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

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# 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  $\alpha$  -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:

 $q_s = \boldsymbol{\alpha} S_u$ 

 $S_u = \mbox{ mean undrained shear strength (kPa)}$ 

 $\alpha$  = adhesion factor applied to S<sub>u</sub>

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

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

Su (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:

$$q_s = 2.8N \text{ if } N \le 53$$

 $q_s = 0.21(N-53) + 150$  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<sup>2</sup>)

#### 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

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

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

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

where

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

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

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

$$q_p = 64N \text{ if } N \le 60$$

 $q_p = 3800$  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, Qp in kN, is:

$$\mathbf{Q}_{\mathbf{p}} = \mathbf{q}_{\mathbf{p}} \mathbf{A}_{\mathbf{p}}$$

where  $A_p = area$  of pile tip (m<sup>2</sup>)

#### 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	Soi	il types
Resistance factors	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 facto	rs
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D	istance between piles	2.5D	3.0D	3.5D	4.0D	4.5D	5.0D	5.5D	6.0D
G	roup 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<sub>u</sub> 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:

$$S_u = \sigma_{\nu 0}' (0.23 \pm 0.04) OCR^{0.8}$$

where  $\sigma'_{\nu 0}$  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

### Võ Đại Nhật

Trường Đại học Bách khoa, ĐHQG-HCM

# 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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						boring log										
Bor	ehol	e Nc	: CL	- <b>A</b> 2 c	oordina	te of Borehol e: X: 1150540.869 Gr	ound \	Nat	er	Ele	vat	tior	: <u>Ap</u>	pe	are	d0.000 m
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Layer	Elevation	Depth	Thickniss				Depth		5 c		30	SPT Chart			"	Sam of S
_	ă		μ				Del	N1	N2	N 3	z	_	ę			ept _
kq			2.40	$\times$		Filling soil: Elastic silt	0.70	3	5	6	11		4	33	а =	0.500270
	-1.00	2.40		r de la compañía de la	₽¥¥	- Clay with plants	2:00	4	6	7	13	┦	$\square$	╫	$\square$	1.80-2.00 UD3
							4.00	0	0	1	1 •	Æ		╢	$\square$	3.40-4.00 UD4
					$\forall / /$		6.00	0	0	0	0	$\vdash$		╢	$\square$	5.40-6.00 UD5
							8.00	0	0	1	1	++		++		7.40-8.00 UD6
							10.00	0	0	1	1.	+		$\parallel$		9.40-10.00
1a			21.20		4//	Elastic silt with sand, greenish,		0	1	1	2					UD7 11.40-12.00
				V LA		greyblackish grey very soft to soft (MH)s	14.00	1	1	1	2	$\parallel \mid$	$\parallel \mid$	$\parallel$	$\parallel$	UD8 13.40-14.00
				$\mathbb{Z}$	1//		<u>16.00</u> 16.45	1	1	1	2	$\parallel \mid$	Щ	$\parallel$	Ш	UD9 15.40-16.00
					¥//,		18.00 18.45	1	1	1	2		Щ	$\parallel$	Щ	UD10 17.40-18.00
							20.00	1	1	2	3	╙		$\parallel$		UD11 19.40-20.00
				$\square$			22.00	1	1	2	3			$\parallel$		UD12 21.40-22.00
	-22.20	23.60		$\langle / \rangle$	4		22.45	0	1	1	2	H		Ш		UD13 23.40-24.00
							26.00	1	2	2	4	₩		Ш		UD14 25.40-26.00
				11			26.45 28.00	1	2	2	4					UD15 27.40-28.00
				1/	11		28.45 30.00 30.45	1	1	2	3					UD16
4a			10.10	///		Lean clay with sand, greenish	32.00	1	2	3	5					UD17 31.40-32.0
44			18.10	11		grey, medium stiff (CL)s	32.45 34.00	1	2	3	5	I				UD18
				1/1	1/1/		34.45 36.00	1	2	3	5	II				UD19 35.40-36.00
				1/1/			36.45 38.00	2	3	3	6	II				UD20
				$\begin{array}{c} 38.45 \\ 40.00 \\ 40.45 \\ 2 \end{array}$	3	5	$\mathbf{I}$				UD21 39.40-40.00					
	-40.30	41.70		14	44		42.00	7	10	13	23	Ν				UD22 41.80-42.00
4 C			5.20			Fat clay with sand, greenish grey	42.45	9	12	15	27			UD23 43.80-44.00		
10			Diackish grey, very stiff (CH)s 44.45 46.45 8	blackish grey, very stiff (CH)s 44.45	blackish grey, very stiff (CH)s		44.45			21			Π		UD24	
	-45.50	46.90			0 0 12	13				Π		45.80-46.00 UD25				
				///			48.45 50.00			14	26			Π		47.80-48.00 UD26
4 e			10.50			I and allow with an all and an able	50.45	50.45 / 10		15	25			Π		49.80-50.00 UD27
				///	[///,	Lean clay with sand, greenish grey, greenish grey,	52.00 52.45 54.00		12	15	27	17		$\square$	Ш	51.80-52.00 D28
				11/	1/1/	blackish grey, very stiff to hard (CL)s	54.00 54.45 56.00			9	17			$\parallel$	$\square$	53.80-54.00 D29
	-56.00	57.40	L				56.45	16	20	22	42		1	$\parallel$	Ш	55.80-56.00 D 30
				()/	14		58.45	10	15	17	32		Ň	Ħ	Π	57.80-58.00 D 3 1
				11	11		60.45	13	19	20	39		N		Π	59.80-60.00 D 3 2
				199			62.00 62.45 64.00	19	29	32	61			Ì	П	61.80-62.00 D 3 3
				11	11		64.45	20	26	30	56			1	Ħ	63.80-64.00 D34
				111	21,1	Silty sand, Poorly graded sand	<u>66.00</u> 66.45	19	24	26	50		It	Ħ	Ħ	65.80-66.00 D 35
7a			25.00	41	11	with silt brownish grey,	<u>68.00</u> 68.45	17	24	27	51	$\parallel \mid$		+	$\parallel$	67.80-68.00 D 36 69.80-70.00
, a			23.00	11	11.	yellowish grey,whitish grey dense to very dense	70.00	17	24	27	51	$\parallel \mid$		+	$\parallel$	D37
				$\langle j \rangle$	1//	SM/(SP-SM)	72.00	19	26	29	55	++	H	ᡛ╟	$\mathbb{H}$	71.80-72.00 D 38
				$\mathbb{Z}/\mathbb{Z}$	11		<u>74.00</u> 74.45	23	29	30	59	++	$\mathbb{H}$	ᡟᡰ	$\mathbb{H}$	73.80-74.00 D 3 9
				1/1	1//		76.00	19	25	26	51	++	∦	+	$\mathbb{H}$	75.80-76.00
				$\langle / / \rangle$	124		78.00	20	27	32	59	$\mathbb{H}$	H	ᡟ┼	$\mathbb{H}$	D 40 77.80-78.00 D 41
				44	14		<u>80.00</u> 80.45	19	30	34	64	$\mathbb{H}$	++	ł	$\mathbb{H}$	D 4 1 79.80-80.00
	-81.00	82.40		222			82.00	22	26	39	65	Ш	Ш	4	Щ	D 4 2 81.80-82.00

Figure 1. The boring log

			Calcı	ulation of bearing	capacity of t	orec	d pile					
	Project:	CMDCP						Standard	applied:	Accordi	ng to 22TC	N 272-05
	Location of pile:	CL - A2						Date:		20- Jul- 12		
INPUT DATA	<u></u>											
Pile nar	ne:	CL - A2		Elevation of bottom of pile	e-cap: -0.12	2	m		Perimeter	of pile:	4.71	m
Pile len pile cap	gth from bottom of	63.98	m	Elevation of ground level:	1.40	)	m		Area of pile	e:	1.77	m²
Pile dia	meter:	1.5	m	Elevation of ground wate	r level: -0.12	2	m		Elevation of tip:	of pile	-62.60	m
SKIN FRICTI	ON CAPACITY:			© END BEARING CAPA	CITY:							
Clay (kPa) :	$q_{\text{s}} = \alpha \; S_{\text{u}}$		Article 10.8.3.3.1	Clay (kPa):	$q_p = N_c S_u <= 4000$							Article 10.8.3.3.2
Sand (kPa) :	qs = 2.8N if N <= 53		Article 10.8.3.4.2		© Nc = 6[1+0.2(Z/	′D)] <=	9	© If Su≻	96 kPa with [	D > 1.9m,	use q <sub>P</sub> = q	pFr
	qs = 0.21(N-53)+1	50 if N > 53			$\ensuremath{\mathbb{O}}$ Su is within 2D	below p	oile tip		Fr = 760/(1 pile tip	2aD <sub>P</sub> +76	i0b) <= 1, w	vhere D <sub>P</sub> is diameter
					© lf Su < 24 kPa, 2/3*Nc	use Nc	=		a = 0.0071	+0.0021(	(Z/D <sub>p</sub> ) <= 0	.015
									b = 1.45*s	qrt(2Su) v	vith 0.5 <=	b <= 1.5
				Sand (kPa):	$q_P = 64N$ if N<=60							Article 10.8.3.4.3
					qp = 3800 if N>60							
					© With diameter of	of pile ti	ip D <sub>P</sub> >1.27	′m, use q <sub>P</sub> =	qp(1.27/Dp)			
Side res	sistance factor:	clay =	0.65	End resistance	ce factor:	С	lay =	0.55				

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

				sand =	0.55						sand =	0.50		Diamet pile tip	er of	Dp =	1.5
Laye r	Count ed	Depth	Elevatio n	Thickness	Soil	Su	α	N	Q₅(kN)=q₅(	kPa)*u*L	Nc	Nc	а	b	F,	Q <sub>p</sub> (kN)=	q <sub>p</sub> (kPa)*A
nam e	from	m	m	m	type	kPa	u	N	clay	sand	INC.	modified	a	0	l r	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														
ka		2	-0.60	0.0	clay	46.82	0.55	13	-	-	7.6	5.1	0.010	0.50	1.00	628.49	-
kq		2.4	-1.00	0.0	clay	46.82	0.55	13	-	-	7.9	5.3	0.010	0.50	1.00	654.95	-
		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	
1a		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	
		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	-
4a		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	-
40	 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
ľ		64	-62.60	1.0	sand	-	-	56	-	710.46	9.0	6.0	0.015	0.50	1.00	-	5,359.6
									5,519	4,139						-	5,359.6
GROL	<b>GROUP EFFECT:</b> 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		CALCU	LATED (kN):		4280
			Resistance	factor:	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00		CHECK:	:		ок
ULTIN	MATE BEA	RING CAPA	ACITY:	15,017	kN		© ALLOW	ABLE BEARING C	APACITY:		8,543	kN		<u>© ALLC</u>	OWABLE BE	ARING CAPA	<u>СІТҮ:</u>
	$\rightarrow$ Skin friction:			9,657	kN				$\rightarrow$ Skin fric	tion:	5,863	kN	(including group r		ng group res	sistance facto	or = 0.7)
		→ End-p	point:	5,360	kN				$\rightarrow$ End-poi	nt:	2,680	kN			4,342	kN	