CONE PENETRATION TEST FOR BEARING CAPACITY ESTIMATION AND SOIL PROFILING, CASE STUDY: CONVEYOR BELT CONSTRUCTION IN A COAL MINING CONCESSION AREA IN LOA DURI, EAST KALIMANTAN, INDONESIA

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Abstract

Cone Penetration Test (CPT) has been recognized as one of the most extensively used *in situ* tests. A series of empirical correlations developed over many years allow bearing capacity of a soil layer to be calculated directly from CPT's data. Moreover, the ratio between end resistance of the cone and side friction of the sleeve has been prove to be useful in identifying the type of penetrated soils. The study was conducted in a coal mining concession area in Loa Duri, east Kalimantan, Indonesia. In this study the Begemann Friction Cone Mechanical Type Penetrometer with maximum push capacity of 250 kg/cm^2 was used to determine bearing layers for foundation of the conveyor belt at six different locations. The friction ratio (R_f) is used to classify the type of soils, and allowable bearing capacity of the bearing layers are calculated using Schmertmann method (1956) and LCPC method (1982). The result shows that the bearing layers in study area comprise of sands, and clay-sand mixture and silt. The allowable bearing capacity of shallow foundations range between 6-16 kg/cm^2 whereas that of pile foundations are around 16-23 kg/cm^2.

Keywords: Cone penetration test, bearing capacity, foundation, Kalimantan, Indonesia.

1. INTRODUCTION

In a coal mining concession area in Loa Duri, East Kalimantan, a 2-kilometer-long coal-transferring conveyor belt was going to be built. As a part of site investigation, a Begemann Friction Cone Mechanical Type Penetrometer with maximum push capacity of 250 kg/cm^2 was deployed to reveal the suitable bearing layers for the conveyor-belt's foundations at six locations. The data derived from the test was then used to determine the type and to calculate the allowable bearing capacity layers on each location of foundation.

2. CONE PENETRATION TEST (CPT)

The first Dutch cone penetrometer was used in 1932 by P. Barentsen, a civil servant at the Rijkwaterstaat in the Netherlands (Mazlan, 2007). The CPT has been developed and improved in so many ways that the latest of which is equipped with a piezometer at the tip of the cone for measuring pore pressures, called piezocone (Murthy, 2002). The type of CPT used in this study is the Begemann Friction Cone Mechanical Type Penetrometer with maximum push capacity of 250 kg/cm^2. The machine's dimension and test's procedures refer to the ASTM D 3441-94.

Fig 1. Area of Study (Courtesy of Google Maps, 2015)

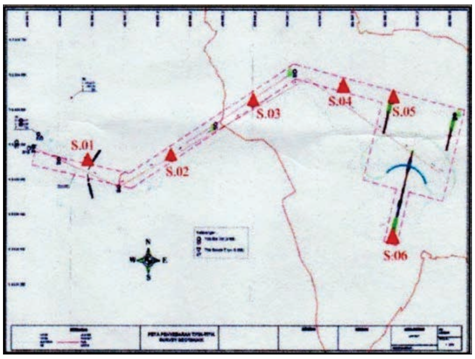

Fig 2. Locations of cone penetration test

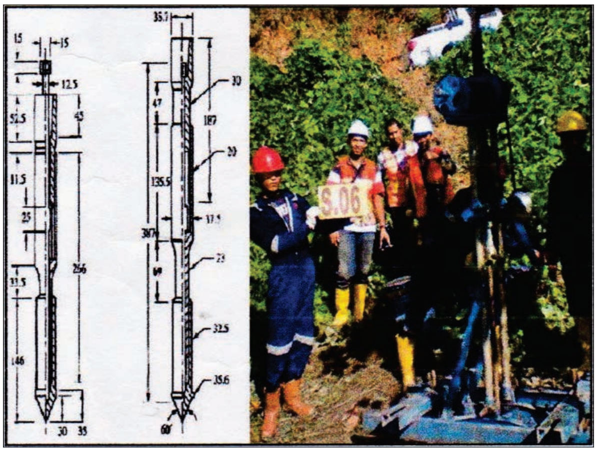

Fig 3. Right to left: Begemann friction-cone mechanical type penetrometer (Murthy, 2002) and the CPT at location S06

3. METHODOLOGY

The study was carried out for about a week in 2015. There are three main aims of this study:

a. To locate very dense bearing layers with $q_c > 200$ kg/cm^2 at six planned locations.
b. To identify and classify the type of soil on each location.
c. To estimate the allowable bearing capacity of each bearing layer on each location.

Using the soil classification developed by Sanglerat (1972), the friction ratio R_f % or the ratio between side friction and cone friction (f_c/q_c) derived from the CPT can be used in soil profiling; thus, the second aim should be accomplished in this way.

Table 1. Soil classification based on friction ratio R_f (Sanglerat, 1972)

R_f %	Type of Soils
0 – 0.5	Loose gravel fill
0.5 – 2.0	Sands or gravels
2.0 – 5.0	Clay sand mixture and silts
> 5.0	Clays, peats, etc.

In order to fulfill the third objective (estimating the allowable bearing pressure of the bearing layers on each location), a set of empirical equations developed by Schmertmann (1978) listed below are used.

For cohesionless soils:

Strip $q_{ult} = 28 - 0.0052\,(300 - q_c)^{1.5}$ (kg/cm^2) (1)

Square $q_{ult} = 48 - 0.009\,(300 - q_c)^{1.5}$ (kg/cm^2) (2)

For clay:

Strip $q_{ult} = 2 + 0.28q_c$ (kg/cm^2) (3)

Square $q_{ult} = 5 + 0.34q_c$ (kg/cm^2) (4)

where:

q_{ult} = ultimate bearing capacity

q_c = cone friction averaged over the depth interval from about B/2 to 1.1B below the footing base with B is foundation's width. Lastly, a safety factor (SF) of 3 is applied to the obtained q_{ult} to produce the allowable bearing capacity.

Equation (1) to (4) are based on chart given by Schmertmann (1978) credited to unpublished reference by Awakti (Bowles, 1988). These equations are, however, only applicable for shallow foundations with $D/B \leq 5$. Thereby, in locations which are not suitable for shallow foundations, driven pre-stressed concrete piles area chosen and LCPC method developed by Bustamante and Gianeselli (1982) is used to estimate the allowable bearing capacity of the piles. The basic formula of LCPC method can be written as:

$q_b = k_c\, q_{ca}$ (5)

$q_s = 1/k_s\, q_c$ (6)

where:

k_c = best resistance factor;

k_s = shaft resistance factor;

q_{ca} = equivalent cone resistance at pile base level;

q_c = representative cone resistance for the bearing layer

Table 2. Values of k_c and k_f for different soils and piles type (Modified from Salgado and Lee, 1999)

Nature Of Soil	Value of k_c		Value of k_s			
	Group I	Group II	I A	I B	II A	II B
Soft clay and mud	0.40	0.50	30	30	30	30
Moderately compact clay	0.35	0.45	40	80	40	80
Silt and loose sand	0.40	0.50	60	150	60	120
Compact to stiff clay and compact silt	0.45	0.55	60	120	60	120
Soft chalk	0.20	0.30	100	120	100	120
Moderately compact sand and gravel	0.40	0.50	100	200	100	200
Weathered to fragmented chalk	0.20	0.40	60	80	60	80
Compact to very compact sand and gravel	0.30	0.40	150	300	150	200

The values of k_c and k_s depend on the nature of soil and its degree of compaction as well as the pile installation method (Lee and Salgado, 1999). The equivalent cone resistance q_{ca} used in equation (6) represent an arithmetical mean of the cone resistance measured along the distance equal to 1.5D above and below the pile base, where D is the pile's diameter.

In LCPC method, different number of safety factor (SF) are subjected to the shaft and base resistance so that the allowable bearing capacity is given by:

$$Q_{all} = \frac{Q\frac{b}{L}}{3} + \frac{Q\frac{s}{L}}{2} \quad (7)$$

where:
Q_{all} = allowable bearing capacity
$Q\frac{b}{L}$ = limit base load
$Q\frac{s}{L}$ = limit shaft load

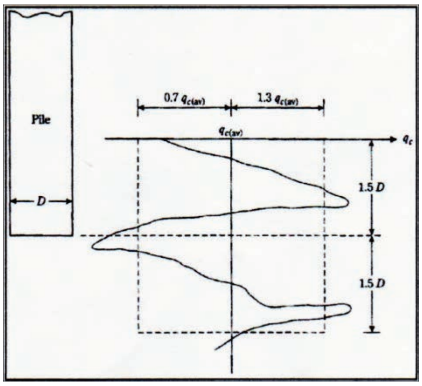

Fig 4. q_{ca} determination of LCPC method (Das, 2004)

4. RESULT AND DISCUSSION

The study shows that although the depth of bearing layer with q_c > 200 kg/cm^2 varies on each location, there are only two types of them (sands and clay sand mixture with silt) The details are shown on the table 2 below.

It is clear that due to cost efficiency and suitability of the foundation, shallow foundation is selected at locations with bearing layers located no more than 2.4 meters (S01, S02, S03) whereas at the others deeper than 2.4 meters (S04, S05, S06), driven pre-stressed concrete pile is preferred. The summary of bearing capacity of each location will be described on table 4 and 5 below.

Table 3. Depth and type of bearing layers on each location

Location	Depth (meter)	Cone Friction (kg/cm^2)	Friction Ratio (%)	Type
S01	2.4	223	1.4	Clay sand mixture with silt
S02	2	222	2	Clay sand mixture with silt
S03	1	222	0.2	Sands
S04	3.4	202	0.6	Sands
S05	4	222	0.8	Sands
S06	4	222	0.4	Sands

Table 4. Allowable bearing capacity for shallow foundations at S01, S02, and S03

Location	Foundation Depth (meter)	Averaged (kg/cm^2)	Ultimate Bearing Capacity (Q_{ult}) (kg/cm^2)		Allowable Bearing Capacity (Q_{all}) (kg/cm^2)	
			Strip	Square	Strip	Square
S01	2.4	133	39.2	50.2	13.1	16.7
S02	2	134	39.5	50.6	13.2	16.9
S03	1	172	20.5	35.0	6.8	11.7

The width of foundation (B) used here is 1 m. According to the friction ratio R_f (table 2.), the bearing layers at S01 and S02 are clay sand mixture with silt; thus, to estimate the allowable bearing capacity, equation (3) and (4) are selected while equation (1) and (2) are used S03.

The diameter of foundation used in the calculation is 1 meter. In accordance to table 2, the value of k_c and k_s used in this study are 0.4 and 150 respectively. This is due to the fact that driven pile pre-stressed concrete pile is categorized into Group II for the value of k_c and IIA for the value of k_s, and the type of bearing layers at S04, S05, and S06 are sands with q_c > 250 kg/cm^2, which in table 2 is categorized into compact to very compact sand and gravel.

Table 5. Allowable bearing capacity for driven pre-stressed concrete piles at S04, S05, and S06

Location	Foundation Depth (meter)	q_b (kg/cm^2)	q_s (kg/cm^2)	Q_{all} (kg/cm^2)
S04	3.4	68.8	1.68	23.8
S05	4	43.2	1.85	15.3
S06	4	45.6	1.85	16.1

The allowable bearing capacity (Q_{all}) at S04 is about 8 kg/cm^2 higher than the others although its q_s is slightly lower. Actually, this can be explained if we take a look into the q_c (cone friction) curves of these three locations. Unlike the q_c curves of S05 and S06 which reach a number of > 100 kg/cm^2 at about 1 meter prior to the bearing layers (q_c > 100 kg/cm^2), the q_c curve of S04 touch > 100 kg/cm^2 at around 2 meters and the number increase gradually before the test is stopped. This variation affects the values of q_{ca} obtained at each location: the lower q_c value at around 1.5B from pile's base, the lower q_{ca} it will produce.

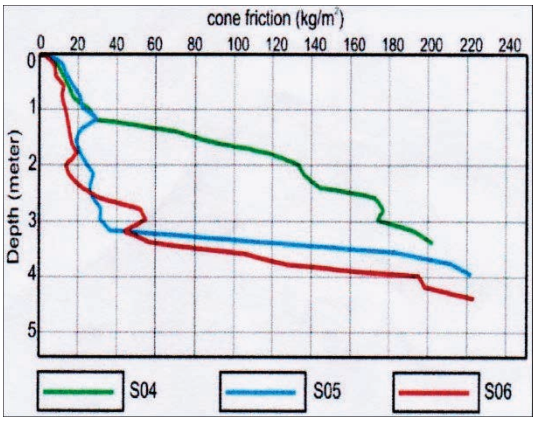

Fig 5. Cone friction (q_c) over depth at S04, S05, and S06

5. DISCUSSION

The presence of groundwater table (GWT) within the depth less than D_f + B from the base of footing will affect the bearing capacity calculation. In this study, however, GWT is not included into the calculations because the data were no available. Meyerhof (1956) developed a set of equations in which GWT is considered. Nevertheless, due to these equations are found to be conservative, some writers modified it with a 50% increase over the original values (Murthy, 2002) as given below.

$q_s = 3.6\ q_c R_{w2}$ kPa for B < 1.2 m (8)

$q_s = 2.1\ q_c\,(1+\frac{1}{B})^2\, R_{w2}$ kPa for B > 1.2 m (9)

The R_{w2} can be obtained by equation (10) below.

$R_{w2} = \frac{1}{2}(1+\frac{D_{w2}}{B})$ (10)

where:

q_s = cone friction in k/cm^2; q_s in kPa

R_{w2} = reduction factor for GWT below the base of foundation

D_{w2} = depth of GWT measured from footing's base

Because the actial GWT data are not available, all foundations are presumed below GWT; therefore, the R_{w2} will be 0.5 and by using equation (8) we will get the value of safe bearing pressure at all locations.

Table 6. Safe bearing pressure at all locations, calculated using equation (8)

Location	Cone Resistance (q_c) (kg/cm^2)	Safe Bearing Pressure (q_s)	
		kPa	kg/cm^2
S01	223.50	402.30	4.10
S02	222.49	400.48	4.08
S03	222.49	400.48	4.08
S04	202.27	364.09	3.71
S05	222.49	400.48	4.08
S06	222.49	400.48	4.08

The calculation results show that safe bearing pressure q_s of all locations, calculated using equation (8), area far lower than allowable bearing capacity q_{all} shown in table 4 and 5. These differences can be explained as well as the variables taken into account on each method are different. Even though Meyerhof (1956) method considers GWT as a reduction factor, this method does not include safety factor SF as other methods do. However, in practical when GWT's data are not available, the results obtained from these aforementioned methods are then divided by SF and also R_{w2} with assumption that the foundations are below GWT. Thereby it is often that the results are very pessimistic.

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