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CAN ONE USE THE DYNAMIC CONE PENETROMETER TO PREDICT THE ALLOWABLE BEARING PRESSURE?

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Abstract

It is a common question asked by the structural engineer to the geotechnical engineer whether one can determine allowable bearing pressure from a set of Dynamic Cone Penetrometer (DCP) results. This often comes as a shock to the geotechnical engineer as the DCP test wouldn't be applicable in most applications. The DCP was originally designed in South Africa by Kleyn (1975) and was originally intended to be used for pavement applications as an indicator test.

The test is done by driving a cone into the ground by means of an 8 kg standard mass falling through a constant distance of 575mm. The penetration depth is recorded after every 5 blows. A number of methods have been developed to estimate soil properties from the penetration rate. This paper discusses the DCP as a tool to predict bearing capacity.

Keywords: *In-situ testing, Dynamic Cone Penetrometer, bearing pressure estimation, economic testing.*

1 Introduction

The objective of a subsurface investigation is to determine the engineering properties of the soils on which the foundations will be placed. Dynamic Cone Penetration (DCP) test is one of the most inexpensive field testing methods and is used worldwide in conjunction with various empirical correlations. Since its development, the DCP has been widely used as a simple, but effective means of determining the in-situ stiffness of subgrade materials, and can be used to determine the load bearing capacity of the soil. This paper discusses and compares means of establishing the allowable bearing pressure (ABP) from DCP readings.

2 Methodology and testing

In a DCP test, an 8 kg free fall hammer is lifted and dropped through a height of 575mm as shown in Figure 1. The distance of penetration of the cone tip is then recorded after every 5 blows and the cycle is repeated.

The DCP may also be referred to as a Dynamic Probe Light (DPL) which slightly departs from the European standard ISO/DIS 22476-2:2002. Both the DCP and DPL have similar energy inputs as shown in Table 1.

Table 1: Comparison of DCP and DPL

Device	**Hammer mass (kg)**	**Drop height (mm)**	**Cone angle (º)**	**Cone Diameter (mm)**	**Energy (J)**	**Diameter of rods (mm)**
DCP	8	575	60	20	45	16
DPL	10	500	90	35.7	49	22

It should be noted from Table 1 that the cone diameter is significantly larger than the rod diameter for the DPL when compared to the DCP. The DPL will therefore have reduced friction acting on the rods if any friction is present. Therefore the DCP should not ideally be undertaken over layer depths exceeding 1m, in one go (Paige-Green, 2009).
Extraction of the DCP rod by 300mm and subsequent redrive of the rod can be considered to establish friction although the cone is not disposable and therefore not entirely correct.

A typical DCP logging sheet is shown in Figure 2.

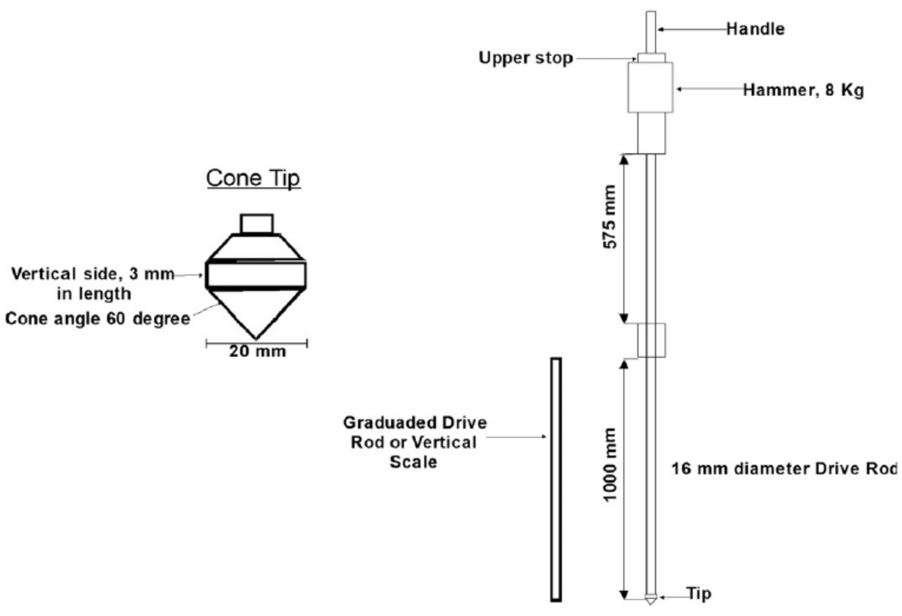

Figure 1. Schematic of a DCP Device (Mohannadi and Khamehciyan, 2008)

			Dynamic Cone Penetration recording sheet			
			Client			
			Location/Site			
			Project ID			
			Hole ID			
			Date			
Blow	Reading	Blow	Reading	Blow	Reading	Blow
5		105		205		5
10		110		210		10
15		115		215		15
20		120		220		20
25		125		225		25
30		130		230		30
35		135		235		35
40		140		240		40
45		145		245		45
50		150		250		50
55		155		255		55
60		160		260		60
65		165		265		65
70		170		270		70
75		175		275		75
80		180		280		80
85		185		285		85
90		190		290		90
95		195		295		95
100		200		300		100

Figure 2. Typical logging sheet used by GaGE Consulting

3 Correlation between DCP and SPT

Lacroix and Horn (1973) proposed that nonstandard penetration resistance obtained from the DCP test, N_{30L}, could be correlated with Standard Penetration Resistance, N_{30SB}, for drive samples or a solid conical point, such as a static cone, which incorporated consideration of driving energy and distance of penetration. They reasoned that the energy required to drive the sampler or cone a given distance or "depth" (L) was directly proportional to the square of the outside diameter (D) and the distance of penetration, and inversely proportional to the energy per blow (Weight of hammer multiplied by the height of drop, WH).

The flowing equation was derived to compare DCP to SPT results:

$$N_{30SB} = N_{30L}\left(\frac{WH}{48260}\right)\left(\frac{1290}{OD^2}\right)$$

where N_{30SB} = SPT-equivalent blow count, over 300mm,
N_{30L} = Measured blow count, over 300mm from DCP results,
W = Mass of DCP hammer (kg),

H = Fall-distance (mm),
OD = Outer diameter cone (mm),
ID = Inner diameter cone (mm),
48260 is the energy weight of the SPT test (760mm x 63.5kg),
and 1290mm is OD^2-ID^2 for the SPT test.

From the above equation, we can assume that the corrected SPT-N_{30SB} value will be equal to 30% of the N_{30L}

$$N_{30SB} = 0.3N_{30L}$$

4 Meyerhof's Allowable Bearing Pressure (ABP)

The SPT test was developed in 1927 (Bowles, 1997), and has become one of the most popular in situ tests. According to Meyerhof (1956), the allowable bearing pressure of the soil may be obtained from SPT-N values.

The following equations where slightly adjusted by Bowels (1997) to determine the ABP of sandy soil:

$$q_a = \frac{N_{30SB}}{F_1} k_d \qquad \text{where } B \leq F_4,$$

$$q_a = \frac{N_{30SB}}{F_2}\left(\frac{B+F_3}{B}\right) k_d \qquad \text{where } B > F_4,$$

$$k_d = 1 + 0.33\frac{D}{B} \leq 1.33$$

where q_a = allowable bearing pressure for ΔH = 25mm
F = F-Factors as given in Table 2

If one reviews Terzaghi's ultimate bearing pressure equations, the ultimate bearing pressure resistance of a footing would increase if the footing size increases. These formulations are however based on conservative assumptions for the design of shallow foundations and the largest footing should not settle by more than 25mm and limited by the serviceability limit state. Therefore the 25mm is a maximum value and the formulas not intended to yield actual settlements.

Table 2. Meyerhof F factor values

$\frac{N_{30SB}}{SI}$	
F_1	0.05
F_2	0.08
F_3	0.30
F_4	1.20

Figure 3, plots the ABP for a N30L at different foundation widths and embedment depths of 0m.

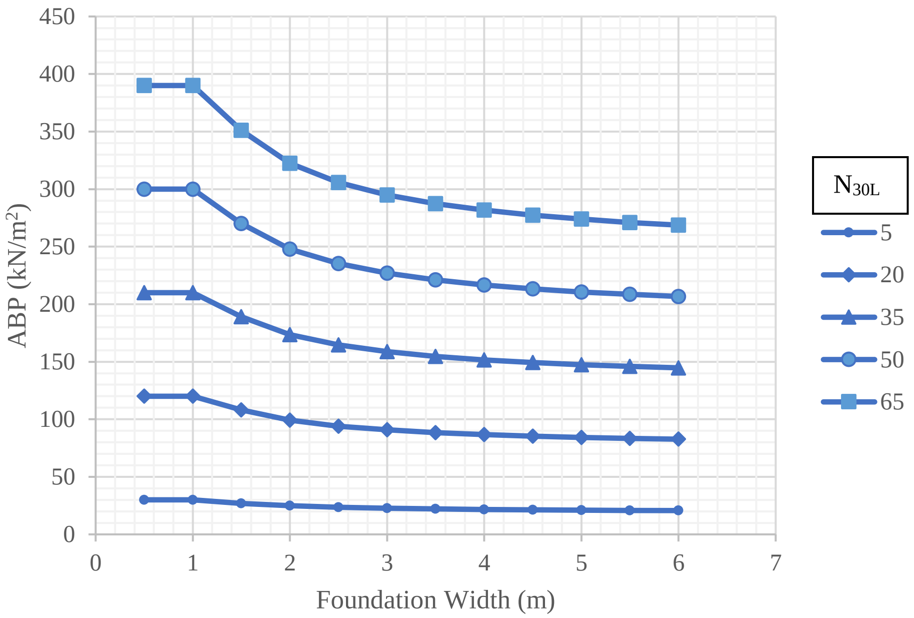

Figure 3. Allowable Bearing Pressure for a surface-loaded footing values at different N_{30L} values

Although these formulations were not originally intended to be used for clayey materials, a factor of 6 to 21 times the N_{30SB} can be used for clayey materials. The lower range will typically be for clays of low plasticity (SL-ML) and the upper range for clays, of high plasticity (CH), (Aggour, 2002).

5 Correlation between DCP and CBR

A number of methods to correlate DCP penetration values and CBR have been derived by various authors. Paige-Green (2009), suggests that the following can be used to estimate the CBR of in-situ materials from the DCP test as previously published by the Transvaal Roads Department if DN > 2 mm/blow

$$CBR=410DN^{-1.27}$$

where DN= Cone penetration rate (mm/blow)

The US Army Corps of Engineers as taken from Kessler (2010) recommend that the CBR of in-situ materials can be derived from the following equation:

$$CBR=\frac{292}{DN^{1.12}}$$

They went on to suggest that the above equation can be used on all soils except for CL material. CBR values less than 10% and CH soils. The following equations were suggested for these exceptions:

For CL soils CBR<10%:

$$CBR = \frac{1}{(0.017019DN)^2}$$

for CH soils:

$$CBR = \frac{1}{0.002871DN}$$

Figure 4 shows the CBR value versus penetration and shows that the US Army Corps and Transvaal Roads Department gives almost exactly the same values for all soils except for CL and CH values. CH soils results in slightly higher CBR values and CL almost identical.

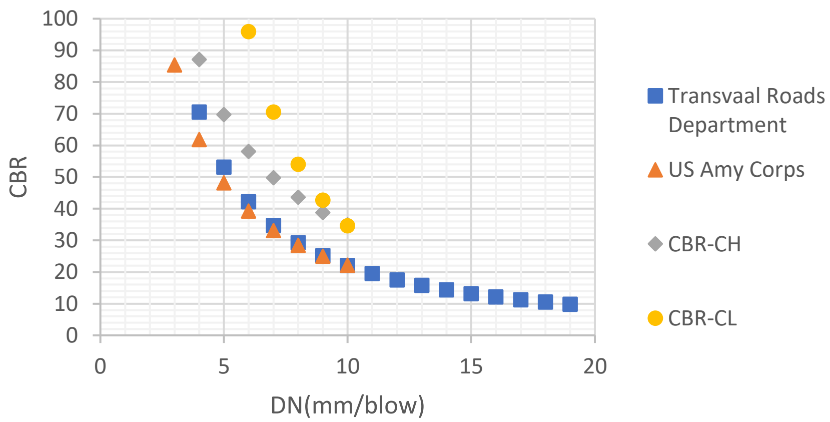

Figure 4. CBR Value plot against Penetration depths

6 DCP and Bearing Pressure resistance correlations (Packard, 1973)

Packard (1973) discusses the procedures given as part of the design of concrete airport pavements through the plate load test. This Plate-load test consists of a reaction or dead load and a hydraulic jack with dial gauges. Tests were undertaken on various CBR materials and the bearing pressure measured at 2.5mm of deflection which corresponds to the CBR test deflection.

Similarly, Paige-Green (2009) suggested that bearing pressure resistance can be estimated from the following equation:

$$\text{Bearing pressure resistance} = 3426DN^{-1.014}$$

Figure 6 plots the CBR versus bearing pressure as taken from Figure 5 at 2.5mm deflection and from the Paige-Green's correlation.

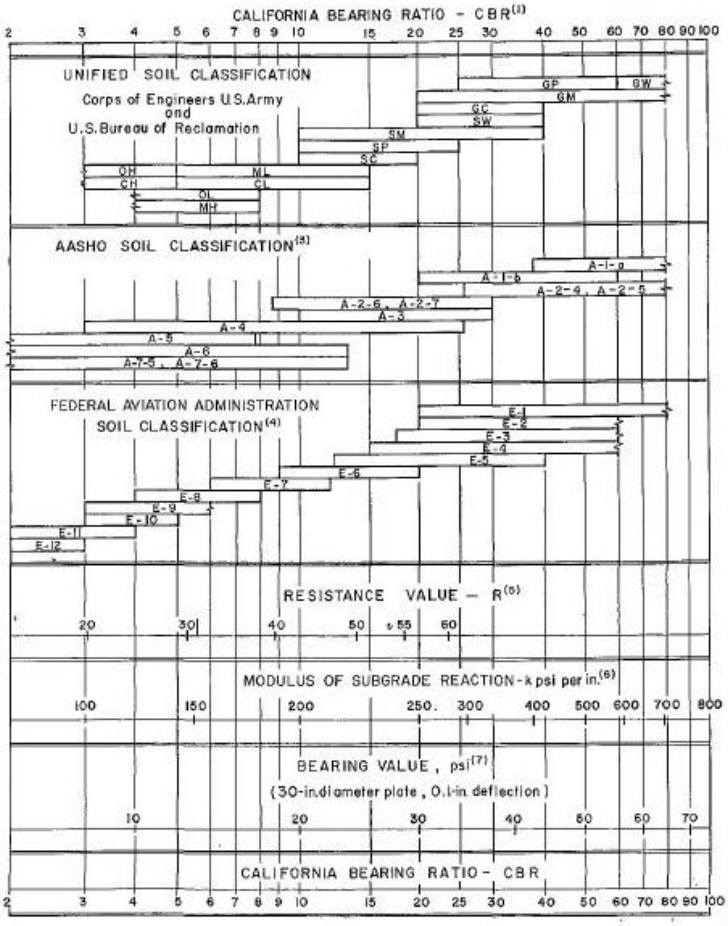

Figure 5. Interpretation of soil classification at different CBR with bearing pressure (Packard, 1973)

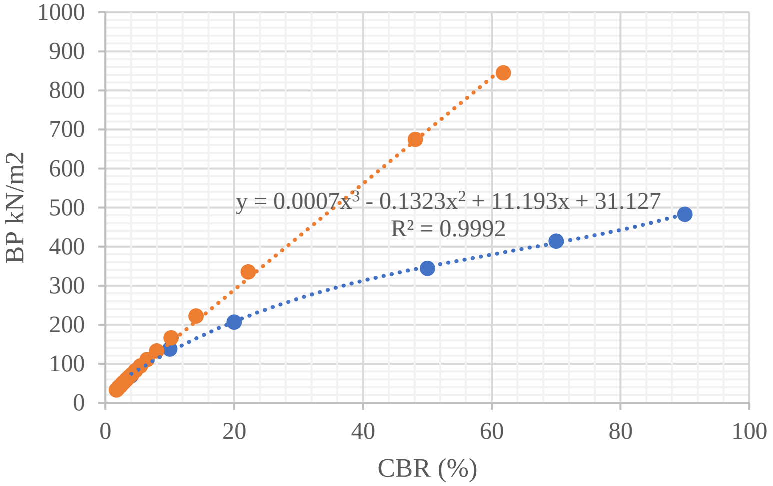

Figure 6. CBR versus Bearing Pressure

Packard (1973) is derived from various plate load test undertaken on materials with various CBR values and the bearing pressure measured at 2.5mm (same as CBR test). This doesn't imply that the values are ultimate or allowable values and therefore it is considered that at lower CBR values the bearing pressure resistance is closer to an ultimate value whilst at higher CBR values further from the ultimate load with higher factors of safety (FoS), but nevertheless unknown. It is not known if Paige-Green's (2009) formulation are ultimate or allowable or how the formulation was derived.

7 Comparison between Meyerhof and Packard

Figure 7 compares the ABP for N_{30L} at B = 0.75m (foundation width)
from Packard (1973) and the values derived from Meyerhof' for N_{30L} at various widths.

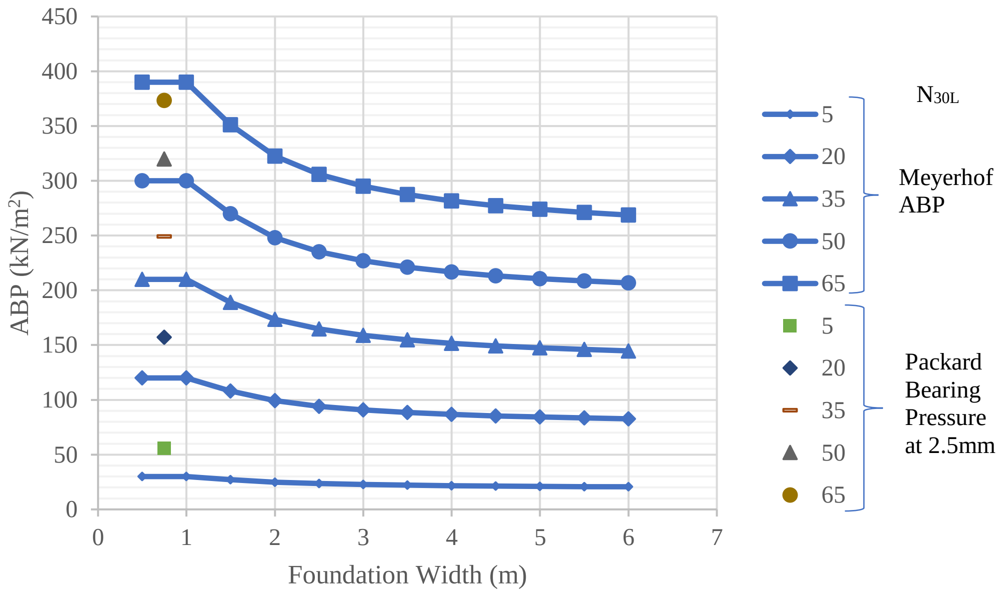

Figure 7. ABP for various N_{30L} values and widths

From Figure 7 it is concluded that the Packard (1973) bearing pressure resistance is at a lower FoS at low N_{30L} values and at higher FoS at higher N_{30L} values. It is therefore recommended that the Meyerhof N_{30L} values be used in sands and that 2 to 6 times the N_{30L} be used for clayey materials, depending on the plasticity.

8 Limitations of the DCP to predict ABP

Investigations are normally undertaken to establish stiffness and ground profile to a 2B influence zone below a foundation (SAPEM, 2014). Therefore, if undertaken only over a 1m depth, a footing of maximum 0.5m, can be placed based on the ABP derived. If a DCP is undertaken as a test pit progresses to 3m, one can probably place a footing of maximum 1.5m, based on the ABP derived. If larger footings are required a deeper investigation would be required.

If one profile is in sand and saturated, the ABP should be halved and if the water table is within 2B below the footing consideration should be given to reducing the derived ABP (Craig, 2007).

The reader should take cognisance of the fact that the ABP would reduce further if the footing is not placed on level ground but adjacent to a slope. This paper does not discuss the anticipated reduction and is based on ABP on level ground.

The N_{30L} value for clayey materials should be used with discrete adjustment since silts and clays may be stiffened or softened depending on an increase or decrease of their moisture contents. N_{30L} values can be reduced by half for CL, ML, SL and SM materials if not originally saturated and expected to become saturated during the structures life (Sathawara, 2013).

Additionally, the above limitations shows the importance to undertake foundation indicator and moisture content tests to establish the unified soil classification (USCS) and saturation level.

N_{30L} average values should additionally be derived continuously with statistical methods.

9 Conclusion and limitations of the methods

Conventionally values derived for pavement tests have been used to estimate the ABP, these do not take footing size into consideration and were derived from plate load tests on different CBR(%) materials. From this paper, it is shown that an equivalent N_{30SB} value can be derived from the N_{30L} by using Lacroix and Horn's formulations. These equivalent values can be used in Meyerhof's ABP formulations for sands and computes well to plate load test undertaken on sands with various CBR (%) values. Discrete judgement should however be used in deriving the ABP from DCP results and the limitations as discussed on Section 8 should be noted.

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