Technical Justification: Bearing Capacity of Bored Piles

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Abstract

In this document, we are estimating the capacity bored piles at each depth based on Standard Penetration Test (SPT) data. The presentation given in this document only outlines the theoretical framework for estimating the capacity of bored piles but does not explicitly present the computational process to keep the privacy restriction of the original SPT data. This document is intended for a portfolio and to demonstrate the competency and experience of the author in the corresponding problem solving.

1 Introduction

In project Smelter Ferronickel Kolaka, we (PT. PP) have a partner company who work together with us. The scopes of works are divided between our company and our partner's. This document will cover a technical justification for determining the capacity of bored piles in a Furnace area, a subarea within the whole Smelter area.

In this particular area, our partner will perform the engineering design as well as construction of the Furnace building. However, we are required to provide the estimation on the capacity of bored piles which are possibly used for the substructure. In their engineering design, our partner require the depth of the bored piles. Therefore, we provide the estimation of the capacity at each possible depth. This task becomes our duty since our company was the one who conducted the soil investigation on the whole Smelter area.

2 Preliminary Information

2.1 Standards and Codes

The requirements contained in the latest editions of the following standards and codes shall form an integral part of the requirements of this specification in the manner and to the extent specified herein.

SPC-1-000-C-0001	: Specification for Piles (Belonging to the project)
SNI 8460-2017	: Persyaratan Perencanaan Geoteknik
SNI 2847-2019	: Persyaratan Beton Struktural untuk Bangunan Gedung

2.2 Definitions and Abbreviations

The following terms and phrases shall have the meanings hereby assigned to them, except where the context otherwise requires.

1. Technical terms and abbreviations:

D800	:	Piles with a diameter of 800 mm
AMSL	:	Above the Mean Sea Level
SF	:	Factor of safety related to the soil capacity (Das, 2011)
Q_p	:	Pile end bearing capacity in kN (Das, 2011)
Q_s	:	Pile skin frictional capacity in kN (Das, 2011)
Q_{all}	:	Pile allowable capacity in kN (Das, 2011)

2. Mathematical symbols and notations:

$\forall$	:	Universal quantifier in formal logic (Bergmann et al., 2014)
$\exists$	:	Existential quantifier in formal logic (Bergmann et al., 2014)
$\in$	:	Set membership in set theory (Stoll, 1963)
$\mathbb{R}$	:	The set of all real numbers (Stoll, 1963; Rudin, 1964)
$[a,\, b]$	:	An interval of real numbers with $a < b$ (Rudin, 1964)
$f : [a,\, b] \to \mathbb{R}$	:	A real-valued function (Rudin, 1964)
∂	:	Partial differential operator (Rudin, 1964)
$\sup$	:	Supremum operator (Rudin, 1964)
$\max$	:	Maximum operator (Rudin, 1964)

3 Theoretical Framework

In order to determine the depth of bored piles (or pile foundations in general), it is necessary to determine the bearing capacity of the piles at a given depth. Thus, the depth of bored piles is taken as the depth in which the allowable bearing capacity of piles is sufficient against the loads applied to the piles from the upper structure at that depth.

Therefore, in this section, we will construct the theoretical framework as the guidance for the computational process. We employ the theory from (Das, 2011) as well as mathematical formalism to develop the framework. Note that first order language will regularly be applied in the framework, therefore, the readers are referred to (Bergmann et al., 2014).

The fundamental aspect of the bearing capacity of piles is divided into two parts, namely the end bearing capacity and the skin frictional capacity (Das, 2011). These mechanical properties can be mathematically modelled as functions (Stoll, 1963)

$$Q_p : [0,\, \mathcal{A}] \times [0,\, M] \to \mathbb{R}$$

and

$$Q_s : [0,\, M] \to \mathbb{R}$$

for the end bearing and the skin frictional respectively both in kN. In the expressions above, $M > 0$ is a positive real number (Rudin, 1964) representing the final observable depth (in meters) of the soil in which the soil investigation can still be conducted, and $\mathcal{A} > 0$ is a positive real number representing the possible maximum cross section (in m^2) of the pile.

In this setting, the end bearing capacity is desired to be a function of the pile tip cross section and the chosen depth of the pile. Then Q_p is desired to satisfy the partial differential equation

$$\forall x \in [0,\, M] \forall A \in (0,\, \mathcal{A})\,,\ \frac{\partial Q_p}{\partial A} = q_p(x)\,,$$

where $q_p : [0,\, M] \to \mathbb{R}$ is the point resistance per unit area in kN/m^2, with the initial value problem

$$\forall x \in [0,\, M]\,,\ Q_p(0,\, x) = 0\,.$$

Several theory were developed to determine q_p such as those belonging to (Meyerhof, 1976), (Vesic, 1977) and (Coyle and Castello, 1981). Note that $q_p : [0, M] \to \mathbb{R}$ does not depend on $(0, \mathcal{A})$, since its domain (Stoll, 1963) is $[0, M]$. Thus, Q_p is given by the integral

$$\forall x \in [0,\, M] \forall A \in [0,\, \mathcal{A}]\,,\ Q_p(A,\, x) = \int q_p(x) dA = A\, q_p(x) + c\,.$$

And follows from the initial value problem, we have

$$\forall x \in [0,\, M]\,,\; 0 = Q_p(0,\, x) = 0 \cdot q_p(x) + c = c\,,$$

and hence

$$\forall x \in [0,\, M] \forall A \in [0,\, \mathcal{A}]\,,\; Q_p(A,\, x) = A\, q_p(x)\,.$$

On the other hand, the skin frictional capacity is desired to satisfy the integral equation

$$\forall x \in (0,\, M)\,,\; Q_s(x) = \int_0^x p(u) f_s(u)\, du\,,$$

where $p : [0,\, M] \to [0,\, \infty)$ is the pile perimeter function in m and $f_s : [0,\, M] \to \mathbb{R}$ is the stress resistance between the pile shaft and soil through the act of friction expressed in kN/m^2. In most practices, piles of uniform dimension are preferred. And Q_s becomes

$$\forall x \in [0,\, M]\,,\; Q_s(x) = \tilde{p} \int_0^x f_s(u)\, du$$

such that

$$\forall x \in [0,\, M]\,,\; p(x) = \tilde{p}\,.$$

Several theory were developed to determine f_s such as those belonging to (Meyerhof, 1976), (Vijayvergiya and Focht, 1972), (Mansur and Hunter, 1970), etc.

The allowable bearing capacity of piles can be expressed as a linear combination of Q_p and Q_s , as given by

$$\forall x \in [0,\, M]\,,\; Q_{all}(x) = \mu_p Q_p(x) + \mu_s Q_s(x)$$

where $\mu_p, \mu_s \in (0,\, 1)$ such that the inverse of μ_p is the factor of safety for Q_p and the inverse of μ_s is the factor of safety for Q_s (Das, 2011), i. e.,

$$\mathrm{SF}_p = \mu_p^{-1} \;\wedge\; \mathrm{SF}_s = \mu_s^{-1}\,.$$

Here is our suggested method for the engineer to determine the depth of the bored piles. Suppose $P > 0$ is the design load from the upper structure (in kN). The depth of the pile is given by

$$d_p := \inf \{x \in [0,\, M] \mid P < Q_{all}(x)\}$$

In practice, there will only be finitely many points in $[0,\, M]$ available for computation, since the SPT values are recorded at certain depths. Suppose $\mathcal{M} \subset [0,\, M]$ is the set of depth points in record. Hence d_p can practically be given by

$$d_p = \min \{x \in \mathcal{M} \mid P < Q_{all}(x)\}\,.$$

4 Computing the Capacity of Bored Piles

The borehole references for the bored piles are BH.5.1.02, BH.5.1.16, BH.5.1.17 and BH.5.1.18 as contained in the soil investigation report (Marshela et al., 2022). Bored piles of D800 are used for this foundation as indicated on the document provided by our partner. Hence the pile cross sectional area is given by

$$A = \frac{\pi\, 0.8^2}{4} = 0.628 \text{ m}^2\,.$$

And the pile perimeter is given by

$$\tilde{p} = \pi\, 0.8 = 2.513 \text{ m}.$$

The values for both μ_p and μ_s are 0.5 and hence

$$\mathrm{SF}_p = \mathrm{SF}_s = 2\,,$$

as stated in the corresponding document. And the pile allowable bearing capacity Q_{all} for each observed depth is computed by Soilens using Shaft software and is presented on tables 1, 2, 3 and 4.

Table 1: Allowable Bearing Capacity for BH.5.1.02

Elevation (meters AMSL)	d_p (m)	Q_s (kN)	Q_p (kN)	Q_{all} (kN)
148.35	0.00	0.00	0.00	0.00
147.85	0.50	23.50	143.90	83.70
147.35	1.00	47.00	255.90	151.45
146.85	1.50	70.50	924.40	497.45
146.35	2.00	94.00	1434.30	764.15
145.85	2.50	135.40	1515.70	825.55
145.35	3.00	303.80	1515.70	909.75
144.85	3.50	472.20	1515.70	993.95
144.35	4.00	640.60	1515.70	1078.15
143.85	4.50	809.00	1515.70	1162.35
143.35	5.00	977.40	1515.70	1246.55
142.85	5.50	1145.80	1515.70	1330.75
142.35	6.00	1314.20	1515.70	1414.95
141.85	6.50	1482.60	1515.70	1499.15
141.35	7.00	1651.00	1515.70	1583.35
140.85	7.50	1819.50	1515.70	1667.60
140.35	8.00	1987.90	1515.70	1751.80
139.85	8.50	2156.30	1515.70	1836.00
139.35	9.00	2324.70	1515.70	1920.20
138.85	9.50	2493.10	1515.70	2004.40
138.35	10.00	2661.50	1515.70	2088.60
137.85	10.50	2829.90	1515.70	2172.80
137.35	11.00	2998.30	1515.70	2257.00
136.85	11.50	3166.70	1515.70	2341.20
136.35	12.00	3335.20	1515.70	2425.45
135.85	12.50	3503.60	1515.70	2509.65
135.35	13.00	3672.00	1515.70	2593.85
134.85	13.50	3840.40	1419.50	2629.95
134.35	14.00	4008.80	825.70	2417.25
133.85	14.50	4177.20	551.90	2364.55
133.35	15.00	4329.80	1043.40	2686.60
132.85	15.50	4376.10	1421.30	2898.70
132.35	16.00	4472.50	1444.20	2958.35
131.85	16.50	4687.10	1444.20	3065.65
131.35	17.00	4905.90	1444.20	3175.05

Table 2: Allowable Bearing Capacity for BH.5.1.16

Elevation (meters AMSL)	d_p (m)	Q_s (kN)	Q_p (kN)	Q_{all} (kN)
144.700	0.00	0.00	0.00	0.00
144.200	0.50	97.50	506.70	302.10
143.700	1.00	194.90	284.40	239.65
143.200	1.50	292.40	127.50	209.95
142.700	2.00	362.90	122.20	242.55
142.200	2.50	381.50	122.20	251.85
141.700	3.00	400.20	122.20	261.20
141.200	3.50	418.90	122.20	270.55
140.700	4.00	437.50	122.20	279.85
140.200	4.50	456.20	122.20	289.20
139.700	5.00	474.90	122.20	298.55
139.200	5.50	493.50	122.20	307.85
138.700	6.00	512.20	122.20	317.20
138.200	6.50	530.80	122.20	326.50
137.700	7.00	549.50	122.20	335.85
137.200	7.50	568.20	122.20	345.20
136.700	8.00	584.00	4898.20	2741.10
136.200	8.50	584.00	4898.20	2741.10
135.700	9.00	584.00	4898.20	2741.10
135.200	9.50	584.00	4898.20	2741.10
134.700	10.00	584.00	4898.20	2741.10
134.200	10.50	584.00	4898.20	2741.10
133.700	11.00	584.00	4898.20	2741.10
133.200	11.50	584.00	4898.20	2741.10
132.700	12.00	584.00	4898.20	2741.10

Table 3: Allowable Bearing Capacity for BH.5.1.17

Elevation (meters AMSL)	d_p (m)	Q_s (kN)	Q_p (kN)	Q_{all} (kN)
144.700	0.00	0.00	0.00	0.00
144.200	0.50	78.80	497.10	287.95
143.700	1.00	157.60	536.50	347.05
143.200	1.50	236.40	561.20	398.80
142.700	2.00	1195.60	582.70	889.15
142.200	2.50	2179.10	597.00	1388.05
141.700	3.00	3097.00	605.50	1851.25
141.200	3.50	3957.50	610.90	2284.20
140.700	4.00	4775.70	614.50	2695.10
140.200	4.50	5555.70	616.80	3086.25
139.700	5.00	6305.10	618.30	3461.70
139.200	5.50	7029.10	613.10	3821.10
138.700	6.00	7728.20	368.90	4048.55
138.200	6.50	8407.50	155.60	4281.55
137.700	7.00	9068.80	108.60	4588.70
137.200	7.50	9098.80	108.60	4603.70
136.700	8.00	9112.90	4898.20	7005.55
136.200	8.50	9112.90	4898.20	7005.55
135.700	9.00	9112.90	4898.20	7005.55
135.200	9.50	9112.90	4898.20	7005.55
134.700	10.00	9112.90	4898.20	7005.55
134.200	10.50	9112.90	4898.20	7005.55
133.700	11.00	9112.90	4898.20	7005.55
133.200	11.50	9112.90	4898.20	7005.55
132.700	12.00	9112.90	4898.20	7005.55
132.200	12.50	9112.90	4898.20	7005.55
131.700	13.00	9112.90	4898.20	7005.55
131.200	13.50	9112.90	4898.20	7005.55
130.700	14.00	9112.90	4898.20	7005.55
130.200	14.50	9112.90	4898.20	7005.55
129.700	15.00	9112.90	4898.20	7005.55
129.200	15.50	9112.90	4898.20	7005.55
128.700	16.00	9112.90	4898.20	7005.55

Table 4: Allowable Bearing Capacity for BH.5.1.18

Elevation (meters AMSL)	d_p (m)	Q_s (kN)	Q_p (kN)	Q_{all} (kN)
147.800	0.00	0.00	0.00	0.00
147.300	0.50	17.30	128.40	72.85
146.800	1.00	34.60	142.90	88.75
146.300	1.50	51.80	189.70	120.75
145.800	2.00	69.10	235.20	152.15
145.300	2.50	86.40	254.50	170.45
144.800	3.00	110.80	254.50	182.65
144.300	3.50	141.90	254.50	198.20
143.800	4.00	173.00	254.50	213.75
143.300	4.50	204.10	254.50	229.30
142.800	5.00	235.20	254.50	244.85
142.300	5.50	266.30	254.50	260.40
141.800	6.00	297.40	254.50	275.95
141.300	6.50	328.50	254.50	291.50
140.800	7.00	359.60	254.50	307.05
140.300	7.50	390.70	254.50	322.60
139.800	8.00	421.80	254.50	338.15
139.300	8.50	452.90	254.50	353.70
138.800	9.00	484.10	254.50	369.30
138.300	9.50	515.20	254.50	384.85
137.800	10.00	546.30	254.50	400.40
137.300	10.50	577.40	254.50	415.95
136.800	11.00	608.50	271.10	439.80
136.300	11.50	639.60	598.20	618.90
135.800	12.00	670.70	956.60	813.65
135.300	12.50	701.80	1138.20	920.00
134.800	13.00	774.80	1138.20	956.50
134.300	13.50	911.70	1138.20	1024.95
133.800	14.00	1048.60	964.40	1006.50
133.300	14.50	1185.50	601.00	893.25
132.800	15.00	1322.30	325.10	823.70
132.300	15.50	1459.20	274.30	866.75
131.800	16.00	1963.20	937.90	1450.55
131.300	16.50	2502.10	1768.30	2135.20
130.800	17.00	3016.00	2216.30	2616.15
130.300	17.50	3398.50	2256.60	2827.55
129.800	18.00	3464.10	2256.60	2860.35

5 Conclusion

We have developed a theoretical framework for estimating the capacity of bored piles by employing geotechnical engineering theory in (Das, 2011). We have also conducted the computation for the capacity of bored piles with respect to bore holes BH.5.1.02, BH.5.1.16, BH.5.1.17 and BH.5.1.18. The result of the computation can be used by our partner for determining the depth of the bored piles for their design.

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