneous 1.0m cycles of penetration-withdrawal and re-penetration. The N_{DPL} values from the two boreholes are compared and the results analyzed to obtain a preliminary assessment of the N''_{DPL} and the implications for the correlation equations.

2 METHODOLOGY

2.0 *Equipment Description*

The equipment used for the investigation consisted of a standard Dynamic Probing Light equipment together with a percussive drilling rig to provide the standard data to calibrate the DPL results against. The typical DPL equipment employed in this study is shown in Fig. 1(a). It conforms to DIN 4094 standard. This equipment has a theoretical impact energy of 45J and an impact energy per unit cone area of 98kJ/m^2.

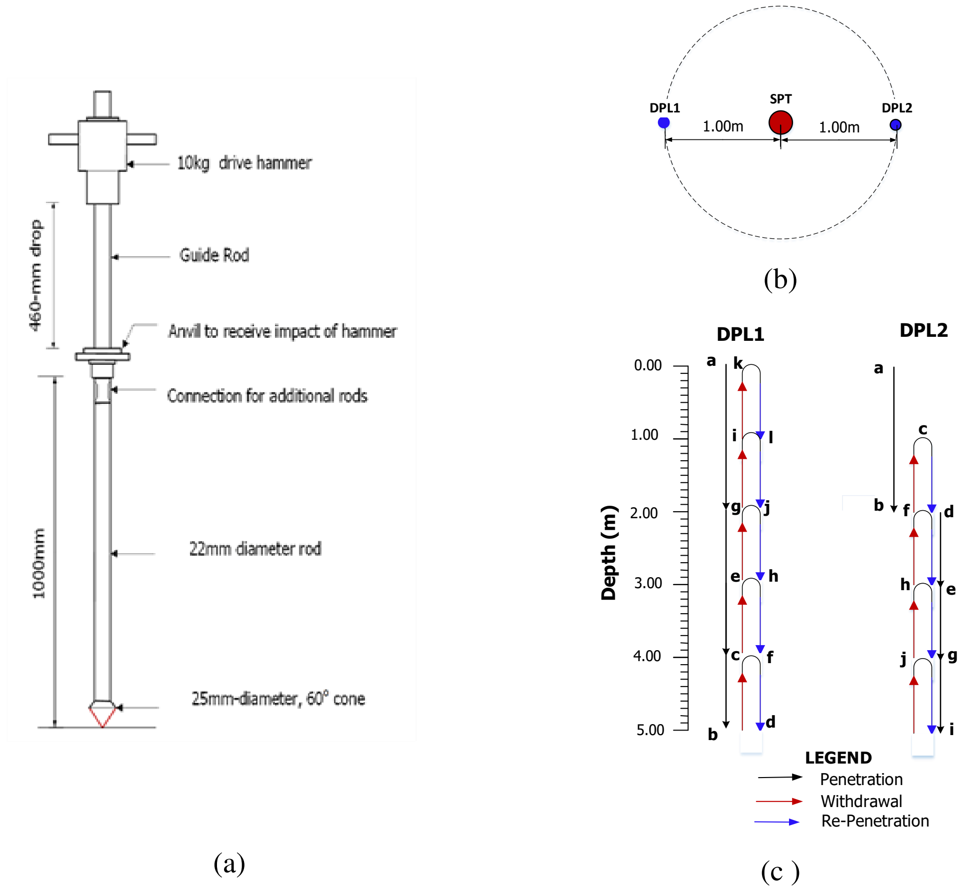

Figure 1(a) The Standard DPL (after Ampadu et al 2018) (b) Layout of boreholes (c) Rod friction measurement test cycles

2.1 *Test Procedures*

The configuration for the test is shown in Fig 1(b). At the test site in the College of Engineering, a borehole was drilled by percussive drilling to a depth of 5.0m retrieving samples and logging the boreholes. The SPT test was conducted at 1.0m intervals in accordance with the ASTM 1586. The two DPL tests were conducted diametrically opposite each other at a radial distance of 1.0m from the SPT location. In the DPL test three operators were involved. The first operator stood the cone with the rod attached upright on the ground at the designated location. Then the second operator raised the hammer full length along the guiding rod and dropped it onto the anvil and repeated this until the penetration attained 0.1m. The third operator then observed, counted and recorded the number of blows of the hammer to achieve the 0.1m penetration.

2.1.1 *Method 1*

At the location of DPL1, when the whole length of the first rod penetrated the soil, another extension rod was attached and the procedure was repeated until the target 5.0m penetration was attained recording the number of blows for each 0.1m penetration as the N_{DPL} values (i.e. as shown in Figure 1(b) a→b). After the 5.0m penetration, the rod was withdrawn using the withdrawal mechanism by 1.0m to a depth of 4.0m (i.e., b→c). The DPL arrangement was then hammered back into the disturbed soil to the depth of 5.0m (i.e., c→d) while reading and recording the DPL readings at intervals of 0.1m re-penetration from 4.0m to 5.0m i.e. N'_{DPL}. The rod was then withdrawn to 3m, one meter extension rod was removed and the remainder was hammered back to 4.0m (i.e, d→e→f) recording the rod friction. This cycle was repeated until the whole rod was removed and the complete re-penetration readings were obtained as the rod friction from the depth of 5.0m. It may be noted that in this procedure, the friction is measured after the DPL values had been measured. Thus, in Method 1 the cycles of withdrawal and hammering back occurred when the rod was being withdrawn.

2.1.2 *Method 2*

In the second approach, the rod was first hammered to a depth of 2m, with measurement of the DPL readings at 0.1m intervals (a→b). The rod was then withdrawn to 1.0m (i.e., b→c) and hammered back first to 2m (c→d) to measure the re-penetration and then hammered further to 3.0m (i.e. d→e) to measure the penetration from 2 to 3m. This alternative measurement of penetration (N_{DPL}) followed by withdrawal and re-penetration (N'_{DPL}) in 1.0m cycles was continued until the final depth of 5.0m was attained. In Method 2, the cycles of withdrawal and penetration occurred while the rod was in the overall direction of penetration of the formation.

3 RESULTS AND DISCUSSIONS

3.0 *The Soil Profile*

The sub-surface profile shows a top layer, 0.3m thick made up of construction debris underlain by a silty clay layer to a depth of 2.0m. Below this layer is the clayey sand to gravel layer. The soil profile obtained from the borehole is shown in Figure 3(a). The SPT N-values are also shown in the log increasing with depth from a value of 11 at 2.0m to a maximum of 19 at a depth of 4.3m and thereafter remaining effectively constant.

3.1 *The DPL variation with Depth*

The results of DPL1 and DPL2 variation with depth are plotted in Figure 2(a) and (b) respectively. In this plot the raw DPL readings, the friction and the corrected readings obtained by subtracting the rod friction readings from the raw readings are all shown. The raw readings show some differences between the DPL1 readings and DPL2 readings. The readings from DPL2 were significantly higher than those from DPL1 at certain depths including the top 0.5m, between 1.5m and 2.0m, and between 3.0 and 3.5m. Beyond a depth of 3.5m, however, DPL2 recorded lower values than DPL1. Apart from the material heterogeneity of the top 0.3m, it must be pointed out that the method of measurement of the readings were also different. Whereas DPL1 was measured by penetration only, the results from DPL2 involved both penetration, withdrawal and penetration. These could have affected the results.

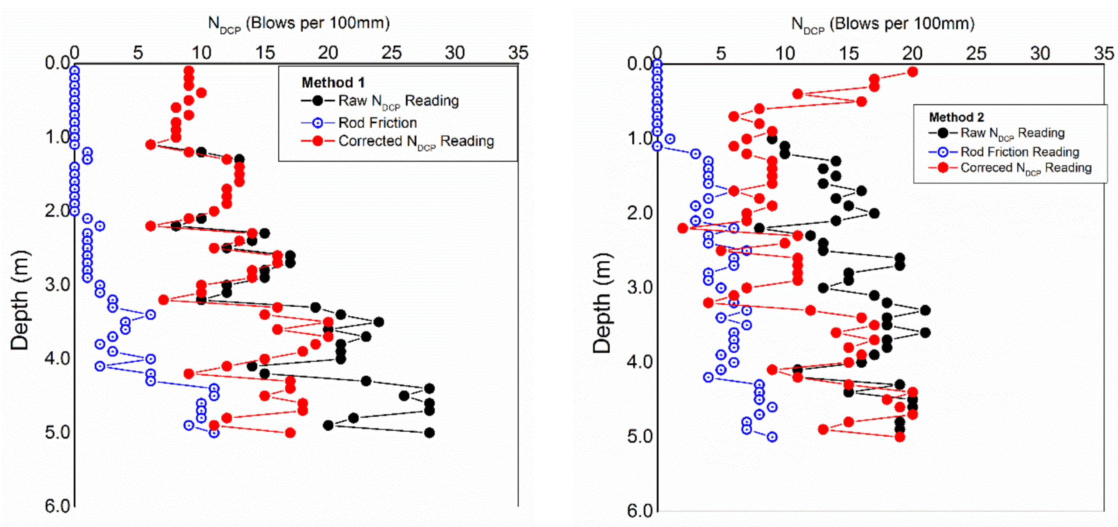

Fig. 2: Variation of DCP Readings with depth for rod friction evaluation using (a) Method 1 and (b) Method 2.

3.2 *The Rod Friction Correction*

In the friction measurement approach used in this investigation, the rod with the cone attached is withdrawn a distance of 1.0m and then hammered back through the already penetrated soil into the final position. The number of blows required for the re-penetration is counted and recorded as the re-penetration resistance (N'_{DPL}). Due to the design of this equipment, the cone cannot be detached from the rod, unlike the procedure used in Abuel-Naga (2011), which complicates further the mechanism. However, if it is assumed that the re-penetration cone resistance is negligible, ($R'_c = 0$) then it may be implied that re-penetration resistance is equal to the resistance offered by the rod friction ($R'_f = 0$). The re-penetration number of blows is then assumed to be a measure of the rod friction. The smoothened plot of the rod friction from DPL1 and DPL2 are shown in Figure 3(b).

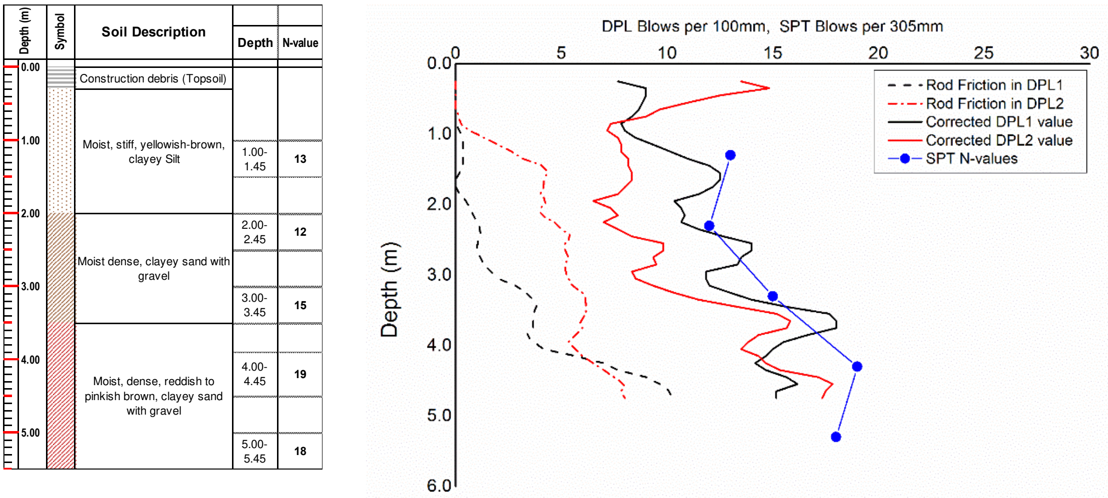

Fig. 3: (a) Field Borehole log (b) Variation of average rod friction and corrected DPL Readings superimposed on the SPT N-values

The results in Figure 3(b) shows that the rod friction in DPL1 is effectively zero for the top 2.0m. after which the friction increases with depth. This is broadly in agreement with observations from Ampadu et al 2018 in the coarse-grained formation where the DPL reading started to deviate from the SPT N-values from a depth of about 2.5m and also from Abuel-Naga (2011) who found out that there were no rod friction values for depths of between 2.5m and 3.2m.

In the case of the rod friction in DPL2, however, the zero rod friction zone is only about 1.0m. After that there was some increase to a depth of about 1.5m remains almost constant to a depth of about 4.2m when it begins to increase with depth like DPL1.

The N''_{DPL} readings obtained by subtracting N'_{DPL} from N_{DPL} and smoothened are also shown. Again, the relatively large difference in the values of the two readings in the top 0.5m in the construction debris layer is shown. Apart from that the DPL1 leads DPL2 by up to about 5 blows per 100mm until a depth of about 4.2m

3.3 *Correlation between N_{DPL} and SPT N-value*

The N_{DPL} values were then averaged over a depth of 0.300m to correspond to the depths where the SPT N-values were taken to determine the equivalent N_{DPL} at depth of 1.3m, 2.3m, 3.3m and 4.3m respectively. These readings were then correlated with the SPT N-value. Figure 4 shows the plot of N_{DPL} for DPL1 and DPL2 against the equivalent SPT N-values with the results from Ampadu et al 2018 for coarse grained soils superimposed. The plot shows very good agreement between the results of this preliminary study and the correlation equation. The rather excellent agreement with the results of DPL1 is striking. It must be noted that DPL1 followed the same procedure adopted in Ampadu et al 2018. The N_{DPL} data corrected for the rod friction is also plotted. The plot suggests a different correlation relationship between N''_{DPL} and N_{SPT}.

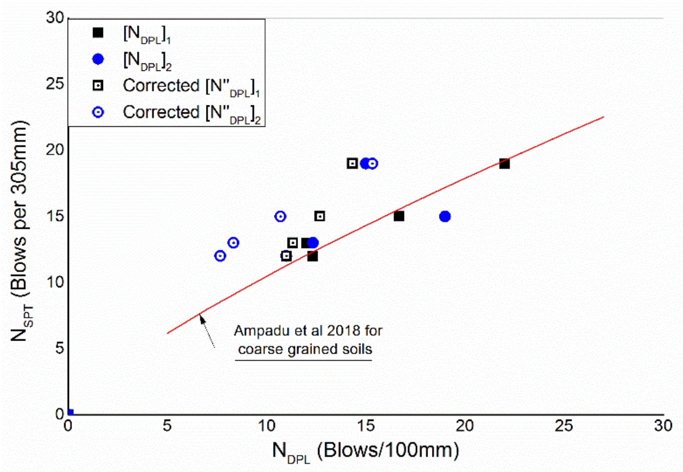

Fig. 4: Comparison between results from preliminary study and those from Ampadu et al 2018

4 CONCLUSIONS

A preliminary field method for estimating the DPL rod friction was attempted based on one borehole and two different trials to a depth of 5.0m in a soil formation that is predominantly clayey sand and gravel. Based on this test it is concluded that:

1. In the field during DPL test, the top 1.0 to 2.0m may be assumed to be free from rod friction, but beyond that the rod friction generally increases with depth.
2. The value of the rod friction depends on whether the values are determined incrementally as the penetration proceeds or the friction is determined after the DPL readings have been obtained to the depth required. Subsequent investigations will need to determine which procedure best models the DPL test.
3. The test results show very good correlation with previous results and suggests that the correction of the DPL readings for rod friction will change the calibration equations already in circulation.

This study is in progress. Several assumptions have been made in these test procedures that will need to be validated including the effect of the cone at the tip of the rod during the withdrawal and re-penetration. The assumption that the re-penetration DPL reading is a true measure of the friction will need to be confirmed by controlled laboratory tests and also by modelling.

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