Determination of bearing capacity of bored pile using SPT number N and undrained shear strength Su

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(Manuscript Received on August 25th, 2014; Manuscript Revised November 11th, 2014)

ABSTRACT:

In this paper, the determination of bearing capacity of bored pile using the SPT number and undrained shear strength is presented. The advantages of this method are simple and always feasible, especially for bridge and pier designing in case of expressway projects constructed on soft soils. The 22TCN 272-05 standard is used to calculate bearing capacity of bored pile including skin friction and end bearing capacities. An applicable form for calculating the bearing capacity of bored pile is made. An example is presented and the applied result is shown.

Keywords: *bearing capacity, bored pile, SPT number, undrained shear strength, skin friction capacity, end bearing capacity.*

1. INTRODUCTION

Recently, bored pile has found widespread applications in many geotechnical problems such as high building, foundation, bridge and etc. The most important part has been how to calculate bearing capacity of pile used to design accurately, effectually. Efforts have been made to enrich the methods for determining the bearing capacity of bored piles. It can be calculated by using SPT, CPT, physical soil properties [1, 2]. However, it is clear that the bearing capacity of bored piles is not always determined because of lack of some parameters. In addition, some equations are complicated with several components.

Therefore, in this paper, a simple, feasible and easy method is presented to calculate the bearing capacity of bored piles based mainly on SPT number and undrained shear strength. The procedure follows the 22TCN 272-05 standard [3]. This standard is translated from AASHTO LRFD Bridge design specification 2010 [4].

2. DETERMINATION OF BEARING CAPACITY OF BORED PILE

2.1. Skin friction capacity

The α -method, based on total stress, may be used to relate the adhesion between the pile and clay to the undrained strength of clay. The nominal unit skin friction, in kPa, may be taken by:

$$q_s = \alpha S_u$$

S_u = mean undrained shear strength (kPa)

α = adhesion factor applied to S_u

The adhesion factor, α , is assumed to vary with the value of the undrained strength, S_u as specified in Table 1.

Table 1: Values of α for determination of side resistance in cohesive soil (Reese and O'Neill, 1988)

S_u (Mpa)	□
< 0.2	*0.55*
0.3 ~ 0.4	*0.42*
0.4 ~ 0.5	*0.38*
0.5 ~ 0.6	*0.35*
0.6 ~ 0.7	*0.33*
0.8 ~ 0.9	*0.31*
> 0.9	*As rock*

The nominal skin friction of piles in cohesionless soils, in kPa, as provided in Reese and Wright (1977), may be taken as:

$q_s = 2.8N$ if $N \leq 53$

$q_s = 0.21(N-53) + 150$ if $N > 53$

where N is the SPT blow number

Therefore, the skin friction capacity of pile, Q_s in kN, is:

$Q_s = q_s A_s$

where A_s = surface area of pile shaft (m^2)

2.2. End bearing capacity

For axially loaded shafts in cohesive soil, the nominal unit tip resistance, q_p, by the total stress method as provided in O'Neill and Reese (1999) shall be taken as:

$q_p = N_c S_u \leq 4000$

in which

$N_c = 6[1+0.2(Z/D)] \leq 9$

where

D = diameter of drilled shaft (m)

Z = penetration of shaft (m)

S_u = undrained shear strength (kPa)

The value of S_u should be obtained within a depth of 2.0 diameters below the tip of the shaft. If the soil within 2.0 diameters of the tip has $S_u < 24$ kPa, the value of N_c should be multiplied by 0.67.

If $S_u > 96$ kPa with diameter > 1.9 m and the settlement of piles is not evaluated, we use $q_p = q_p F_r$ in which

$F_r = 760/(12aD_p+760b) \leq 1$, where D_p is diameter of pile tip

where

$a = 0.0071 + 0.0021(Z/D_p) \leq 0.015$

$b = 1.45\sqrt{2S_u}$ with $0.5 \leq b \leq 1.5$

The nominal tip resistance, q_p, for drilled shaft in cohesionless soils by the Reese and Wright (1977) method shall be taken as:

$q_p = 64N$ if $N \leq 60$

$q_p = 3800$ if $N > 60$

with diameter of pile tip $D_p > 1.27$ m, use $q_p = q_p(1.27/D_p)$

The end bearing capacity of pile, Q_p in kN, is:

$$Q_p = q_p A_p$$

where A_p = area of pile tip (m^2)

2.3. Allowable bearing capacity

To calculate the allowable bearing capacity of bored pile, the resistance factors should be taken as tabulated in Table 2

Table 2: The resistance factors in cohesive and cohesionless soils

Resistance factors	Soil types	
	Cohesive soil	Cohesionless soil
Side resistance factor	0.65	0.55
End resistance factor	0.55	0.50

2.4. Group effect

The effect of pile group can be considered by group effect factor as shown in Table 3 depending on the distance between piles (D is pile diameter).

Table 3: Group effect factors

Distance between piles	2.5D	3.0D	3.5D	4.0D	4.5D	5.0D	5.5D	6.0D
Group effect factor	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00

3. RESULTS OF APPLICATION

The above procedure for calculating the bearing capacity of bored pile is applied to one boring log as presented in Figure 1. This is one of the boreholes in Cao Lanh – Vam Cong high way project. The depth of the borehole is 80m. According to steps for calculating bearing capacity of bored pile as illustrated above, an excel form is established as given in Table 4. As results, with pile of 64m deep from the bottom of pile cap, the ultimate bearing capacity is 15,017 kN. By using resistance factors of 0.65 for cohesive soil and 0.55 for cohesionless soil in case of side resistance and 0.55 for cohesive soil and 0.50 for cohesionless soil in case of end resistance, the allowable bearing capacity is 8,543 kN. The designed distance between piles is equal to 3 times pile diameter, hence the group effect factor is 0.70. Therefore, the allowable bearing capacity of pile is finally 4,342 KN.

4. CONCLUSIONS

This paper presents the method to calculate the bearing capacity of bored pile using the SPT number N and undrained shear strength S_u. The calculation procedure follows the 22TCN 272-05 standard.

Comparing to the other methods, this method has several strong points as follows:

- The formulas are simple, easy and feasible
- Method of calculation has a high reliability
- The input data obtained from field tests describes accurately soil conditions in fact

In case of multi-layer soil with sand layer, it is difficult to take undisturbed sample to conduct laboratory tests for determining bearing capacity; hence, this method is used.

5. DISCUSSION

It has been known that the bearing capacity of bored pile is usually determined based on physical properties of soil. However, sometimes, we have not enough information, that means soil properties, for calculating. To overcome this problem, the above method is used because the input data are always determined. Moreover, in case of a lack of undrained shear strength S_u or it has not been determined yet; the empirical equation proposed by Skempton (1957) and Ladd (1971) can be used as [1]:

for normally consolidated soil:

$$S_u = \sigma'_{v0}(0.11 + 0.0037PI)$$

for overconsolidated soil:

$$S_u = \sigma'_{v0}(0.23 \pm 0.04)OCR^{0.8}$$

where σ'_{v0} is the effective overburden pressure

PI is the plasticity index, determined by using ASTM

OCR is overconsolidation ratio

Xác định sức chịu tải của cọc khoan bằng giá trị SPT N và sức chống cắt không thoát nước Su

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TÓM TẮT:

Bài báo giới thiệu cách xác định sức chịu tải của cọc khoan bằng giá trị SPT và sức chống cắt không thoát nước. Ưu điểm của phương pháp này là đơn giản và luôn luôn khả thi, đặc biệt là trong thiết kế cầu và trụ cầu cho các dự án xây dựng đường cao tốc trên nền đất yếu. Tiêu chuẩn 22TCN 272-05 được sử dụng để tính toán sức chịu tải của cọc khoan bao gồm thành phần sức kháng bên và sức chịu mũi. Bài báo giới thiệu một biểu mẫu excel để tính toán và một bài ví dụ áp dụng.

Từ khóa: *sức chịu tải, cọc khoan, giá trị SPT, sức chống cắt không thoát nước, sức kháng bên, sức chịu mũi.*

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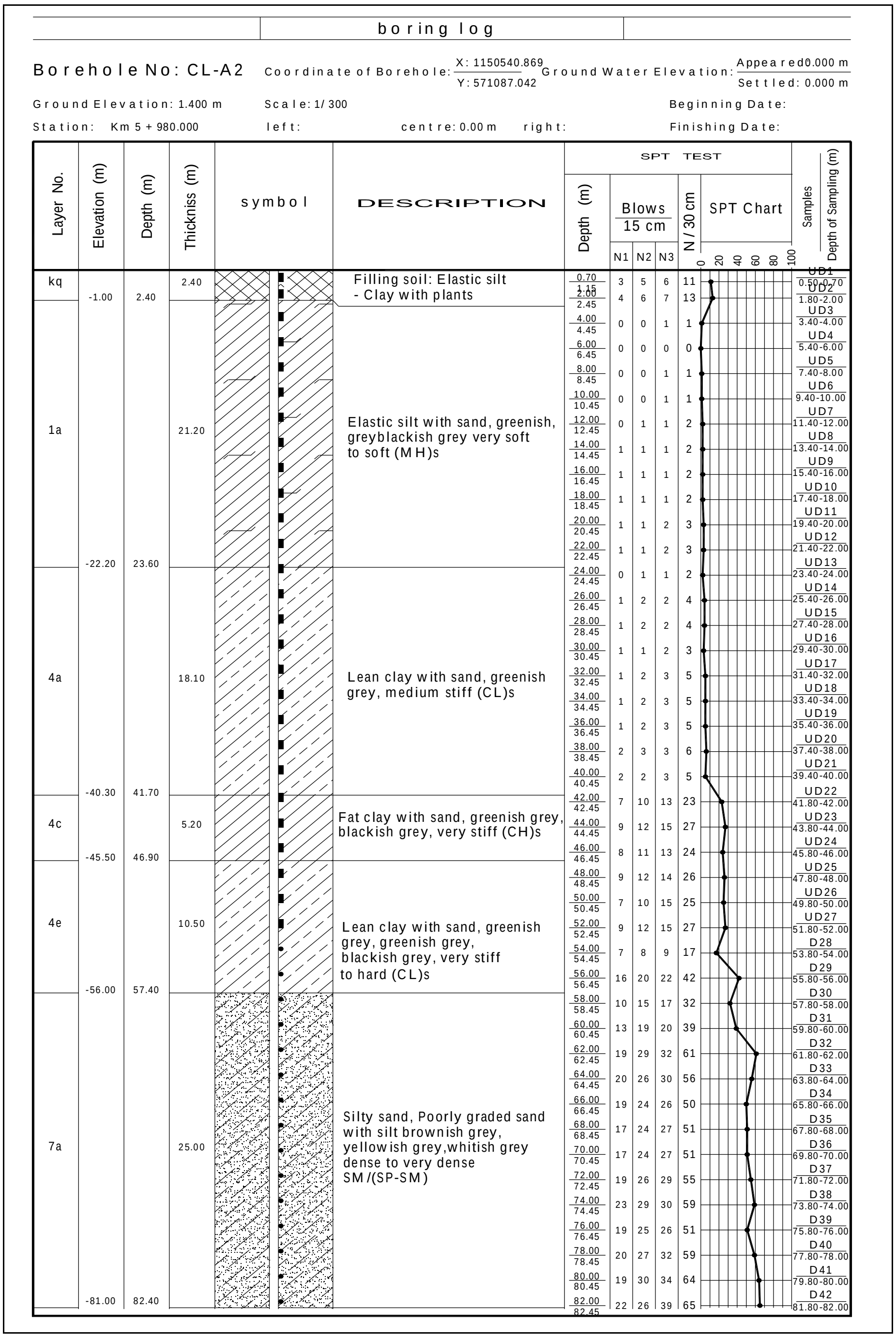

Figure 1. The boring log

Table 4. The result of calculation of bearing capacity of bored pile

Calculation of bearing capacity of bored pile

Project:	CMDCP	***Standard applied:***	According to 22TCN 272-05
Location of pile:	CL - A2	***Date:***	20-Jul-12

© INPUT DATA:

Pile name:	**CL - A2**		Elevation of bottom of pile-cap:	**-0.12**	m	Perimeter of pile:	**4.71**	m
Pile length from bottom of pile cap:	**63.98**	m	Elevation of ground level:	**1.40**	m	Area of pile:	**1.77**	m^2
Pile diameter:	**1.5**	m	Elevation of ground water level:	**-0.12**	m	Elevation of pile tip:	**-62.60**	m

© SKIN FRICTION CAPACITY:

Clay (kPa):	$q_s = \alpha S_u$	Article 10.8.3.3.1
Sand (kPa):	q_s = 2.8N if N <= 53	Article 10.8.3.4.2
	q_s = 0.21(N-53)+150 if N > 53	

© END BEARING CAPACITY:

Clay (kPa):	$q_p = N_cS_u$ <= 4000		Article 10.8.3.3.2
	© N_c = 6[1+0.2(Z/D)] <= 9	© If S_u > 96 kPa with D > 1.9m, use $q_p = q_pF_r$	
	© S_u is within 2D below pile tip	F_r = 760/(12aD_p+760b) <= 1, where D_p is diameter of pile tip	
	© If S_u < 24 kPa, use N_c = 2/3*N_c	a = 0.0071+0.0021(Z/D_p) <= 0.015	
		b = 1.45*sqrt(2S_u) with 0.5 <= b <= 1.5	
Sand (kPa):	q_p = 64N if N<=60		Article 10.8.3.4.3
	q_p = 3800 if N>60		
	© With diameter of pile tip D_p>1.27m, use q_p = q_p(1.27/D_p)		

Side resistance factor:	clay =	0.65	End resistance factor:	clay =	0.55

				sand =	0.55						sand =	0.50		Diameter of pile tip		Dp =	1.5
Layer name	Counted from	Depth m	Elevation m	Thickness m	Soil type	S_u kPa	α	N	$Q_s(kN)=q_s(kPa)*u*L$ clay	sand	N_c	N_c modified	a	b	F_r	$Q_p(kN)=q_p(kPa)*A$ clay	sand
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]
	-1.62	0	1.40														
kq		2	-0.60	0.0	clay	46.82	0.55	13	-	-	7.6	5.1	0.010	0.50	1.00	628.49	-
		2.4	-1.00	0.0	clay	46.82	0.55	13	-	-	7.9	5.3	0.010	0.50	1.00	654.95	-
1a		4	-2.60	1.0	clay	11.70	0.55	1	29.70	-	9.0	6.0	0.013	0.50	1.00	123.99	-
		6	-4.60	2.0	clay	11.70	0.55	0	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		8	-6.60	2.0	clay	11.70	0.55	1	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		10	-8.60	2.0	clay	11.70	0.55	1	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		12	-10.60	2.0	clay	11.70	0.55	2	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		14	-12.60	2.0	clay	11.70	0.55	2	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		16	-14.60	2.0	clay	11.70	0.55	2	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		18	-16.60	2.0	clay	11.70	0.55	2	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		20	-18.60	2.0	clay	11.70	0.55	3	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		22	-20.60	2.0	clay	11.70	0.55	3	60.62	-	9.0	6.0	0.015	0.50	1.00	123.99	-
		23.6	-22.20	1.6	clay	11.70	0.55	3	48.49	-	9.0	6.0	0.015	0.50	1.00	123.99	-
4a		24	-22.60	0.4	clay	26.20	0.55	2	27.15	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		26	-24.60	2.0	clay	26.20	0.55	4	135.74	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		28	-26.60	2.0	clay	26.20	0.55	4	135.74	-	9.0	6.0	0.015	0.50	1.00	416.48	-

		30	-28.60	2.0	clay	26.20	0.55	3	135.74	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		32	-30.60	2.0	clay	26.20	0.55	5	135.74	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		34	-32.60	2.0	clay	26.20	0.55	5	135.74	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		36	-34.60	2.0	clay	26.20	0.55	5	135.74	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		38	-36.60	2.0	clay	26.20	0.55	6	135.74	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		40	-38.60	2.0	clay	26.20	0.55	5	135.74	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		41.7	-40.30	1.7	clay	26.20	0.55	5	115.38	-	9.0	6.0	0.015	0.50	1.00	416.48	-
		42	-40.60	0.3	clay	116.70	0.55	23	90.69	-	9.0	6.0	0.015	0.70	1.00	1,855.09	-
4c		44	-42.60	2.0	clay	116.70	0.55	27	604.62	-	9.0	6.0	0.015	0.70	1.00	1,855.09	-
		46	-44.60	2.0	clay	116.70	0.55	24	604.62	-	9.0	6.0	0.015	0.70	1.00	1,855.09	-
		46.9	-45.50	0.9	clay	116.70	0.55	24	272.08	-	9.0	6.0	0.015	0.70	1.00	1,855.09	-
		48	-46.60	1.1	clay	77.00	0.55	26	219.42	-	9.0	6.0	0.015	0.57	1.00	1,224.01	-
		50	-48.60	2.0	clay	77.00	0.55	25	398.94	-	9.0	6.0	0.015	0.57	1.00	1,224.01	-
4e		52	-50.60	2.0	clay	77.00	0.55	27	398.94	-	9.0	6.0	0.015	0.57	1.00	1,224.01	-
		54	-52.60	2.0	clay	77.00	0.55	17	398.94	-	9.0	6.0	0.015	0.57	1.00	1,224.01	-
		56	-54.60	2.0	clay	77.00	0.55	42	398.94	-	9.0	6.0	0.015	0.57	1.00	1,224.01	-
		57.4	-56.00	1.4	clay	77.00	0.55	42	279.26	-	9.0	6.0	0.015	0.57	1.00	1,224.01	-
		58	-56.60	0.6	sand	-	-	32	-	253.21	9.0	6.0	0.015	0.50	1.00	-	3,062.63
7a		60	-58.60	2.0	sand	-	-	39	-	1,028.66	9.0	6.0	0.015	0.50	1.00	-	3,732.58
		62	-60.60	2.0	sand	-	-	61	-	1,430.80	9.0	6.0	0.015	0.50	1.00	-	5,682.62

		63	-61.60	1.0	sand	-	-	61	-	715.40	9.0	6.0	0.015	0.50	1.00	-	5,682.62
		64	-62.60	1.0	sand	-	-	56	-	710.46	9.0	6.0	0.015	0.50	1.00	-	5,359.60
									5,519	4,139						-	5,359.60

© GROUP EFFECT:											
	Distance between piles:	2.5*d	3.0*d	3.5*d	4.0*d	4.5*d	5.0*d	5.5*d	6.0*d	CALCULATED (kN):	4280
	Resistance factor:	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00	CHECK:	OK

© ULTIMATE BEARING CAPACITY:	15,017	kN	© ALLOWABLE BEARING CAPACITY:	8,543	kN	© ALLOWABLE BEARING CAPACITY:	
→ Skin friction:	9,657	kN	→ Skin friction:	5,863	kN	*(including group resistance factor = 0.7)*	
→ End-point:	5,360	kN	→ End-point:	2,680	kN	4,342	kN