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Material Properties

Characteristic stre	ICP / CEPCO Grade 80MPa Precast (Pretensioned Spun) Driven Circular RC Pile	N/mm^2	NOT OK
Yield strength of longitudinal steel, f_y	460	N/mm^2	
Yield strength of shear link steel, f_{yv}	460	N/mm^2	
Type of concrete and density, ρ_c	Normal Weight 24	kN/m^3	

Factor of Safety

FOS (overall base (effective) bearing and shaft (effective) friction), FOS_1 (usu	2.0	
General Piling: 2.0		
FOS (base (effective) bearing), FOS_2 (usually 3.0)	3.0	
General Piling (Tomlinson): 3.0		
FOS (shaft (effective) friction), FOS_3 (usually 1.5 to 2.0)	1.5	
General Piling (Tomlinson): 1.5		
Loading factor, K (between 1.40 and 1.60 depending on DL to LL ratio)	1.50	*BS8110*

Note loading factor K multiplies SLS loads for ULS loads for section (reinforcement) design; *cl. 2.4.3.1.1*

Soil Description

Water unit weight, γ_w = 9.81kN/m^3	9.8	kN/m^3
Soil name	User Defined	
Dry bulk unit weight, γ_{dry}	20.0	kN/m^3
Saturated bulk unit weight, γ_{sat}	20.0	kN/m^3

Soil Method(s) of Analysis

Method(s) of analysis ? ☑ Undrained ☑ Drained ☑ Empirical

For clays, perform undrained, drained and empirical analyses;

For sands / gravels, perform drained and empirical analyses;

Soil Strength

Soil strength variation with depth function calculation method			Manual	
Soil strength variation step with depth, step			1.500	m
Undrained shear strength, $S_u(z)$	45.0	+	5.9z	kPa
Effective angle of shear resistance, ϕ'	30.0	+	0.3z	degrees
SPT, N(z)	10.0	+	1.3z	

Note that S_u can be obtained from S_u=4.5N (Stroud) or S_u=(0.1+0.15N)x50 (Fukuoka) values; *Tomlinson*

Note that ϕ' = 27.1+0.3N−0.00054N^2 (Peck, 1974 | Wolff, 1989);

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	Valid	N/A		Valid	N/A		Valid	N/A	
z (m)	$S_u(z)$ Manual	$S_u(z)$ Formula	$S_u(z)$ Adopted	$\phi'(z)$ Manual	$\phi'(z)$ Formula	$\phi'(z)$ Adopted	N(z) Manual	N(z) Formula	N(z) Adopted
0.000	0	45	0	27	30	27	0	10	0
1.500	18	54	18	28	31	28	4	12	4
3.000	36	63	36	29	31	29	8	14	8
4.500	50	71	50	30	31	30	11	16	11
6.000	36	80	36	29	32	29	8	18	8
7.500	41	89	41	30	32	30	9	20	9
9.000	41	98	41	30	33	30	9	22	9
10.500	50	106	50	30	33	30	11	24	11
12.000	86	115	86	33	34	33	19	26	19
13.500	99	124	99	33	34	33	22	28	22
15.000	59	133	59	31	35	31	13	30	13
16.500	77	142	77	32	35	32	17	31	17
18.000	90	150	90	33	36	33	20	33	20
19.500	117	159	117	35	36	35	26	35	26
21.000	355	168	355	47	37	47	79	37	79
22.500	375	177	375	48	37	48	83	39	83
24.000	346	185	346	47	37	47	77	41	77
25.500	375	194	375	48	38	48	83	43	83
27.000	450	203	450	52	38	52	100	45	100
28.500	450	212	450	52	39	52	100	47	100
30.000	450	221	450	52	39	52	100	49	100
31.500	450	229	450	52	40	52	100	51	100
33.000	450	238	450	52	40	52	100	53	100
34.500	450	247	450	52	41	52	100	55	100
36.000	450	256	450	52	41	52	100	57	100
37.500	450	264	450	52	42	52	100	59	100
39.000	450	273	450	52	42	52	100	61	100
40.500	450	282	450	52	43	52	100	63	100
42.000	450	291	450	52	43	52	100	65	100
43.500	450	299	450	52	43	52	100	67	100
45.000	450	308	450	52	44	52	100	69	100
46.500	450	317	450	52	44	52	100	70	100
48.000	450	326	450	52	45	52	100	72	100
49.500	450	335	450	52	45	52	100	74	100
51.000	450	343	450	52	46	52	100	76	100
52.500	450	352	450	52	46	52	100	78	100
54.000	450	361	450	52	47	52	100	80	100
55.500	450	370	450	52	47	52	100	82	100
57.000	450	378	450	52	48	52	100	84	100
58.500	450	387	450	52	48	52	100	86	100
60.000	450	396	450	52	48	52	100	88	100
61.500	450	405	450	52	49	52	100	90	100
63.000	450	414	450	52	49	52	100	92	100
64.500	450	422	450	52	50	52	100	94	100
66.000	450	431	450	52	50	52	100	96	100
67.500	450	440	450	52	51	52	100	98	100
69.000	450	449	450	52	51	52	100	100	100
70.500	450	457	450	52	52	52	100	102	100
72.000	450	466	450	52	52	52	100	104	100
73.500	450	475	450	52	53	52	100	106	100
75.000	450	484	450	52	53	52	100	108	100

Note that SPT, N calculated by multiplying SPT, N > 50 by 300/Δs x 50 and should be further limited to 100;

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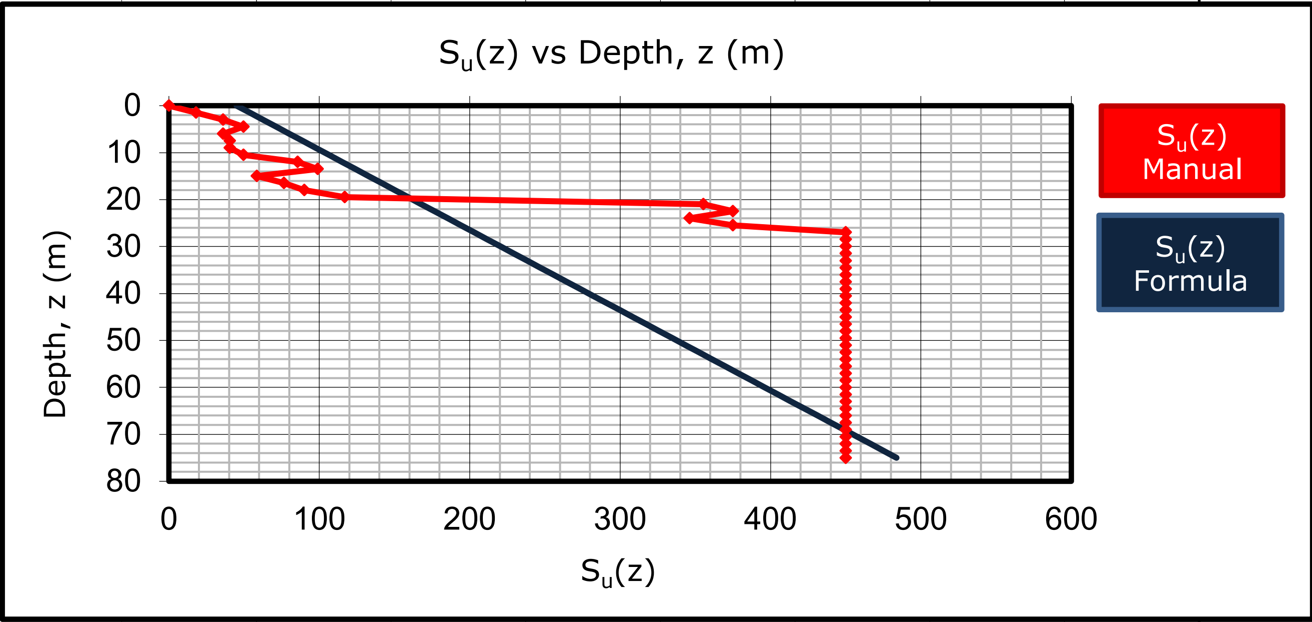

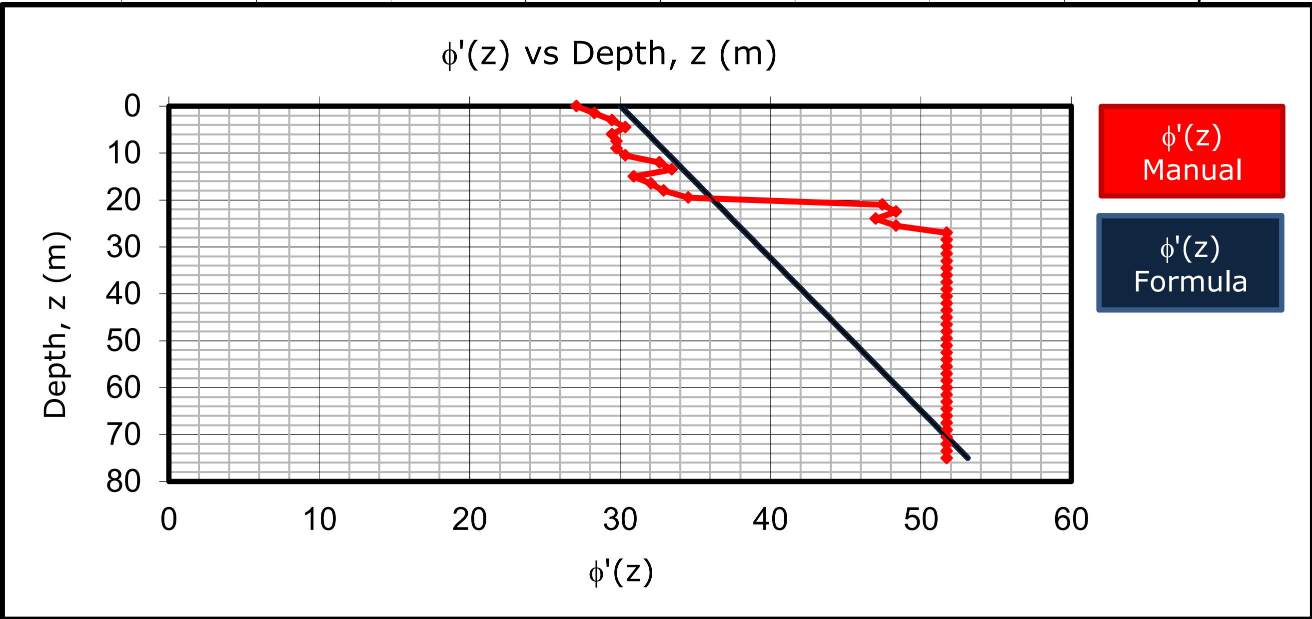

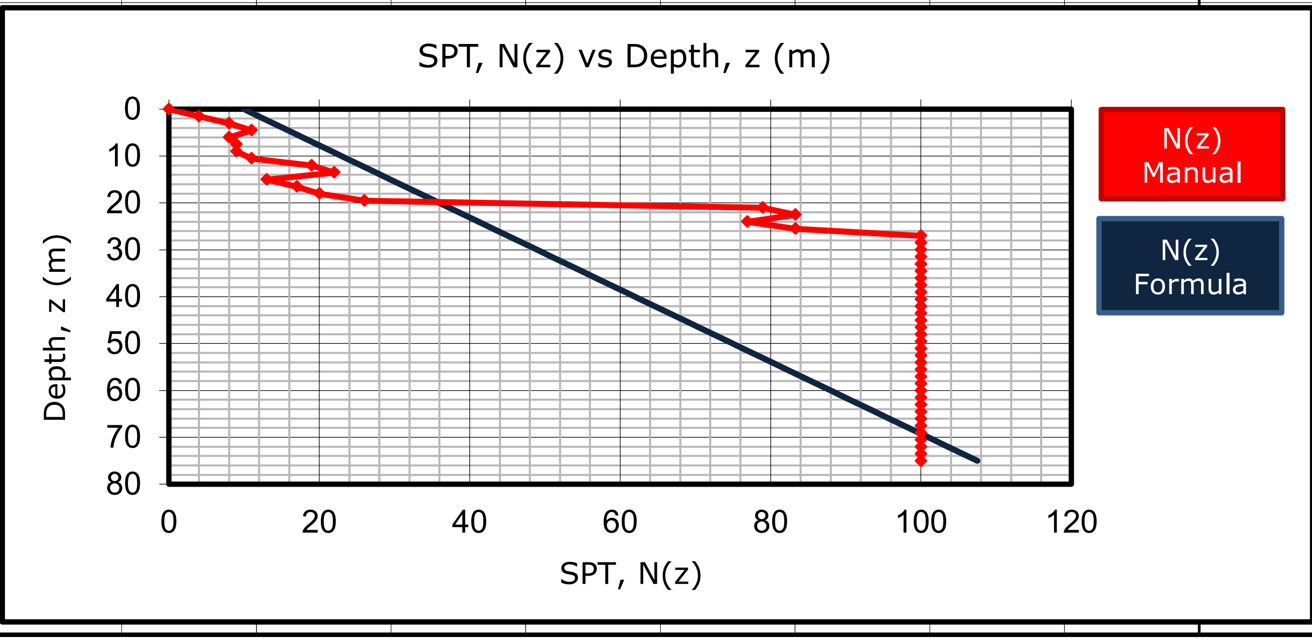

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Soil Strength (Limiting Base and Shaft Resistance)

Undrained Analysis

No limit to base and shaft resistance applicable.

Drained Analysis

Gross effective bearing capacity limit, $q_{flimit}'(z=L-L_0)$	**15000**	kPa	**Note**
$q_{flimit}'(z=L-L_0) = N_{q,strip}.\sigma_v'(z=20D-L_0) \le 15MPa$			*Tomlinson*
$\boxed{N_q = e^{\pi \tan\varphi'} \tan^2(45 + \varphi'/2)}$	201.0		
$\sigma_v'(z=20D-L_0) = p_{surface}+\gamma_{dry}.(L_c+20D)$	Invalid	kPa	
$\sigma_v'(z=20D-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+20D-z_u)+\gamma_{dry}.z_u$	142	kPa	
$\sigma_v'(z=20D-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+20D)$	Invalid	kPa	

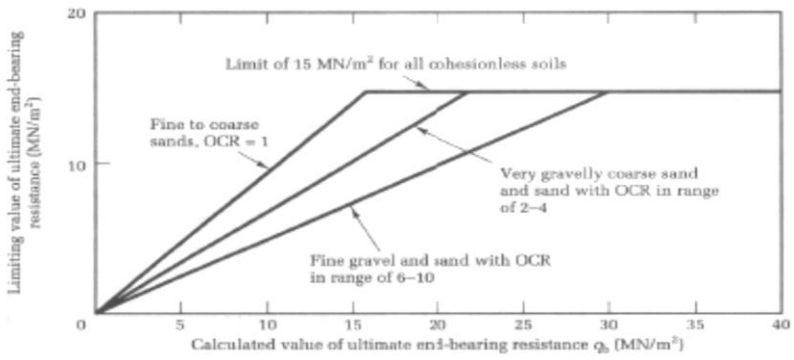

Fig. 7.7 Limiting values of pile end-bearing resistance for solid end piles in cohesionless soils (after te Kamp[7.14]).

Shaft effective stress limit, $\tau_{alimit}'(z)$	**Variable**	kPa	**Note**
$\tau_{alimit}'(z) = K_s.\tan\delta'.\sigma_v'(z=20D-L_0) \le 110kPa$			*Tomlinson*
$\sigma_v'(z=20D-L_0) = p_{surface}+\gamma_{dry}.(L_c+20D)$	Invalid	kPa	
$\sigma_v'(z=20D-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+20D-z_u)+\gamma_{dry}.z_u$	142	kPa	
$\sigma_v'(z=20D-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+20D)$	Invalid	kPa	

Empirical Analysis

Gross effective bearing capacity limit, $q_{flimit}'(z=L-L_0)$ (usually 3,000	17500	kPa
Note $q_{flimit}'(z=L-L_0)$ = 10,000kPa (Meyerhof);		
Note $q_{flimit}'(z=L-L_0)$ = 30xN=100→3,000kPa to 45xN=150→6,750kPa (Balakrishnan);		
Shaft effective stress limit, $\tau_{alimit}'(z)$ (usually 150kPa to 400kPa)	200	kPa
Note $\tau_{alimit}'(z)$ = 150kPa (McClelland 1974, Meyerhof 1976);		
Note $\tau_{alimit}'(z)$ = 2xN=100→200kPa to 2xN=200→400kPa (Balakrishnan);		

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Rock Strength

Depth of rock level from pile cap base, L_{rock}	100.0	m	**Note**
Unconfined uniaxial compressive strength, q_{uc}	10.0	MPa	
Rock quality index, RQD	70	%	
Base effective stress at rock levels, $q_f'(z>=L_{rock}-L_0) = a_1(q_{uc})^{b1}$	**3000**	kPa	
Parameter, $a_1 = \alpha_b$	0.30		
Parameter, b_1	1.00		

- Using unconfined compressive strength (qu)
  - $f_{bu} = a_1 (q_u)^{b1}$

Method	a_1	b_1
Teng (1962)	5 -8	1.0
Coates (1967)	3	1.0
Argema(1962)	4.5 fbu<10 Mpa)	1.0
CGS(1992) : fba	Ksp.D	1.0
Zhang & Einstein (1998)	4.8(mean) Range : 3.0 -6.6	0.5
Poulos	4.8	0.5
Neoh (2002)	0.3	1.0

CGS : Canadian Geotechnical Society
Ksp : Bearing pressure coeff – spacing & aperture of discontinuities

Shaft effective stress at rock levels, $\tau_a'(z>=L_{rock}-L_0) = a(q_{uc})^b$	**1000**	kPa

Note $\tau_a' = 0.05q_{uc}$ | $\tau_a' =$ 100-140kPa weak | 700-1000kPa medium | 1000-1400kPa strong rock; *Neoh*

Table 1 Summary of Rock Socket Friction Design Values

Rock Formation	Working Rock Socket Friction*	Source
Limestone	300kPa for RQD <25% 600kPa for RQD =25 – 70% 1000kPa for RQD >70% The above design values are subject to 0.05x minimum of $\{q_{uc}, f_{cu}\}$ whichever is smaller.	Neoh (1998)
Sandstone	$0.10 \times q_{uc}$	Thorne (1977)
Shale	$0.05 \times q_{uc}$	Thorne (1977)
Granite	1000 – 1500kPa for $q_{uc} > 30N/mm^2$	-

* Note: Lower range to Grade III and higher range for Grade II or better

Rock	Working Rock Socket Friction
Granite	1500kPa to 2000kPa
Sandstone	1000kPa to 1500kPa
Siltstone	1000kPa to 1500kPa

Parameter, a	0.10	
Rock socket reduction factor, $\alpha = f(q_{uc})$	0.13	*Williams and P*
Rock socket reduction factor, $\beta = f(RQD)$	0.80	*Williams and P*
Parameter, b	1.00	

- Using unconfined compressive strength (q_u)
  - $f_{su} = a(q_u)^b$ MPa where q_u in MPa

Method	a	b
Rosenberg & Journeaux (1976)	0.375	0.515
Horvath (1978)	0.33	0.5
Horvath & Kenny (1979)	0.20 – 0.25	0.5
Meigh & Wolski (1979)	0.22	0.6
Williams & Pells (1981)	αβ	1.0
Rowe & Armitage (1987)	0.45	0.5
Reese & O'Neill (1989)	0.21	0.5
Poulos	0.3	0.5
Zhang & Einstein (1998)	0.4(smooth) 0.8 (rough)	0.5
Neoh (2002) : fsa	0.05	1.0

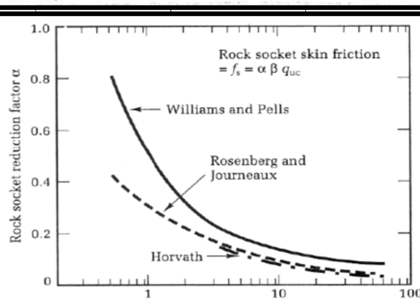

Figure 1 Rock Socket Reduction Factor, α, w.r.t. Unconfined Compressive Strength (after Tomlinson, 1995)

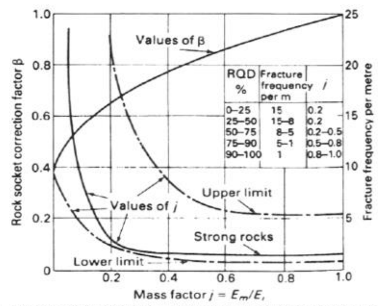

Figure 2 Rock Socket Reduction Factor, β, w.r.t. Rock Mass Discontinuity (after Tomlinson, 1995)

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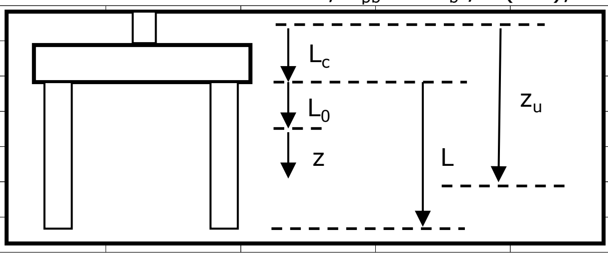
Pile Group Dimensions

Width of pile group (pile cap) in x, B_{cap}	3.000	m	
Length of pile group (pile cap) in y, L_{cap}	3.000	m	

Pile Dimensions

Pile section shape	Circular			
Pile shaft and base width w.r.t. length (rect. only), %.(D | D_b)		50%		
Pile shaft diameter (circ.), width (sq.) or length (rect.), D	600mm	600	mm	
User-defined, $D_{user-defined}$		600	mm	
Pile shaft perimeter, P_{ps} = πD (circ.), 4D (sq.) or (%+1).2D (rect.)		1885	mm	
Pile shaft cross sectional area, A_{ps} = $\pi D^2/4$ (circ.), D^2 (sq.) or %.D^2 (rect.)		282743	mm^2	
Pile base diameter (circ.), width (sq.) or length (rect.), D_b	600mm	600	mm	OK
Pile base cross sectional area, A_{pb} = $\pi D_b^2/4$ (cir.), D^2 (sq.) or %.D^2 (rect.)		282743	mm^2	OK



Depth of pile cap base from ground level, L_c (>= 0.000m)		0.000	m	OK
Depth of pile z=0 level from pile cap base, L_0 (>= 0.000m)	Without NSF	0.000	m	OK
Depth of pile founding level from pile cap base, L (>=L_0)		21.000	m	OK

Note that L_0 accounts for poor ground near surface level where no contribution of shaft skin friction capacity is adopted, in fact negative skin friction is considered over L_0 length if requested;

Depth of water table from ground level, z_u	2.000	m

Note that the soil beneath the water table has an effective submerged unit weight of about half of the soil above the water table, thus reducing the drained overall pile effective capacity;
Hence use the highest water table forseeable;
Enter a negative z_u value for water table above ground level, this representing a flood event or a bridge pier within a sea or river with the ground level being the sea or river bed;
However, a water table above ground level may unconservatively decrease the overall pile (effective) capacity utilisation, thus consider also the case when the water table is at ground level;

Pile Dimensions [Pile Capacity Charts]

Precast Driven Square RC Pile	☐ 150	☐ 175	☐ 200	☐ 225	☐ 250	☐ 275	Not Selected
	☐ 300	☐ 325	☐ 350	☐ 375	☐ 400	☐ 450	
Insitu Micropile Bored Circular RC Pile	☐ 150	☐ 250	☐ 300				Not Selected
Precast (Pretensioned Spun) Driven Circular RC Pile	☐ 250	☐ 300	☐ 350	☐ 400	☐ 450	☐ 500	Not Selected
	☑ 600	☐ 700	☐ 800	☐ 900	☐ 1000	☐ 1200	
Insitu CFA Bored Circular RC Pile	☐ 300	☐ 450	☑ 600	☐ 750	☐ 900	☐ 1050	Not Selected
	☐ 1200						
Insitu Bored Circular RC Pile	☐ 300	☐ 450	☑ 600	☐ 750	☐ 900	☐ 1050	Not Selected
	☐ 1200	☐ 1350	☐ 1500	☐ 1650	☐ 1800	☐ 1950	
	☐ 2100	☐ 2250	☐ 2400				

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Pile Reinforcement

Pile typ ICP / CEPCO Grade 80MPa Precast (Pretensioned Spun) Driven Circular RC Pile	80	N/mm^2	

Precast Driven Square RC Pile or Insitu Bored Circular RC Pile

Pile compression capacity design method	SLS Design		
Cover to all reinforcement, $cover_4$ (usually 75)	75	mm	

Cover for reinforcement = (40mm + values in Table 3.4, BS8110: Part 1)
For example, bored piles (concrete G35) in non-aggressive soil shall required minimum cover of (40mm + 35mm) = 75mm

Longitudinal steel reinforcement diameter, ϕ_p	25	mm	
Longitudinal steel reinforcement number, n_p	15		
Longitudinal steel area provided, $A_{s,prov,p} = n_p.\pi.\phi_p^2/4$	N/A	mm^2	
Shear link diameter, $\phi_{link,p}$	10	mm	
Number of links in a cross section, i.e. number of legs, $n_{link,p}$	2		
Area provided by all links in a cross-section, $A_{sv,prov,p} = n_{link,p}.\pi.\phi_{link,p}^2/4$	N/A	mm^2	
Pitch of links, S_p	150	mm	
Estimated steel reinforcement quantity	N/A	kg/m^3	

[7850 . $A_{s,prov,p}$ / A_{ps}]; No laps; Links ignored;

BS8004: 1986 also recommends the following slump details for concrete used in bored pile construction:

Table 3 Slump details for concrete used in bored pile construction

Typical conditions of use	Slump Range	
	mm	in
Poured into water-free unlined bore. Widely spaced reinforcement leaving ample room for free movement between bars.	75 to 125	3 to 5
Where reinforcement is not spaced widely enough to give free movement between bars. Where cut-off level of concrete is within casing. Where pile diameter is less than 600 mm.	100 to 175	4 to 7
Where concrete as placed by tremie under water or bentonite suspension.	150 to collapse	6 to collapse

Precast (Pretensioned Spun) Driven Circular RC Pile

Effective area of concrete, A_{eff}	157080	mm^2	
Effective prestress, f_{pe}	5.3	N/mm^2	

Insitu Micropile Bored Circular RC Pile

Yield strength of API pipe, $f_{y,API}$	550	N/mm^2	
Outer diameter of API pipe, OD_{API}	177.8	mm	
Wall thickness of API pipe, t_{API}	9.19	mm	
Cross sectional area of API pipe, $A_{API} = \pi.[OD_{API}^2-(OD_{API}-2.t_{API})^2]/4$	N/A	mm^2	
Cross sectional area of grout, $A_{c,API} = A_{ps}-A_{API}$	N/A	mm^2	
Elastic modulus of concrete, $E_c = 5500.(f_{cu}/1.5)^{0.5}$	40166	N/mm^2	*BS8110*
Elastic modulus of steel, E_s	210000	N/mm^2	*cl. 2.5.3*

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Pile SLS Loading (Including Negative Skin Friction)

Surcharge at surface, $p_{surface}$	0	kPa	
Pile SLS vertical load, $F_{pile,v,n}$	2100	kN	
Pile group (pile cap) SLS vertical load, $F_{pilecap,v}$	8400	kN	
Note that $F_{pile,v,n}$ and $F_{pilecap,v}$ can be positive (downward) or negative (upwards);			
Pile SLS vertical (compressive) NSF load, $F_{pile,v,NSF}$	0	kN	
Note NSF = negative skin friction; Note $F_{pile,v,NSF} = P_{ps}.L_0.\beta.[\sigma_v'(z=-L_0)+\sigma_v'(z=0)]/2$;			
Consideration of NSF ?	Not Considered		
NSF reduction factor, β	0.30		*Meyerhof*
	Clay		
	0.20-0.25		*Garlanger*
	Silt		
	0.25-0.35		*Garlanger*
	Sand		
	0.35-0.50		*Garlanger*

The unit negative skin friction force at any depth can be calculated from the equation

$$f_{sneg} = \beta p_0 \qquad (7.19)$$

where p_0 is the effective overburden pressure and β is a reduction factor shown by Meyerhof[7.31] to be equal to 0.3 for piles up to 15 m long, decreasing to 0.2 and 0.1 for 40 and 60 m long piles respectively.

Effective vertical stress at z=-L0 level, $\sigma_v'(z=-L_0)$	0	kPa
Case when $(z_u - L_c) >= MAX(B_{cap}, L_{cap})$	Invalid	
$\sigma_v'(z=-L_0) = p_{surface}+\gamma_{dry}.L_c$	N/A	kPa
Case when $0 < (z_u - L_c) < MAX(B_{cap}, L_{cap})$	Valid	
$\sigma_v'(z=-L_0) = p_{surface}+\gamma_{dry}.L_c$	0	kPa
Case when $(z_u - L_c) = 0$	Invalid	
$\sigma_v'(z=-L_0) = p_{surface}+\gamma_{dry}.L_c$	N/A	kPa
Case when $(z_u - L_c) < 0$ and $z_u >= 0$	Invalid	
$\sigma_v'(z=-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c-z_u)+\gamma_{dry}.z_u$	N/A	kPa
Case when $z_u < 0$	Invalid	
$\sigma_v'(z=-L_0) = p_{surface}+\gamma_{sat}.L_c+\gamma_w.(-z_u)-\gamma_w.(L_c+(-z_u))$	N/A	kPa
Note that the above equation reduces to $\sigma_v'(z=-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).L_c$;		
Effective vertical stress at z=0 level, $\sigma_v'(z=0)$	0	kPa
Case when $(z_u - L_c - L_0) >= MAX(B_{cap}, L_{cap})$	Invalid	
$\sigma_v'(z=0) = p_{surface}+\gamma_{dry}.(L_c+L_0)$	N/A	kPa
Case when $0 < (z_u - L_c - L_0) < MAX(B_{cap}, L_{cap})$	Valid	
$\sigma_v'(z=0) = p_{surface}+\gamma_{dry}.(L_c+L_0)$	0	kPa
Case when $(z_u - L_c - L_0) = 0$	Invalid	
$\sigma_v'(z=0) = p_{surface}+\gamma_{dry}.(L_c+L_0)$	N/A	kPa
Case when $(z_u - L_c - L_0) < 0$ and $z_u >= 0$	Invalid	
$\sigma_v'(z=0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+L_0-z_u)+\gamma_{dry}.z_u$	N/A	kPa
Case when $z_u < 0$	Invalid	
$\sigma_v'(z=0) = p_{surface}+\gamma_{sat}.(L_c+L_0)+\gamma_w.(-z_u)-\gamma_w.(L_c+L_0+(-z_u))$	N/A	kPa
Note that the above equation reduces to $\sigma_v'(z=0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+L_0)$;		

Total pile SLS vertical (compressive) load (per pile), $F_{pile,v,comp}$	2100	kN
Note $F_{pile,v,comp} = MAX(0, F_{pile,v,n})+F_{pile,v,NSF}$;		
Total pile SLS vertical (tensile) load (per pile), $F_{pile,v,tens}$	0	kN
Note $F_{pile,v,tens} = ABS(MIN(0, F_{pile,v,n}))$;		

Pile ULS Loading (Including Negative Skin Friction)

Total pile ULS vertical (compressive) load (per pile), $F_{pile,v,comp,uls} = K.F_{pile,v,comp}$	3150	kN
Total pile ULS vertical (tensile) load (per pile), $F_{pile,v,tens,uls} = K.F_{pile,v,tens}$	0	kN

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Inclusion of Base Resistance for Soils in All Methods of Analysis | Rocks

Include or exclude base resistance ?	Include Base Resistance		Note

Executive Summary

Undrained overall pile capacity	137%	NOT OK
Drained overall pile effective capacity	84%	OK
Empirical overall pile effective capacity	85%	OK
Pile axial compression capacity	72%	OK
Pile axial tension capacity	N/A	N/A
Pile detailing requirements	N/A	
Undrained overall pile group capacity	4%	OK
Drained overall pile group capacity	N/A	N/A
Empirical overall pile group capacity	N/A	N/A
Overall utilisation summary		137%

% Vertical reinforcement in pile			N/A	%
Estimated pile steel reinforcement quantity			N/A	kg/m^3

[Note that steel quantity in kg/m^3 can be obtained from 78.5 x % rebar];

Material cost:	concrete, c	300	$units/m^3$	steel, s 3500	units/tonne
Reinforced concrete material cost = c+(est. rebar quant).s				N/A	$units/m^3$

Shaft = 600 mm | Base = 600 mm | CR						CR
D (m)	D_b (m)	z (m)	Undrained Capacity	Drained Capacity	Empirical Capacity	$L=z+L_0$ (m)
0.600	0.600	0.000	0	0	0	0.0
0.600	0.600	1.500	27	53	83	1.5
0.600	0.600	3.000	81	120	185	3.0
0.600	0.600	4.500	147	198	285	4.5
0.600	0.600	6.000	176	265	271	6.0
0.600	0.600	7.500	224	360	328	7.5
0.600	0.600	9.000	268	463	369	9.0
0.600	0.600	10.500	328	591	452	10.5
0.600	0.600	12.000	449	795	672	12.0
0.600	0.600	13.500	569	975	824	13.5
0.600	0.600	15.000	605	998	731	15.0
0.600	0.600	16.500	702	1191	879	16.5
0.600	0.600	18.000	812	1376	1021	18.0
0.600	0.600	19.500	961	1636	1241	19.5
0.600	0.600	21.000	1530	2508	2484	21.0
		22.500	1966	2613	2940	
		24.000	2336	2719	3187	
		25.500	2779	2824	3676	
		27.000	3339	2929	4130	
		28.500	3846	3034	4505	
		30.000	4353	3140	4880	
		31.500	4861	3245	5170	
		33.000	5368	3350	5451	
		34.500	5875	3456	5732	
		36.000	6382	3561	6013	
		37.500	6890	3666	6294	
		39.000	7397	3771	6575	
		40.500	7904	3877	6856	
		42.000	8411	3982	7137	
		43.500	8918	4087	7418	
		45.000	9426	4192	7699	
		46.500	9933	4271	7980	
		48.000	10440	4349	8261	
		49.500	10947	4428	8542	
		51.000	11455	4506	8824	
		52.500	11962	4585	9105	
		54.000	12469	4663	9386	
		55.500	12976	4742	9667	
		57.000	13484	4820	9948	
		58.500	13991	4899	10229	
		60.000	14498	4978	10510	
		61.500	15005	5056	10791	
		63.000	15513	5135	11072	
		64.500	16020	5213	11353	
		66.000	16527	5292	11634	
		67.500	17034	5370	11915	
		69.000	17542	5449	12196	
		70.500	18049	5527	12477	
		72.000	18556	5606	12758	
		73.500	19063	5684	13039	
		75.000	19571	5763	13320	

Note unlike the chart tables, herewith D and D_b can be unique and user-defined and pile shape can be rect.

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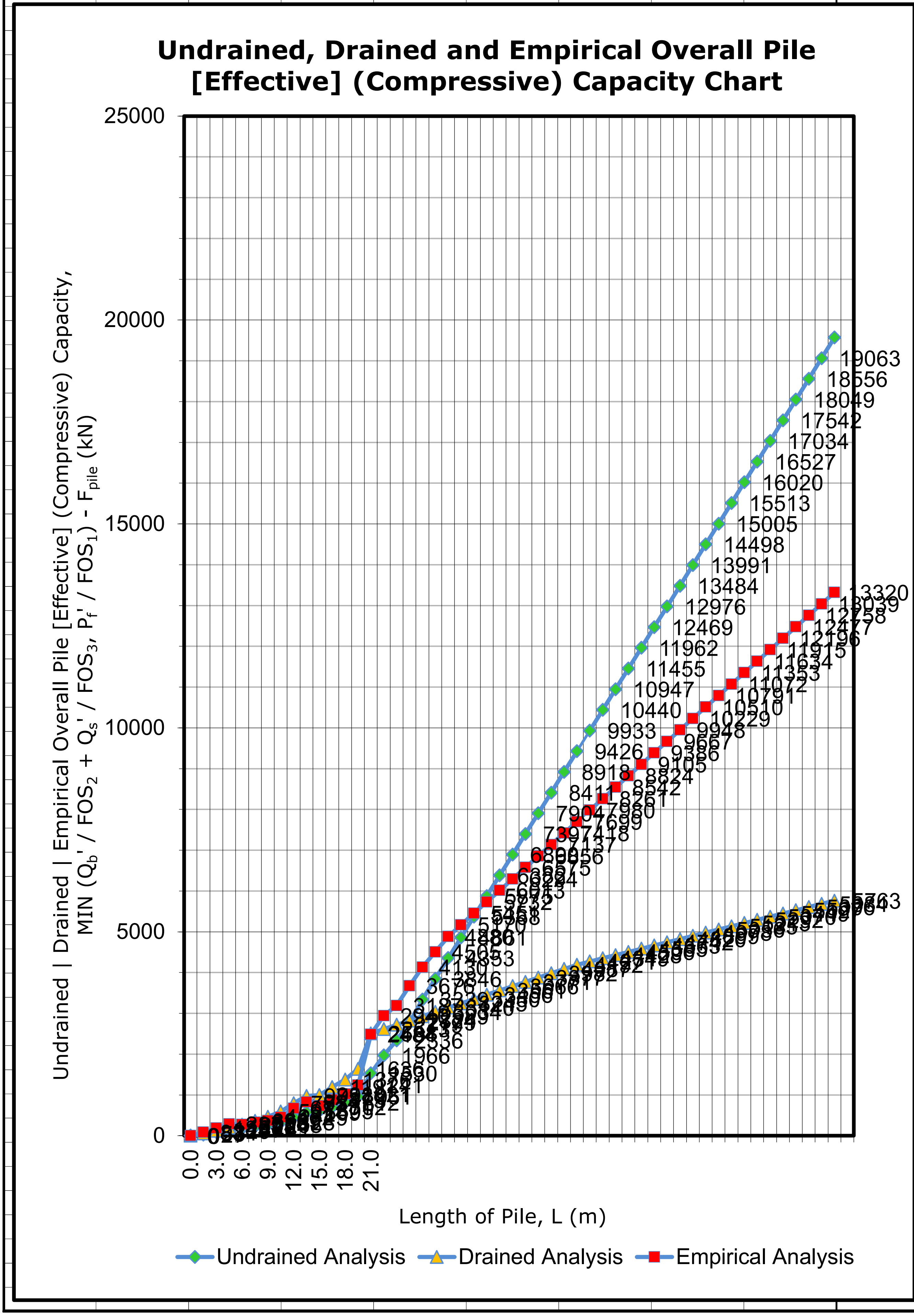

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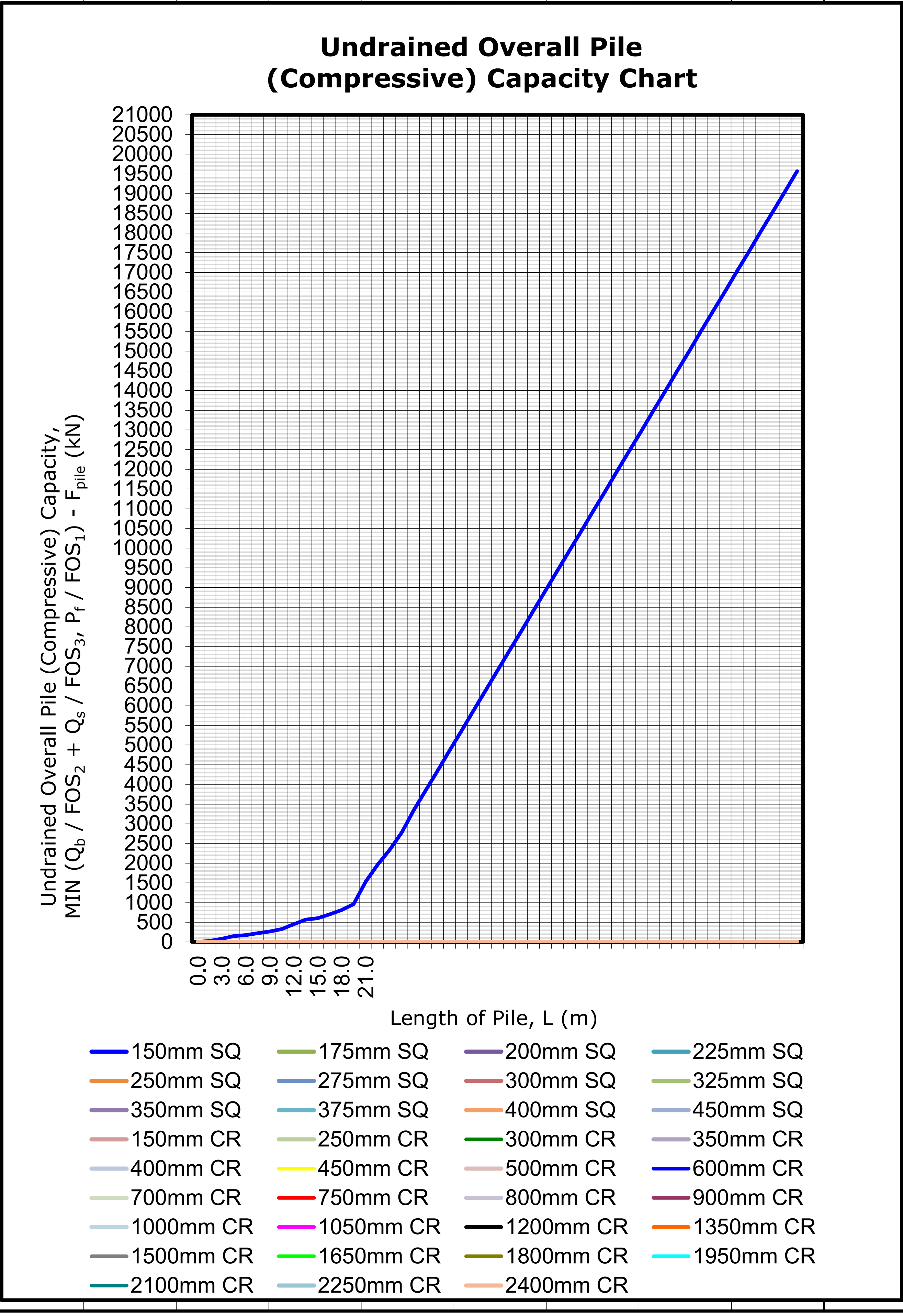
Pile Capacity Chart for Undrained Method of Analysis | All D = D_b



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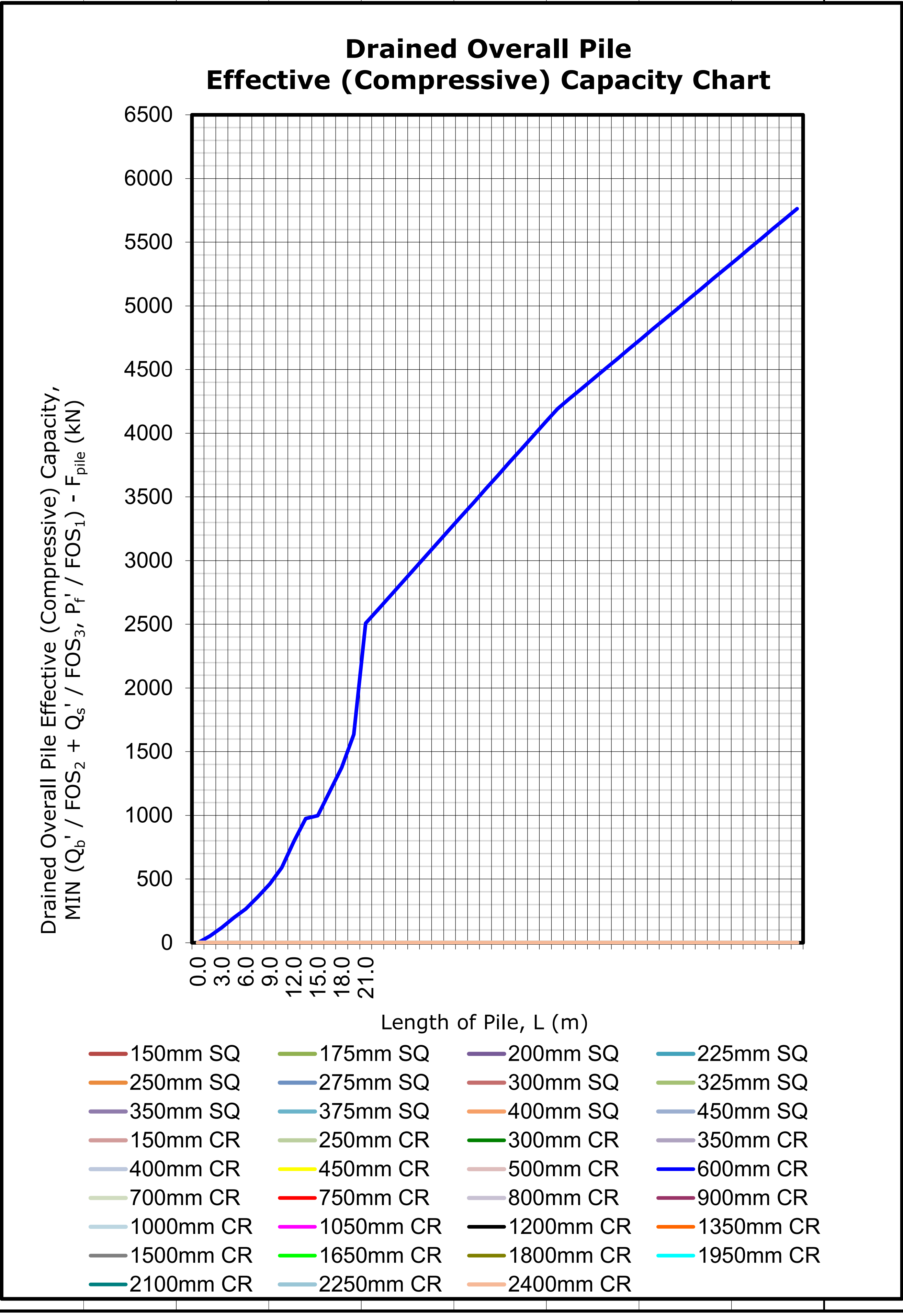
Pile Capacity Chart for Drained Method of Analysis | All D = D_b



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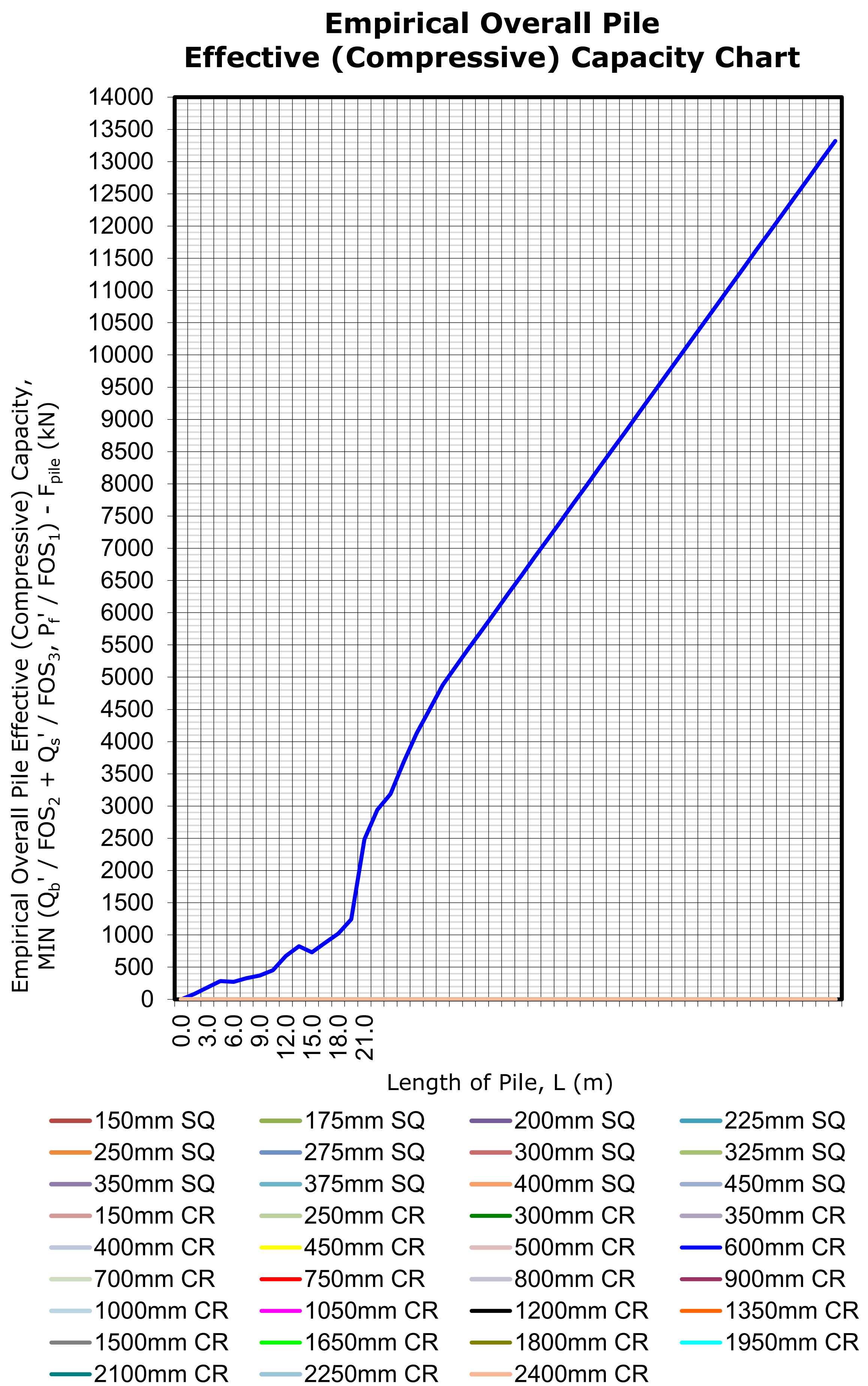
Pile Capacity Chart for Empirical Method of Analysis | All D = D_b



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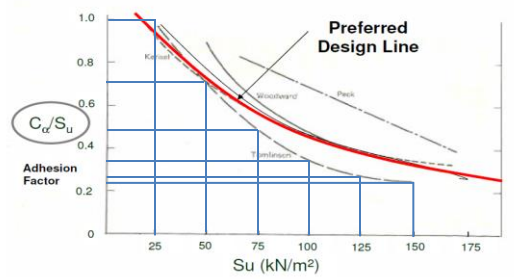
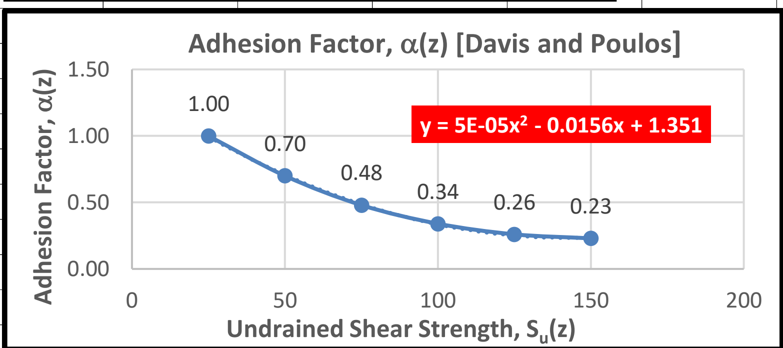
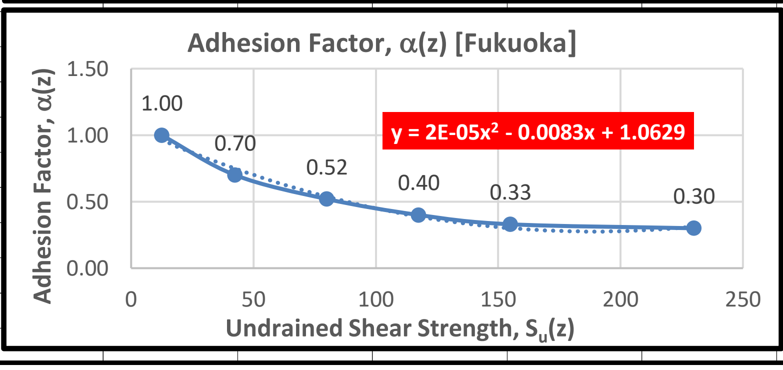
Undrained Overall Pile Capacity

Base bearing capacity, $Q_b = A_{pb}.q_f(z=L-L_0)$	904	kN		
Gross bearing capacity, $q_f(z=L-L_0) = N_c.S_u(z=L-L_0)$	28776	kPa		Terzaghi
Note gross bearing capacity set to 0.0kPa if base resistance excluded;				
Bearing capacity factor, N_c = 9.0	9.0			Meyerhof
Shaft friction capacity, $Q_s = \int P_{ps}.S_a(z).dz$	2203	kN		
Note shaft stress at z level, $S_a(z) = \alpha(z).S_u(z)$;				
a = 0.80 (driven piles) (Sutton)				Co
Shaft adhesion factor, $\alpha(z)$ for $S_u(z) \leq$	25	MPa	0.80	Compressive a
Shaft adhesion coefficient, K_1			0.0000	Co
Shaft adhesion coefficient, K_2			0.0000	
Shaft adhesion coefficient, K_3			0.8000	
Shaft adhesion factor, $\alpha(z)$ for $S_u(z) \geq$	150	MPa	0.80	Co
Note that α is 0.30 (under-reamed base piles);				Tomlinson
Note that α is 0.30-0.60 (stiff over-consolidated clay);				Whitaker and Co
Note that α is 0.30 (heavily fissured clay);				Tomlinson
Note that α is 0.45 (very stiff clay, S_u >= 150kPa);				Neoh
Note that α is 0.45-0.60 (firm to stiff clay, eg. London Clay);				Tomlinson
Note that α is 0.45 (bored piles), 0.80 (driven piles);				Sutton
Note that α is 1-[(S_u-25)/90] (soft to firm clay, 25kPa < S_u < 70kPa);				McClelland, Nord
Note that α is 0.50 (firm to stiff clay, S_u >= 70kPa);				McClelland, Nord
Note that α is 0.80-1.00 (soft Malaysian Clay);				Gue and Partn
Note that α is 1.00 (very soft clay, S_u <= 25kPa);				Neoh, API

Adhesion factor (α) – Shear strength (S_u) (McClelland, 1974)







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Pile weight minus soil weight removed, $F_{pile} = A_{ps}.L.(\rho_c - \gamma_{dry})$	**24**	kN	
Note under-reamed base dimensions ignored in calculation of F_{pile} as deemed negligible;			
Note conservatively, dry bulk unit weight assumed for density of displaced soil;			
Combined base bearing and shaft friction capacity, $P_f = Q_b + Q_s$	**3107**	kN	
Base and Shaft Capacity Factored Individually			
mpressive Undrained pile base capacity (factored), Q_b / FOS_2	301	kN	
nd Tensile Undrained pile shaft capacity (factored), Q_s / FOS_3	1469	kN	
mpressive Undrained pile base and shaft capacity (factored), Q_b / FOS_2 + Q_s /	**1770**	kN	
Base and Shaft Capacity Factored Together			
mpressive Undrained pile base and shaft capacity (factored), P_f / FOS_1	**1554**	kN	
Tensile Undrained pile base and shaft capacity (factored), Q_s / FOS_1	**1102**	kN	
ooke			
Undrained overall pile capacity for vertical (compressive) load, MIN (Q_b / FOS	**1530**	kN	
Undrained overall pile capacity for vertical (tensile) load, MIN (Q_s / FOS_3, Q_s /	**1102**	kN	
Undrained overall pile capacity utilisation = MAX ($F_{pile,v,comp}$ / (MIN (Q_b / FOS_2	**137%**		**NOT OK**
llund			
llund			
ers			

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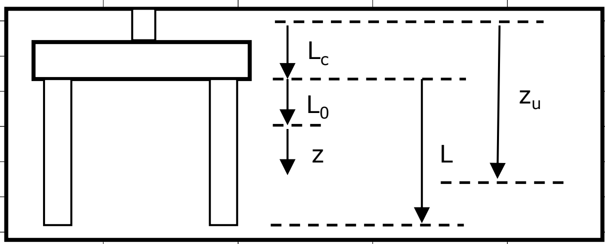
Shaft = 600 mm | Base = 600 mm | CR									CR
D (m)	D_b (m)	z (m)	$S_u(z)$ (kPa)	$q_f(z)$ (kPa)	$S_a(z)$ (kPa)	Q_b (kN)	Q_s (kN)	MIN (Q_b / FOS_2 +	$L=z+L_0$ (m)
0.600	0.600	0.000	0	0	0	0	0	0	0.000
0.600	0.600	1.500	18	162	14	46	20	27	1.500
0.600	0.600	3.000	36	324	29	92	81	81	3.000
0.600	0.600	4.500	50	446	40	126	178	147	4.500
0.600	0.600	6.000	36	324	29	92	275	176	6.000
0.600	0.600	7.500	41	365	32	103	361	224	7.500
0.600	0.600	9.000	41	365	32	103	453	268	9.000
0.600	0.600	10.500	50	446	40	126	555	328	10.500
0.600	0.600	12.000	86	770	68	218	707	449	12.000
0.600	0.600	13.500	99	891	79	252	916	569	13.500
0.600	0.600	15.000	59	527	47	149	1094	605	15.000
0.600	0.600	16.500	77	689	61	195	1247	702	16.500
0.600	0.600	18.000	90	810	72	229	1435	812	18.000
0.600	0.600	19.500	117	1053	94	298	1669	961	19.500
0.600	0.600	21.000	355	3197	284	904	2203	1530	21.000
0.600	0.600	22.500	375	3375	300	954	3029	1966	22.500
0.600	0.600	24.000	346	3115	277	881	3845	2336	24.000
0.600	0.600	25.500	375	3375	300	954	4661	2779	25.500
0.600	0.600	27.000	450	4050	360	1145	5594	3339	27.000
0.600	0.600	28.500	450	4050	360	1145	6611	3846	28.500
0.600	0.600	30.000	450	4050	360	1145	7629	4353	30.000
0.600	0.600	31.500	450	4050	360	1145	8647	4861	31.500
0.600	0.600	33.000	450	4050	360	1145	9665	5368	33.000
0.600	0.600	34.500	450	4050	360	1145	10683	5875	34.500
0.600	0.600	36.000	450	4050	360	1145	11701	6382	36.000
0.600	0.600	37.500	450	4050	360	1145	12719	6890	37.500
0.600	0.600	39.000	450	4050	360	1145	13737	7397	39.000
0.600	0.600	40.500	450	4050	360	1145	14754	7904	40.500
0.600	0.600	42.000	450	4050	360	1145	15772	8411	42.000
0.600	0.600	43.500	450	4050	360	1145	16790	8918	43.500
0.600	0.600	45.000	450	4050	360	1145	17808	9426	45.000
0.600	0.600	46.500	450	4050	360	1145	18826	9933	46.500
0.600	0.600	48.000	450	4050	360	1145	19844	10440	48.000
0.600	0.600	49.500	450	4050	360	1145	20862	10947	49.500
0.600	0.600	51.000	450	4050	360	1145	21880	11455	51.000
0.600	0.600	52.500	450	4050	360	1145	22898	11962	52.500
0.600	0.600	54.000	450	4050	360	1145	23915	12469	54.000
0.600	0.600	55.500	450	4050	360	1145	24933	12976	55.500
0.600	0.600	57.000	450	4050	360	1145	25951	13484	57.000
0.600	0.600	58.500	450	4050	360	1145	26969	13991	58.500
0.600	0.600	60.000	450	4050	360	1145	27987	14498	60.000
0.600	0.600	61.500	450	4050	360	1145	29005	15005	61.500
0.600	0.600	63.000	450	4050	360	1145	30023	15513	63.000
0.600	0.600	64.500	450	4050	360	1145	31041	16020	64.500
0.600	0.600	66.000	450	4050	360	1145	32058	16527	66.000
0.600	0.600	67.500	450	4050	360	1145	33076	17034	67.500
0.600	0.600	69.000	450	4050	360	1145	34094	17542	69.000
0.600	0.600	70.500	450	4050	360	1145	35112	18049	70.500
0.600	0.600	72.000	450	4050	360	1145	36130	18556	72.000
0.600	0.600	73.500	450	4050	360	1145	37148	19063	73.500
0.600	0.600	75.000	450	4050	360	1145	38166	19571	75.000

Note unlike the chart tables, herewith D and D_b can be unique and user-defined and pile shape can be rect.

Drained Overall Pile Effective Capacity



Effective cohesion, $c'(z)$ = 0.0 conservatively	**0.0**	
Effective angle of shear resistance at pile base $z=L-L_0$ level, $\phi'(z=L-L_0)$	**47.4**	degrees
Effective vertical stress at pile $z=0$ level, $\sigma_v'(z=0)$	**0**	kPa
Case when $(z_u - L_c - L_0) >= 0$	***Valid***	
$\sigma_v'(z=0) = p_{surface}+\gamma_{dry}.(L_c+L_0)$	0	kPa
Case when $(z_u - L_c - L_0) < 0$ and $z_u >= 0$	***Invalid***	
$\sigma_v'(z=0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+L_0-z_u)+\gamma_{dry}.z_u$	N/A	kPa
Case when $z_u < 0$	***Invalid***	
$\sigma_v'(z=0) = p_{surface}+\gamma_{sat}.(L_c+L_0)+\gamma_w.(-z_u)-\gamma_w.(L_c+L_0+(-z_u))$	N/A	kPa
Note that the above equation reduces to $\sigma_v'(z=0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+L_0)$;		
Effective vertical stress at water table $z=z_u-L_c-L_0$ level, $\sigma_v'(z=z_u-L_c-L_0)$	**40**	kPa
Case when $z_u >= 0$	***Valid***	
$\sigma_v'(z=z_u-L_c-L_0) = p_{surface}+\gamma_{dry}.z_u$	40	kPa
Case when $z_u < 0$	***Invalid***	
$\sigma_v'(z=z_u-L_c-L_0) = 0$	N/A	kPa
Effective vertical stress at critical depth $z=20D-L_0$ level, $\sigma_v'(z=20D-L_0)$	**142**	kPa
Case when $(z_u - L_c - 20D) >= 0$	***Invalid***	
$\sigma_v'(z=20D-L_0) = p_{surface}+\gamma_{dry}.(L_c+20D)$	N/A	kPa
Case when $(z_u - L_c - 20D) < 0$ and $z_u >= 0$	***Valid***	
$\sigma_v'(z=20D-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+20D-z_u)+\gamma_{dry}.z_u$	142	kPa
Case when $z_u < 0$	***Invalid***	
$\sigma_v'(z=20D-L_0) = p_{surface}+\gamma_{sat}.(L_c+20D)+\gamma_w.(-z_u)-\gamma_w.(L_c+2$	N/A	kPa
Note that the above equation reduces to $\sigma_v'(z=20D-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+20D)$		
Effective vertical stress at pile base $z=L-L_0$ level, $\sigma_v'(z=L-L_0)$	**234**	kPa
Unit weight, γ'	10.2	kN/m^3
Case when $(z_u - L_c - L) >= MAX(B_{cap}, L_{cap})$	***Invalid***	
$\sigma_v'(z=L-L_0) = p_{surface}+\gamma_{dry}.(L_c+L)$	N/A	kPa
$\gamma' = \gamma_{dry}$	N/A	kN/m^3
Case when $0 < (z_u - L_c - L) < MAX(B_{cap}, L_{cap})$	***Invalid***	
$\sigma_v'(z=L-L_0) = p_{surface}+\gamma_{dry}.(L_c+L)$	N/A	kPa
$\gamma' = z_u/MAX(B_{cap}, L_{cap}) . [\gamma_{dry} - (\gamma_{sat} - \gamma_w)] + (\gamma_{sat} - \gamma_w)$	N/A	kN/m^3
Case when $(z_u - L_c - L) = 0$	***Invalid***	
$\sigma_v'(z=L-L_0) = p_{surface}+\gamma_{dry}.(L_c+L)$	N/A	kPa
$\gamma' = \gamma_{sat} - \gamma_w$	N/A	kN/m^3
Case when $(z_u - L_c - L) < 0$ and $z_u >= 0$	***Valid***	
$\sigma_v'(z=L-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+L-z_u)+\gamma_{dry}.z_u$	234	kPa
$\gamma' = \gamma_{sat} - \gamma_w$	10.2	kN/m^3
Case when $z_u < 0$	***Invalid***	
$\sigma_v'(z=L-L_0) = p_{surface}+\gamma_{sat}.(L_c+L)+\gamma_w.(-z_u)-\gamma_w.(L_c+L+(-z_u))$	N/A	kPa
Note that the above equation reduces to $\sigma_v'(z=L-L_0) = p_{surface}+(\gamma_{sat}-\gamma_w).(L_c+L)$;		
$\gamma' = \gamma_{sat} - \gamma_w$	N/A	kN/m^3

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Base effective bearing capacity, $Q_b' = A_{pb}.q_f'(z=L-L_0)$	**4241**	kN	
Gross effective bearing capacity, $q_f'(z=L-L_0)$ ($<=q_{flimit}'(z=L-L_0)$)	**15000**	kPa	*Terzaghi*
$= s_c.d_c.N_{c,strip}.c'$	0	kPa	
$+ s_q.d_q.N_{q,strip}.\sigma_v'(z=L-L_0)$	46962	kPa	
$+ s_\gamma.d_\gamma.N_{\gamma,strip}.D_b/2.\gamma'$ — Exclude	0	kPa	
Note gross effective bearing capacity set to 0.0kPa if base resistance excluded;			
Note for piles bored in rock, $s_c.d_c$ = 1.2, $s_q.d_q$ = 1.0 and $s_\gamma.d_\gamma$ = 0.7;			*Gue and Partn*
Note for piles bored in rock, $q_f' = 0.3q_{uc}$, where			*Neoh*
q_f' for weak rock	*1500*	*kPa*	*Neoh*
q_f' for medium rock	*2400-7300*	*kPa*	*Neoh*
q_f' for strong fresh rock	*10000*	*kPa*	*Neoh*

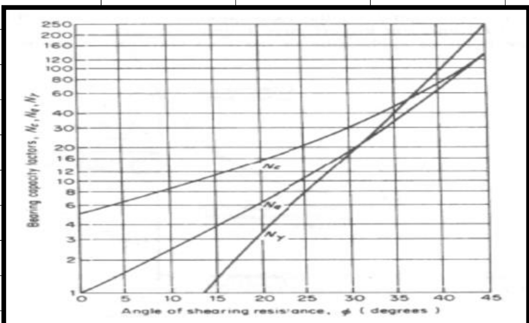


Fig. 2.8 Bearing capacity factors N_c, N_q, and N_γ (after Brinch Hansen[2.1]).

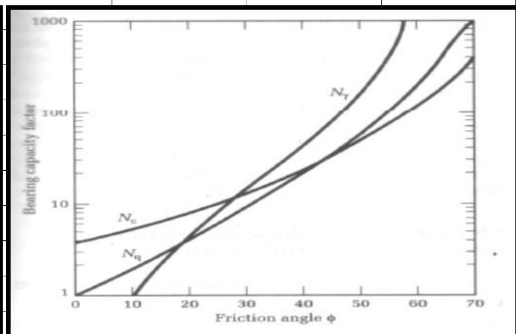
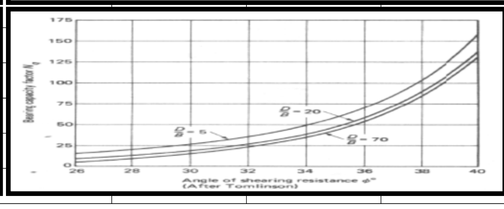


Fig. 2.17 Wedge bearing capacity factor for foundations on rock.

Typical values of pile bearing capacity factor, N_q*

Angle of internal friction, ϕ (°)	Ratio of pile length/pile diameter 5	20	70
25	16	11	7
30	29	24	20
35	69	53	45
40	175	148	130

Based on charts by Berezantsev for N_q



Note typically for driven piles, N_q = 20 (loose sand) to 100 (very dense sand),			*Neoh*
and for bored piles N_q = 12 (loose sand) to 40 (very dense sand);			
Equations for bearing capacity — Prandtl, Reissner and Hansen Equations for Soils			
Cohesion Factors			
Shape factor, $s_c = (s_q N_q - 1)/(N_q - 1)$	**1.0**		EC7
Depth factor, $d_c = 1 + 0.4\arctan(D/B)$	**1.6**		
Note D and B in the above equation are L_c+L and D_b, respectively;			
Bearing capacity factor, $N_{c,strip}$	**183.8**		
Soils $N_{c,strip} = (N_{q,strip}-1).\cot\phi'$; $N_c = (N_q - 1)\cot\varphi'$	**183.8**		*EC7 (Prandtl*
Rocks $N_{c,strip}$; N_c : $2N_\phi^{1/2}(N_\phi+1)$; N_ϕ : $\tan^2(45°+\phi/2)$	**38.9**		*Kulhawy and Goo*
Surcharge Factors			*Compressive a*
Shape factor, $s_q = 1 + (B'/L')\sin\varphi'$ — Exclude	**1.0**		EC7
Note B' and L' in the above equation are D_b and D_b, respectively;			
Depth factor, d_q : $1 + 2\tan\varphi'(1-\sin\varphi')^2\arctan\frac{}{B'}$ — Exclude	**1.0**		
			Co
Note D and B' in the above equation are L_c+L and D_b, respectively;			
Bearing capacity factor, $N_{q,strip}$	**201.0**		
Soils $N_q = e^{\pi\tan\varphi'}\tan^2(45° + \varphi'/2)$	**201.0**		*EC7 (Reissne*
Rocks $N_{q,strip}$; N_q : N_ϕ^2 ; N_ϕ : $\tan^2(45°+\phi/2)$	**43.4**		*Kulhawy and Goo*
Self Weight Factors			
Shape factor, $s_\gamma = 1 - 0{,}3\,(B'/L')$	**0.7**		EC7
Note B' and L' in the above equation are D_b and D_b, respectively;			
Depth factor, $d_\gamma = 1.0$	**1.0**		
Bearing capacity factor, $N_{\gamma,strip}$	**435.3**		
Soils $N_{\gamma,strip} = 2.0(N_{q,strip}-1).$ta ; $N_\gamma = 2(N_q - 1)\tan\varphi'$	**435.3**		*EC7 (Hanser*
Rocks $N_{\gamma,strip}$; N_γ : $N_\phi^{1/2}(N_\phi^2-1)$; N_ϕ : $\tan^2(45°+\phi/2)$	**108.7**		*Kulhawy and Goo*

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Shaft effective friction capacity, $Q_s' = \int P_{ps}.\tau_a'(z).dz$ — **1677** kN

Note shaft effective stress at z level, $\tau_a'(z) = K_s.\tan\delta'.\sigma_v'(z)$ (<= $\tau_{alimit}'(z)$);

Note effective cohesion, c' ignored due to disturbed soil adjacent to pile foundation;

$K_s.\tan\delta'$ — Manual — **0.40**

Calculated

$K_s.\tan\delta' = k_{Ks}.(1-\sin\phi').(OCR)^{0.5}.\tan\delta'$	Variable		*Burland, Meye*
Coefficient of horizontal soil stress, k_{Ks}	**1.00**		*Tomlinson*
Bored and Cast-in-Place Piles (Dense Soil)			*ers*

Table 7.1 Values of the coefficient of horizontal soil stress K_s (after Kulhawy[7.2])

Installation method	K_s/K_0
Driven piles, large displacement	1–2
Driven piles, small displacement	0.75–1.75
Bored and cast-in-place piles	0.71–1
Jetted piles	0.5–0.7

Overconsolidation ratio, OCR	1.0		
Effective angle of friction on shaft, δ'	**1.00**	ϕ' degrees	
1.00ø' (Cast-in-Place Concrete - Soil Interface)			
Effective angle, δ' for sandy gravel	*40.0*	*degrees*	*Neoh*
Effective angle, δ' for sand	*32.0*	*degrees*	*Neoh*
Effective angle, δ' for silt and clay	*21.0-31.0*	*degrees*	*Neoh*

Manual

$K_s.\tan\delta'$	0.40	
Pile bored in very loose to dense sand	*$K_s.\tan\delta'$ = 0.10-0.35*	*Meyerhof*
Pile bored in loose sand	*$K_s.\tan\delta'$ = 0.15-0.30*	*Davies and Ch*
Pile bored in dense sand	*$K_s.\tan\delta'$ = 0.25-0.60*	*Davies and Ch*
Pile CFA in chalk	*$K_s.\tan\delta'$ = 0.45*	*CIRIA574*
Pile bored in clay	*0.50-0.80*	*Poulos*
Pile CFA in chalk with N >= 10, q_{uc} > 4MPa	*$K_s.\tan\delta'$ = 0.80*	*CIRIA86*
Pile bored or driven cast-in-place in chalk	*$K_s.\tan\delta'$ = 0.80*	*CIRIA574*
Pile driven in very loose to dense sand	*$K_s.\tan\delta'$ = 0.44-1.20*	*Meyerhof*

Pile weight minus soil weight removed, $F_{pile} = A_{ps}.L.(\rho_c-\gamma_{dry})$ — **24** kN

Note under-reamed base dimensions ignored in calculation of F_{pile} as deemed negligible;

Note conservatively, dry bulk unit weight assumed for density of displaced soil;

Combined base effective bearing and shaft effective friction capacity, $P_f' = Q_b'$ — **5918** kN

) **Base and Shaft Effective Capacity Factored Individually**

mpressive	Drained pile base effective capacity (factored), Q_b' / FOS_2	1414	kN
nd Tensile	Drained pile shaft effective capacity (factored), Q_s' / FOS_3	1118	kN
mpressive	Drained pile base and shaft effective capacity (factored), Q_b' / FOS	**2532**	kN

Base and Shaft Effective Capacity Factored Together

mpressive	Drained pile base and shaft effective capacity (factored), P_f' / FOS_1	**2959**	kN
Tensile	Drained pile base and shaft effective capacity (factored), Q_s' / FOS	**838**	kN

Drained overall pile effective capacity for vertical (compressive) load, MIN (Q_b	**2508**	kN	
Drained overall pile effective capacity for vertical (tensile) load, MIN (Q_s' / FO	**838**	kN	
Drained overall pile effective capacity utilisation = MAX ($F_{pile,v,comp}$ / (MIN (Q_b'	**84%**		**OK**

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Shaft = 600 mm | Base = 600 mm | CR

D (m)	D_b (m)	z (m)	$\phi'(z)$ (°)	$\sigma_v'(z)$ (kPa)	γ' (kN/m^3)	$q_{flimit}'(z)$ (kPa)	$q_f'(z)$ (kPa)	$\tau_{alimit}'(z)$ (kPa)	$\tau_a'(z)$ (kPa)
0.600	0.600	0.000	27	0	16.7	10437	0	56.8	0.0
0.600	0.600	1.500	28	30	16.7	15000	456	56.8	12.0
0.600	0.600	3.000	29	50	10.2	15000	869	56.8	20.1
0.600	0.600	4.500	30	65	10.2	15000	1252	56.8	26.2
0.600	0.600	6.000	29	81	10.2	15000	1399	56.8	32.3
0.600	0.600	7.500	30	96	10.2	15000	1719	56.8	38.4
0.600	0.600	9.000	30	111	10.2	15000	1993	56.8	44.5
0.600	0.600	10.500	30	127	10.2	15000	2420	56.8	50.6
0.600	0.600	12.000	33	142	10.2	15000	3532	56.8	56.8
0.600	0.600	13.500	33	157	10.2	15000	4323	56.8	56.8
0.600	0.600	15.000	31	172	10.2	15000	3521	56.8	56.8
0.600	0.600	16.500	32	188	10.2	15000	4374	56.8	56.8
0.600	0.600	18.000	33	203	10.2	15000	5225	56.8	56.8
0.600	0.600	19.500	35	218	10.2	15000	6863	56.8	56.8
0.600	0.600	21.000	47	234	10.2	15000	15000	56.8	56.8
0.600	0.600	22.500	48	249	10.2	15000	15000	56.8	56.8
0.600	0.600	24.000	47	264	10.2	15000	15000	56.8	56.8
0.600	0.600	25.500	48	279	10.2	15000	15000	56.8	56.8
0.600	0.600	27.000	52	295	10.2	15000	15000	56.8	56.8
0.600	0.600	28.500	52	310	10.2	15000	15000	56.8	56.8
0.600	0.600	30.000	52	325	10.2	15000	15000	56.8	56.8
0.600	0.600	31.500	52	341	10.2	15000	15000	56.8	56.8
0.600	0.600	33.000	52	356	10.2	15000	15000	56.8	56.8
0.600	0.600	34.500	52	371	10.2	15000	15000	56.8	56.8
0.600	0.600	36.000	52	386	10.2	15000	15000	56.8	56.8
0.600	0.600	37.500	52	402	10.2	15000	15000	56.8	56.8
0.600	0.600	39.000	52	417	10.2	15000	15000	56.8	56.8
0.600	0.600	40.500	52	432	10.2	15000	15000	56.8	56.8
0.600	0.600	42.000	52	448	10.2	15000	15000	56.8	56.8
0.600	0.600	43.500	52	463	10.2	15000	15000	56.8	56.8
0.600	0.600	45.000	52	478	10.2	15000	15000	56.8	56.8
0.600	0.600	46.500	52	493	10.2	15000	15000	56.8	56.8
0.600	0.600	48.000	52	509	10.2	15000	15000	56.8	56.8
0.600	0.600	49.500	52	524	10.2	15000	15000	56.8	56.8
0.600	0.600	51.000	52	539	10.2	15000	15000	56.8	56.8
0.600	0.600	52.500	52	555	10.2	15000	15000	56.8	56.8
0.600	0.600	54.000	52	570	10.2	15000	15000	56.8	56.8
0.600	0.600	55.500	52	585	10.2	15000	15000	56.8	56.8
0.600	0.600	57.000	52	600	10.2	15000	15000	56.8	56.8
0.600	0.600	58.500	52	616	10.2	15000	15000	56.8	56.8
0.600	0.600	60.000	52	631	10.2	15000	15000	56.8	56.8
0.600	0.600	61.500	52	646	10.2	15000	15000	56.8	56.8
0.600	0.600	63.000	52	662	10.2	15000	15000	56.8	56.8
0.600	0.600	64.500	52	677	10.2	15000	15000	56.8	56.8
0.600	0.600	66.000	52	692	10.2	15000	15000	56.8	56.8
0.600	0.600	67.500	52	707	10.2	15000	15000	56.8	56.8
0.600	0.600	69.000	52	723	10.2	15000	15000	56.8	56.8
0.600	0.600	70.500	52	738	10.2	15000	15000	56.8	56.8
0.600	0.600	72.000	52	753	10.2	15000	15000	56.8	56.8
0.600	0.600	73.500	52	769	10.2	15000	15000	56.8	56.8
0.600	0.600	75.000	52	784	10.2	15000	15000	56.8	56.8

Note unlike the chart tables, herewith D and D_b can be unique and user-defined and pile shape can be rect.

			CR
Q_b' (kN)	Q_s' (kN)	MIN (Q_b' / FOS_2 +	$L=z+L_0$ (m)
0	0	0	0.000
129	17	53	1.500
246	62	120	3.000
354	128	198	4.500
396	210	265	6.000
486	310	360	7.500
563	428	463	9.000
684	562	591	10.500
999	714	795	12.000
1222	875	975	13.500
996	1035	998	15.000
1237	1196	1191	16.500
1477	1356	1376	18.000
1940	1516	1636	19.500
4241	1677	2508	21.000
4241	1837	2613	22.500
4241	1998	2719	24.000
4241	2158	2824	25.500
4241	2319	2929	27.000
4241	2479	3034	28.500
4241	2640	3140	30.000
4241	2800	3245	31.500
4241	2961	3350	33.000
4241	3121	3456	34.500
4241	3282	3561	36.000
4241	3442	3666	37.500
4241	3603	3771	39.000
4241	3763	3877	40.500
4241	3924	3982	42.000
4241	4084	4087	43.500
4241	4245	4192	45.000
4241	4405	4271	46.500
4241	4566	4349	48.000
4241	4726	4428	49.500
4241	4887	4506	51.000
4241	5047	4585	52.500
4241	5208	4663	54.000
4241	5368	4742	55.500
4241	5529	4820	57.000
4241	5689	4899	58.500
4241	5850	4978	60.000
4241	6010	5056	61.500
4241	6171	5135	63.000
4241	6331	5213	64.500
4241	6492	5292	66.000
4241	6652	5370	67.500
4241	6812	5449	69.000
4241	6973	5527	70.500
4241	7133	5606	72.000
4241	7294	5684	73.500
4241	7454	5763	75.000

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Empirical Overall Pile Effective Capacity

Base effective bearing capacity, $Q_b' = A_{pb}.q_f'(z=L-L_0)$	**4464**	kN	
Gross effective bearing capacity, $q_f'(z=L-L_0)=K_{SPT,b}.N(z=L-L_0)$ (<=	**15789**	kPa	
Note gross effective bearing capacity set to 0.0kPa if base resistance excluded;			
Factor for SPT, N value (base effective bearing), $K_{SPT,b}$	**200**		
Pile (Driven Displacement) in Clay (Martin): 200			
Pile (bored) in Kenny Hill formation	*40*		*Balakrishnai*
Pile (bored) in Kenny Hill formation	*50*		*Chiu and Perumal*
Pile (drilled shaft) in sand with L ≤ 10m, Q_b' ≤ 2900kPa	*57.5L/10*		*Quiros and Re*
Pile (drilled shaft) in sand with L > 10m, Q_b' ≤ 2900kPa	*57.5*		*Quiros and Re*
Pile (drilled shaft) in sand with L ≥ 10m, Q_b' ≤ 2900kPa	*100*		*Shioi and Fuk*
Pile (bored) in sand	*100*		*Shioi and Fuk*
Pile (driven) in clay	*120*		*Decourt*
Pile (bored) in sand	*150*		*Yamashita*
Pile in undrained cohesive soil	*200*		*Neoh*
Pile (driven) in clay	*200*		*Martin*
Pile (driven) in all soil	*300*		*Shioi and Fuk*
Pile (driven displacement) in non-plastic silt	*38L/D ≤ 300*		
Pile (driven) in silt	*350*		*Martin*
Pile (driven displacement) in sand and gravel	*38L/D ≤ 380*		*Meyerhof*
Pile in drained cohesionless soil	*400*		*Neoh*
Pile (driven) in sand	*450*		*Martin*
Shaft effective friction capacity, $Q_s' = \int P_{ps}.\tau_a'(z).dz$	**1530**	kN	
Note shaft effective stress at z level, $\tau_a'(z) = K_{SPT,s}.N(z)$ (<= $\tau_{alimit}'(z)$);			
Factor for SPT, N value (shaft effective friction), $K_{SPT,s}$	**2.5**		
Pile in Undrained Soil (Meyerhof): 2.5			
Pile in undrained cohesive or drained cohesionless soil	*2.0*		*Neoh*
Pile (bored) in meta-sedimentary formation	*2.3*		*Balakrishnai*
Pile (bored) in Kenny Hill formation	*2.5*		*Chiu and Perumal*
Pile (bored) in residual soil	*2.6*		*Tan*
Pile (bored) in sand	*3.3*		*Wright and Re*
Pile (bored) in clay	*5.0*		*Yamashita*
Pile (bored) in sand	*5.0*		*Shioi and Fuk*
Pile (bored or driven) in clay	*10.0*		*Shioi and Fuk*
Pile weight minus soil weight removed, $F_{pile} = A_{ps}.L.(\rho_c-\gamma_{dry})$	**24**	kN	
Note under-reamed base dimensions ignored in calculation of F_{pile} as deemed negligible;			
Note conservatively, dry bulk unit weight assumed for density of displaced soil;			
Combined base effective bearing and shaft effective friction capacity, $P_f' = Q_b'$	**5995**	kN	

	Base and Shaft Effective Capacity Factored Individually			
mpressive	Empirical pile base effective capacity (factored), Q_b' / FOS_2	1488	kN	
nd Tensile	Empirical pile shaft effective capacity (factored), Q_s' / FOS_3	1020	kN	
mpressive	Empirical pile base and shaft effective capacity (factored), Q_b' / FO	**2508**	kN	
	Base and Shaft Effective Capacity Factored Together			
mpressive	Empirical pile base and shaft effective capacity (factored), P_f' / FOS	**2997**	kN	
Tensile	Empirical pile base and shaft effective capacity (factored), Q_s' / FO	**765**	kN	
Empirical overall pile effective capacity for vertical (compressive) load, MIN (C		**2484**	kN	
Empirical overall pile effective capacity for vertical (tensile) load, MIN (Q_s' / FC		**765**	kN	
Empirical overall pile effective capacity utilisation = MAX ($F_{pile,v,comp}$ / (MIN (Q_b		**85%**		**OK**

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Shaft = 600 mm | Base = 600 mm | CR									**CR**
D (m)	**D_b (m)**	**z (m)**	**N(z)**	**q_f'(z) (kPa)**	**τ_a'(z) (kPa)**	**Q_b' (kN)**	**Q_s' (kN)**	**MIN (Q_b' / FOS_2 +**	**$L=z+L_0$ (m)**
0.600	0.600	0.000	0	0	0	0	0	0	0.000
0.600	0.600	1.500	4	800	10	226	14	83	1.500
0.600	0.600	3.000	8	1600	20	452	57	185	3.000
0.600	0.600	4.500	11	2200	28	622	124	285	4.500
0.600	0.600	6.000	8	1600	20	452	191	271	6.000
0.600	0.600	7.500	9	1800	23	509	251	328	7.500
0.600	0.600	9.000	9	1800	23	509	315	369	9.000
0.600	0.600	10.500	11	2200	28	622	385	452	10.500
0.600	0.600	12.000	19	3800	48	1074	491	672	12.000
0.600	0.600	13.500	22	4400	55	1244	636	824	13.500
0.600	0.600	15.000	13	2600	33	735	760	731	15.000
0.600	0.600	16.500	17	3400	43	961	866	879	16.500
0.600	0.600	18.000	20	4000	50	1131	997	1021	18.000
0.600	0.600	19.500	26	5200	65	1470	1159	1241	19.500
0.600	0.600	21.000	79	15789	197	4464	1530	2484	21.000
0.600	0.600	22.500	83	16667	200	4712	2092	2940	22.500
0.600	0.600	24.000	77	15385	192	4350	2647	3187	24.000
0.600	0.600	25.500	83	16667	200	4712	3201	3676	25.500
0.600	0.600	27.000	100	17500	200	4948	3767	4130	27.000
0.600	0.600	28.500	100	17500	200	4948	4332	4505	28.500
0.600	0.600	30.000	100	17500	200	4948	4898	4880	30.000
0.600	0.600	31.500	100	17500	200	4948	5463	5170	31.500
0.600	0.600	33.000	100	17500	200	4948	6029	5451	33.000
0.600	0.600	34.500	100	17500	200	4948	6594	5732	34.500
0.600	0.600	36.000	100	17500	200	4948	7160	6013	36.000
0.600	0.600	37.500	100	17500	200	4948	7725	6294	37.500
0.600	0.600	39.000	100	17500	200	4948	8291	6575	39.000
0.600	0.600	40.500	100	17500	200	4948	8856	6856	40.500
0.600	0.600	42.000	100	17500	200	4948	9422	7137	42.000
0.600	0.600	43.500	100	17500	200	4948	9987	7418	43.500
0.600	0.600	45.000	100	17500	200	4948	10552	7699	45.000
0.600	0.600	46.500	100	17500	200	4948	11118	7980	46.500
0.600	0.600	48.000	100	17500	200	4948	11683	8261	48.000
0.600	0.600	49.500	100	17500	200	4948	12249	8542	49.500
0.600	0.600	51.000	100	17500	200	4948	12814	8824	51.000
0.600	0.600	52.500	100	17500	200	4948	13380	9105	52.500
0.600	0.600	54.000	100	17500	200	4948	13945	9386	54.000
0.600	0.600	55.500	100	17500	200	4948	14511	9667	55.500
0.600	0.600	57.000	100	17500	200	4948	15076	9948	57.000
0.600	0.600	58.500	100	17500	200	4948	15642	10229	58.500
0.600	0.600	60.000	100	17500	200	4948	16207	10510	60.000
0.600	0.600	61.500	100	17500	200	4948	16773	10791	61.500
0.600	0.600	63.000	100	17500	200	4948	17338	11072	63.000
0.600	0.600	64.500	100	17500	200	4948	17904	11353	64.500
0.600	0.600	66.000	100	17500	200	4948	18469	11634	66.000
0.600	0.600	67.500	100	17500	200	4948	19035	11915	67.500
0.600	0.600	69.000	100	17500	200	4948	19600	12196	69.000
0.600	0.600	70.500	100	17500	200	4948	20166	12477	70.500
0.600	0.600	72.000	100	17500	200	4948	20731	12758	72.000
0.600	0.600	73.500	100	17500	200	4948	21297	13039	73.500
0.600	0.600	75.000	100	17500	200	4948	21862	13320	75.000

Note unlike the chart tables, herewith D and D_b can be unique and user-defined and pile shape can be rect.

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Pile Reinforcement Design

Precast Driven Square RC Pile or Insitu Bored Circular RC Pile

Pile Longitudinal Reinforcement Design

Percentage of reinforcement $A_{s,prov,p}/A_{ps}$ x 100%		N/A	%	
Axial compression capacity, $N_{cap,pile,comp}$		N/A	kN	
SLS Design	$N_{cap,pile,comp} = 0.25f_{cu}.A_{ps}$	N/A	kN	
ULS Design	$N_{cap,pile,comp} = 0.35f_{cu}.A_{ps} + (0.67f_y\text{-}0.35f_{cu}).A$	N/A	kN	
Note alternatively, SLS design including steel reinforcement can be estimated by $N_{cap,pile,comp}$ $= 0.275f_{cu}.A_{ps} + 0.55f_y.A_{s,prov,p}$ with $0.55f_y$ limited to 175N/mm^2;				BS8004
Total pile vertical (compressive) load (per pile), $F_{pile,v,comp,(uls)}$		N/A	kN	
SLS Design	$F_{pile,v,comp}$	N/A	kN	
ULS Design	$F_{pile,v,comp,uls}$	N/A	kN	
Axial compression capacity utilisation = $F_{pile,v,comp,(uls)}/N_{cap,pile,comp}$		N/A		N/A
Axial tension capacity, $N_{cap,pile,tens}$		N/A	kN	
SLS Design	$N_{cap,pile,tens} = 0.55f_y.A_{s,prov,p}$	N/A	kN	
ULS Design	$N_{cap,pile,tens} = 0.95f_y.A_{s,prov,p}$	N/A	kN	
Total pile vertical (tensile) load (per pile), $F_{pile,v,tens,(uls)}$		N/A	kN	
SLS Design	$F_{pile,v,tens}$	N/A	kN	
ULS Design	$F_{pile,v,tens,uls}$	N/A	kN	
Axial tension capacity utilisation = $F_{pile,v,tens,(uls)}/N_{cap,pile,tens}$		N/A		N/A

Pile Shear Reinforcement Design

Note that pile shear design to be performed as per column design;

Pile Detailing Requirements

All detailing requirements met ?		N/A		
Min longitudinal steel reinforcement number, n_p (>=6 circ.; >=4 sq.; >=8 rec		N/A		N/A
Min longitudinal steel reinforcement diameter, ϕ_p (>=12mm)		N/A	mm	N/A
Percentage of reinforcement $A_{s,prov,p}/A_{ps}$ x 100% (>0.4% and <5.0%)		N/A	%	N/A
Longitudinal steel reinforcement pitch (>=75mm+ϕ_p but >=100mm+ϕ_p for T4		N/A	mm	N/A
	Circ. pile bar pitch = $\pi.(D\text{-}2.cover_4\text{-}2.\phi_{link,p}\text{-}\phi_p)/n_p$	N/A	mm	
	Sq. pile bar pitch = $4.(D\text{-}2.cover_4\text{-}2.\phi_{link,p}\text{-}\phi_p)/n_p$	N/A	mm	
	Rect. pile bar pitch = $4.(0.5D+0.5\%D\text{-}2.cover_4\text{-}2.\phi_{link,p}\text{-}\phi_p)/n_p$	N/A	mm	
Min link diameter, $\phi_{link,p}$ (>=0.25ϕ_p; >=8mm)		N/A	mm	N/A
Max link pitch, S_p (<=12ϕ_p, <=300mm, <=D)		N/A	mm	N/A

Require an overall enclosing link.

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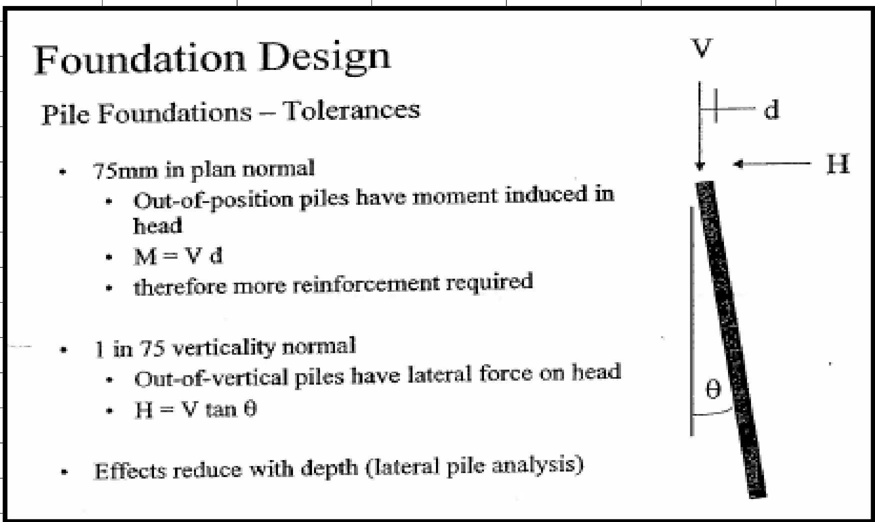
Precast (Pretensioned Spun) Driven Circular RC Pile

SLS axial compression capacity, $N_{cap,pile,comp} = 0.25.(f_{cu}-f_{pe}).A_{eff}$	2933	kN	
SLS total pile vertical (compressive) load (per pile), $F_{pile,v,comp}$	2100	kN	
Axial compression capacity utilisation = $F_{pile,v,comp}/N_{cap,pile,comp}$	72%		OK

Insitu Micropile Bored Circular RC Pile

SLS axial compression capacity, $N_{cap,pile,comp}$		N/A	kN	
Reinforcement only	$N_{cap,pile,comp} = f_{y,API}.A_{API}/2.0$	N/A	kN	
Composite section (strain compatibility)	$N_{cap,pile,comp} = 0.5f_{y,API}.(A_{API}+A_{c,API}.$	N/A	kN	*04 cl. 7.4.6*
Concrete filled CHS	$N_{cap,pile,comp} = (0.91f_{y,API}.A_{API}+0.45$	N/A	kN	*400 cl. 11.*
SLS total pile vertical (compressive) load (per pile), $F_{pile,v,comp}$		N/A	kN	
Axial compression capacity utilisation = $F_{pile,v,comp}/N_{cap,pile,comp}$		N/A		N/A

Pile Installation Tolerance



Moment induced at head due to out-of-position, $M = 0.075F_{pile,v,comp,uls}$	236	kNm
Lateral force induced at head due to out-of-vertical, $H = F_{pile,v,comp,uls}/75$	42	kN

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Group Pile Design

Undrained Analysis

Consideration of NSF ?	Not Considered		
Total pile group SLS vertical (compressive) NSF load, $F_{pilegroup,v,NSF}$	0	kN	*Tomlinson*

Note NSF = negative skin friction; Note $F_{pilegroup,v,NSF} = B_{cap} . L_{cap} . \gamma_{dry\ or\ sat} . L_0$;

.3.1

3.7

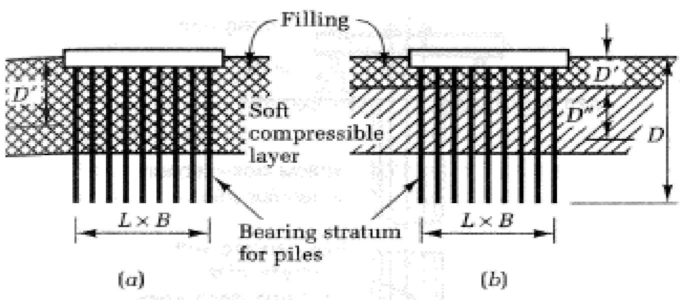

Fig. 7.29 Pile groups in filled ground.

Thus, in Fig. 7.29(*a*), the total load on pile group at level of bearing stratum is given by

$$Q_1 = \text{Working load} + L \times B \times \gamma' D', \quad (7.22)$$

where γ' is the density of fill and *D'* the depth of fill over which the movement is sufficient to cause drag-down.

In Fig. 7.29(*b*), the total load on pile group at level of bearing stratum is given by

$$Q_2 = \text{Working load} + L \times B \times \gamma' D' + L \times B \times \gamma'' D'', \quad (7.23a)$$

where γ'' is the density of soft stratum and *D''* the depth of soft stratum over which movement is sufficient to cause drag-down. However, total load on pile group will not exceed ultimate skin friction on piles from fill and soft clay, i.e.

$$Q_2 = \ngtr \text{Working load} + S_1 f' + S_2 f'', \quad (7.23b)$$

where

- S_1 = sum of surface area of piles embedded in fill,
- S_2 = sum of surface area of piles embedded in soft clay,
- f' = skin friction between fill and piles,
- f'' = skin friction between soft clay and piles.

Pile group capacity,	$Q_u = 2D(B+L)\,s + 1.3(s_b.N_c.B.L)$	404270	kN	*Tomlinson*

Note D, B, L, s and s_b in the above equation are $L-L_0$, B_{cap}, L_{cap}, S_a, $S_u(z=L-L_0)$ and D, respectively;

Undrained overall pile group capacity for vertical (compressive) loa	202135	kN	
Undrained overall pile group capacity utilisation	4%		OK

Note utilisation is $(F_{pilecap,v} + F_{pilegroup,v,NSF}) / (Q_u / FOS_1)$;

For a group of bored piles in a cohesive material the following expression can be used:

$$Q_{a\,group} = n\, Q_a\, E_f$$

where

- n = number of piles in group
- Q_a = capacity of a single pile
- E_f = group efficiency ratio

$$= 1 - \left(\tan^{-1}\frac{D}{s}\right)\frac{m(n-1)+n(m-1)}{90\,m\,n}$$

where

- D = pile diameter
- s = pile spacing
- m = number of piles in one direction
- n = number of piles in orthogonal direction

If $s = 3D$

$$E_f = 1 - \frac{18.43m(n-1) + n(m-1)}{90mn}$$

The values of E_f can be obtained from Table 3.28.

Table 3.28
Values for E_f for piles spaced at three times diameter

Number of piles, m	Number of piles, n				
	2	3	4	5	6
1	0.90	0.86	0.85	0.84	0.83
2	0.80	0.76	0.74	0.73	0.73
3	–	0.73	0.71	0.70	0.69
4	–	–	0.69	0.68	0.68
5	–	–	–	0.67	0.67
6	–	–	–	–	0.66

Note
For other combinations use 0.65.

Drained Analysis

Note there is no risk of drained overall pile group failure if FOS of individual piles are adequate; *Gue and Partn*

Empirical Analysis

Note perform undrained or drained analysis;

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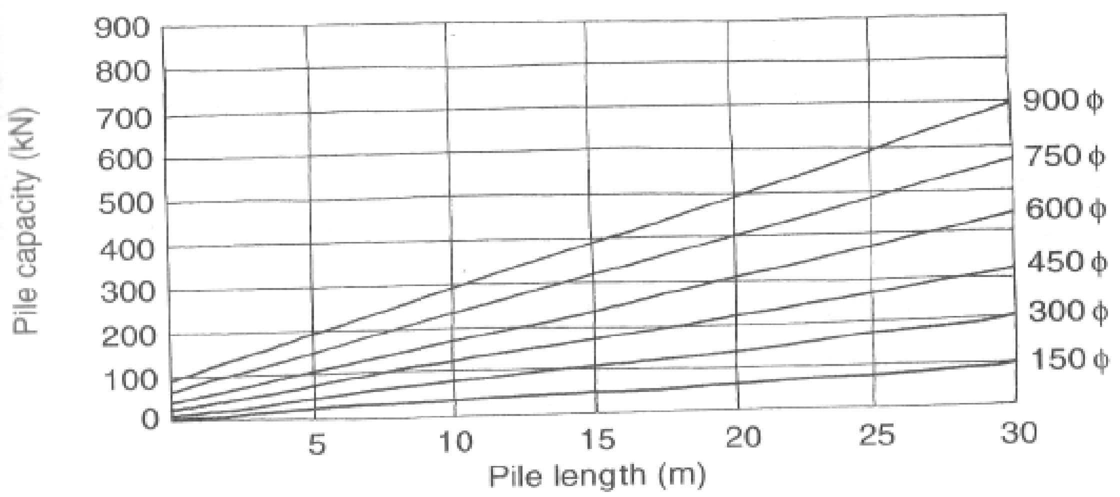
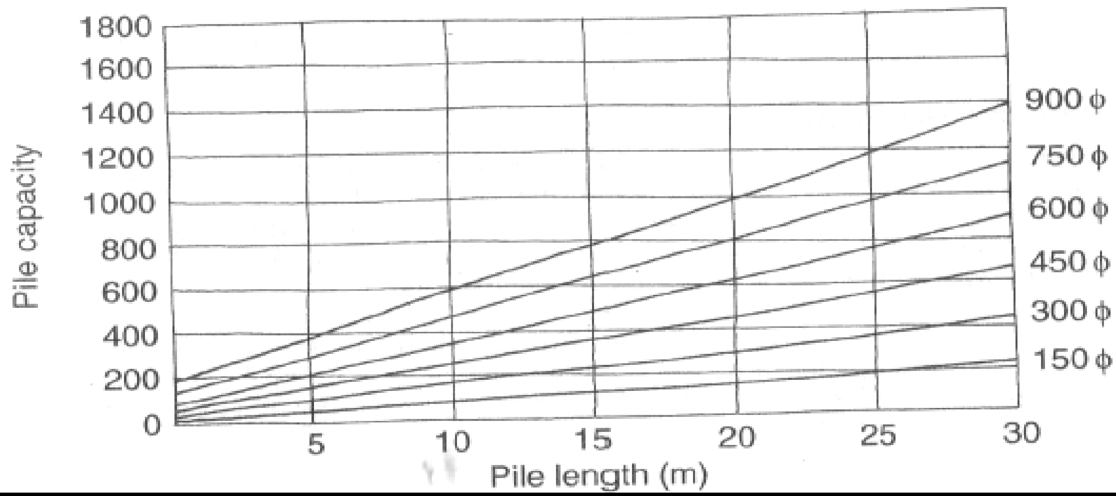
Scheme Design (Cohesive Soils)

Working pile loads for CFA piles in cohesive soil ($C_u = 50$)



Working pile loads for CFA piles in cohesive soil ($C_u = 100$)



Working load on pile < 0.25fcu (0.1fcu for continuous flight auger)

Warning: The following relationships apply only to bored cast in place concrete piles in London clay. For all other piles check with Geotechnics (which should always be done anyway).

$$\text{Working bearing capacity of straight shafted piles} = \left(\frac{0.5\overline{c_u} \text{ x perimeter}}{3}\right) + \left(\frac{9c_{u,base} \text{ x base area}}{3}\right)$$

$$\text{Working bearing capacity of large under-reamed piles} = \left(\frac{0.35\overline{c_u} \text{ x perimeter}}{f_1}\right) + \left(\frac{9c_{u,base} \text{ x base area}}{f_2}\right)$$

For straight sided piles higher capacities may be available by following the guidelines for Site Investigations and pile tests in the London District Surveyors Association Publication, Guide Notes for the Design of Straight Shafted Piles in London Clay (1996)

C_u = undrained shear strength of London Clay
Typically diameter of under-ream = 3 x diameter of shaft

Factor of safety: $f_1 = f_2 = 2.5$
or $f_1 = 1$ $f_2 = 3$ whichever gives the lower capacity

Minimum spacing of pile shafts = 3 x diameter (ensure under-reams do not encroach)

Single bored piles in clay

$$Q_{allow} = \frac{N_c A_b c_{base}}{\gamma_{f\ base}} + \frac{\alpha \bar{c} A_s}{\gamma_{f\ shaft}}$$

Where A_b is the area of the pile base, A_s is the surface area of the pile shaft in the clay, $\bar{c}$ is the average value of shear strength over the pile length and is derived from undrained triaxial tests, where $\alpha = 0.3$ to 0.6 depending on the time that the pile boring is left open. Typically $\alpha = 0.3$ for heavily fissured clay and $\alpha = 0.45$–0.5 for firm to stiff clays (e.g. London clay). $N_c = 9$ where the embedment of the tip of the pile into the clay is more than five diameters. The factors of safety are generally taken as 2.5 for the base and 3.0 for the shaft.

Negative skin friction

Negative skin friction occurs when piles have been installed through a compressible material to reach firm strata. Cohesion in the soft soil will tend to drag down on the piles as the soft layer consolidates and compresses causing an additional load on the pile. This additional load is due to the weight of the soil surrounding the pile. For a group of piles a simplified method of assessing the additional load per pile can be based on the volume of soil which would need to be supported on the pile group. $Q_{skin\ friction} = AH\gamma/N_p$ where A is the area of the pile group, H is the thickness of the layer of consolidating soil or fill which has a bulk density of γ, and N_p is the number of piles in the group. The chosen area of the pile group will depend on the arrangement of the piles and could be the area of the building or part of the building. This calculation can be applied to individual piles, although it can be difficult to assess how much soil could be considered to contribute to the negative skin friction forces.

Group action of bored piles in clay

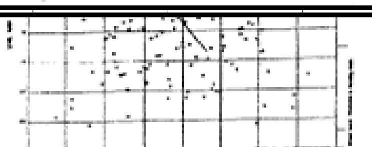
The capacity of groups of piles can be as little as 25 per cent of the collective capacity of the individual piles.

A quick estimate of group efficiency:

$$E = 1 - \left(\tan^{-1}\frac{D}{S}\right)\frac{[m(n-1)+n(m-1)]}{90mn}$$

Where D is the pile diameter, S is the pile spacing and m and n represent the number of rows in two directions of the pile group.

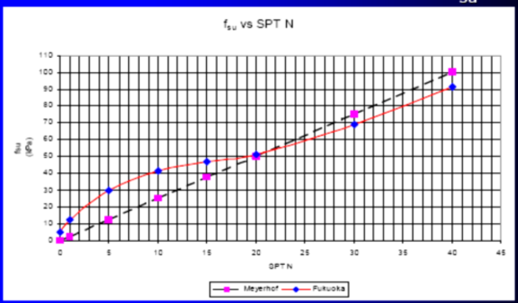
- $c_u = f_1 N$ (Stroud, 1974)
- $f_1 = 4.5$ if PI > 30



Pile Capacity Design

Single Pile Capacity: In Cohesive Soil

Correlation Between SPT N and f_{su}



	Meyerhof	Fukuoka		
SPT N	f_{su}=2.5N (kPa)	s_u = (0.1+0.15N)*50 (kPa)	α	f_{su}=α.s_u (kPa)
0	0	5	1	5
1	2.5	12.5	1	12.5
5	12.5	42.5	0.7	29.75
10	25	80	0.52	41.6
15	37.5	117.5	0.4	47
20	50	155	0.33	51.15
30	75	230	0.3	69
40	100	305	0.3	91.5

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Scheme Design (Non Cohesive Soils)

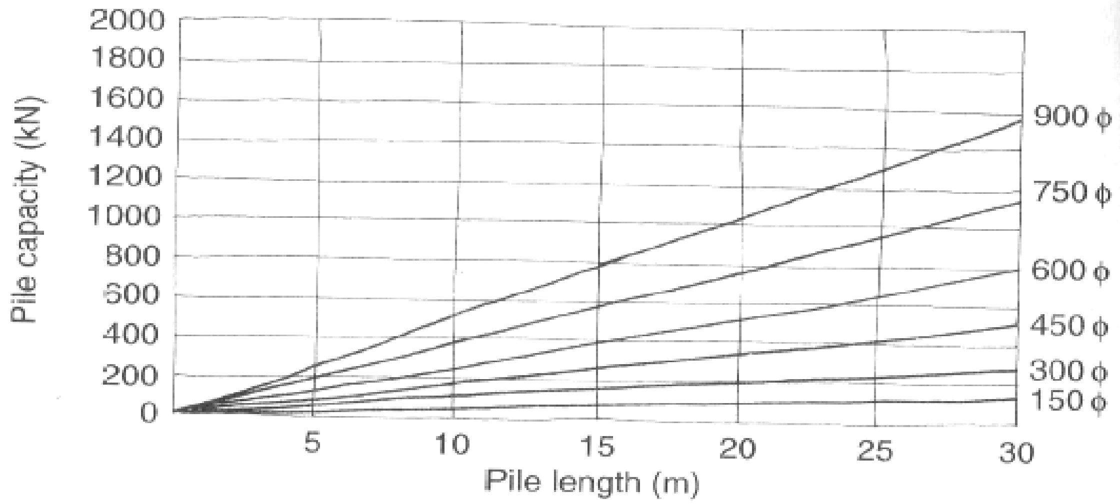
Quick estimate design methods for deep foundations

Concrete and steel pile capacities

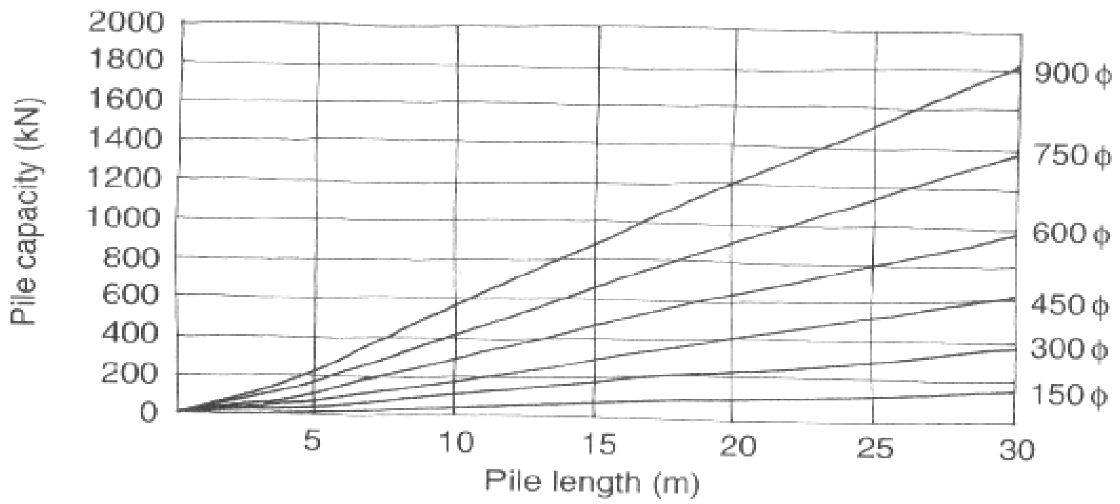
Concrete piles can be cast in situ or precast, prestressed or reinforced. Steel piles are used where long or lightweight piles are required. Sections can be butt welded together and excess can be cut away. Steel piles have good resistance to lateral forces, bending and impact, but they can be expensive and need corrosion protection.

Typical maximum allowable pile capacities can be 300 to 1800 kN for bored piles (diameter 300 to 600 mm), 500 to 2000 kN for driven piles (275 to 400 mm square precast or 275 to 2000 mm diameter steel), 300 to 1500 kN for continuous flight auger (CFA) piles (diameter 300 to 600 mm) and 50 to 500 kN for mini piles (diameter 75 to 280 mm and length up to 20 m). The minimum pile spacing achievable is normally about three diameters between the pile faces.

Working pile loads for CFA piles in granular soil ($N = 15$)



Working pile loads for CFA piles in granular soil ($N = 25$)



Piles in granular soil

Although most methods of determining driven pile capacities require information on the resistance of the pile during driving, capacities for both driven and bored piles can be estimated by the same equation. The skin friction and end bearing capacity of bored piles will be considerably less than driven piles in the same soil as a result of loosening caused by the boring and design values of γ, N and $k_s \tan\delta$ should be selected for loose conditions.

$$Q_{allow} = \frac{N_q^* A_b q_o' + A_s q_{o\ mean}' k_s \tan\delta}{\gamma_f}$$

Where N_q^* is the pile bearing capacity factor based on the work of Berezantsev, A_b is the area of the pile base, A_s is the surface area of the pile shaft in the soil, q_o' is the effective overburden pressure, k_s is the horizontal coefficient of earth pressure, k_o is the coefficient of earth pressure at rest, δ is the angle of friction between the soil and the pile face, ϕ' is the effective internal angle of shearing resistance and the factor of safety, $\gamma_f = 2.5$ to 3.

Typical values of N_q*	$\frac{\text{Pile length}}{\text{Pile diameter}}$		
ϕ	5	20	70
25	16	11	7
30	29	24	20
35	69	53	45
40	175	148	130

* Berezantsev (1961) values from charts for N_q based on ϕ calculated from uncorrected N values.

Typical values of δ and k_s for sandy soils can therefore be determined based on work by Kulhawy (1984) as follows:

Pile face/soil type	Angle of pile/soil friction δ/ϕ'
Smooth (coated) steel/sand	0.5–0.9
Rough (corrugated) steel/sand	0.7–0.9
Cast in place concrete/sand	1.0
Precast concrete/sand	0.8–1.0
Timber/sand	0.8–0.9

Installation and pile type	Coefficients of horizontal soil stress/earth pressure at rest k_s/k_o
Driven piles large displacement	1.00–2.00
Driven piles small displacement	0.75–1.25
Bored cast in place piles	0.70–1.00
Jetted piles	0.50–0.70

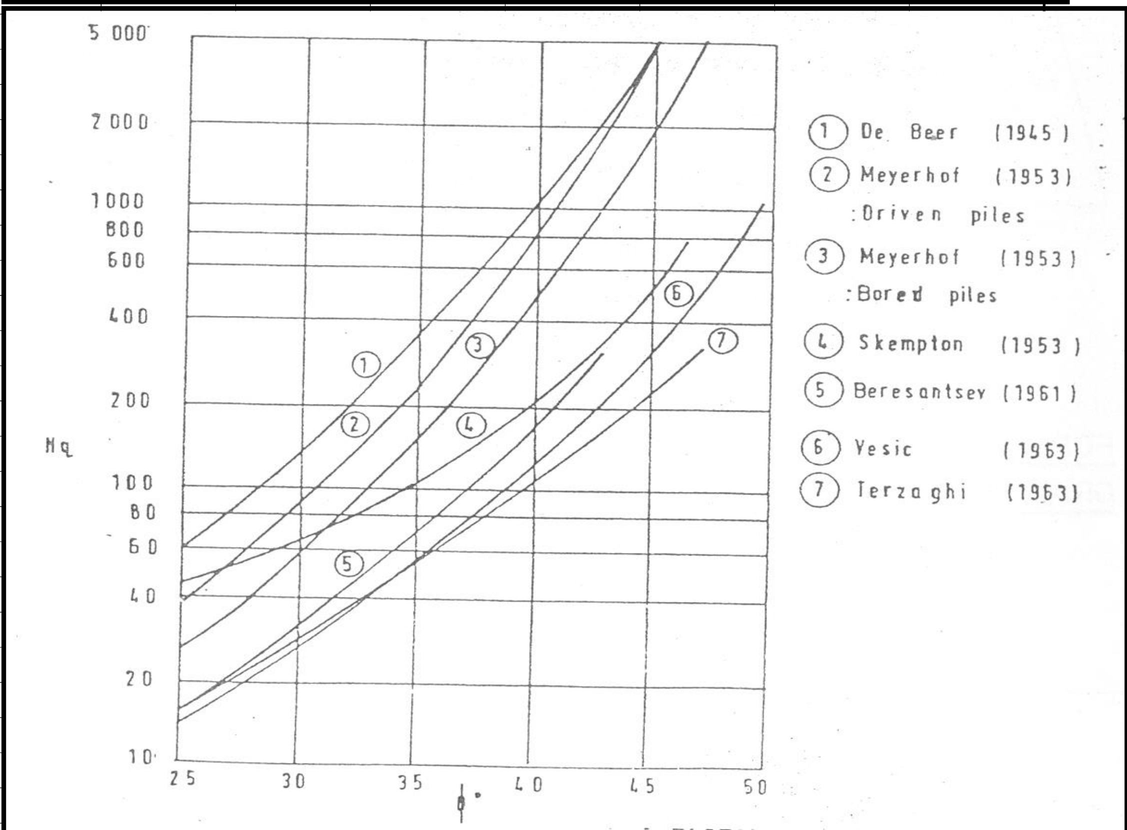
Although pile capacities improve with depth, it has been found that at about 20 pile diameters, the skin friction and base resistances stop increasing and 'peak' for granular soils. Generally the peak value for base bearing capacity is 110 000 kN/m^2 for a pile length of 10 to 20 pile diameters and the peak values for skin friction are 10 kN/m^2 for loose granular soil, 10 to 25 kN/m^2 for medium dense granular soil, 25 to 70 kN/m^2 for dense granular soil and 70 to 110 kN/m^2 for very dense granular soil.

Source: Kulhawy, F.H (1984). Reproduced by permission of the ASCE.

Typical values for δ and k_s in granular material

Angle of internal friction, φ (°)	Angle of friction between the soil and the pile face, δ (°)		Horizontal coefficient of earth pressure, k_s		
	In-situ concrete piles	Precast concrete piles	In-situ concrete piles	Large driven piles	Small driven piles
26	26	23.4	0.393 – 0.562	0.562 – 1.123	0.421 – 0.702
27	27	24.3	0.382 – 0.546	0.546 – 1.092	0.410 – 0.683
28	28	25.2	0.371 – 0.531	0.531 – 1.061	0.398 – 0.663
29	29	26.1	0.361 – 0.515	0.515 – 1.030	0.386 – 0.644
30	30	27.0	0.350 – 0.500	0.500 – 1.000	0.375 – 0.625
31	31	27.0[a]	0.339 – 0.485	0.485 – 0.970	0.364 – 0.606
32	32	27.0[a]	0.329 – 0.470	0.470 – 0.940	0.353 – 0.588
33	33	27.0[a]	0.319 – 0.455	0.455 – 0.911	0.342 – 0.569
34	34	27.0[a]	0.309 – 0.441	0.441 – 0.882	0.331 – 0.551
35	35	27.0[a]	0.298 – 0.426	0.426 – 0.853	0.320 – 0.533
36	36	27.0[a]	0.289 – 0.412	0.412 – 0.824	0.309 – 0.515
37	37	27.0[a]	0.279 – 0.398	0.398 – 0.796	0.299 – 0.498
38	38	27.0[a]	0.269 – 0.384	0.384 – 0.769	0.288 – 0.480
39	39	27.0[a]	0.259 – 0.371	0.371 – 0.741	0.278 – 0.463
40	40	27.0[a]	0.250 – 0.357	0.357 – 0.714	0.268 – 0.447
41	41	27.0[a]	0.241 – 0.344	0.344 – 0.688	0.258 – 0.430
42	42	27.0[a]	0.232 – 0.331	0.331 – 0.662	0.248 – 0.414
43	43	27.0[a]	0.223 – 0.318	0.318 – 0.636	0.239 – 0.398
44	44	27.0[a]	0.214 – 0.305	0.305 – 0.611	0.229 – 0.382
45	45	27.0[a]	0.205 – 0.293	0.293 – 0.586	0.220 – 0.366
46	46	27.0[a]	0.196 – 0.281	0.281 – 0.561	0.210 – 0.351

Key
a It is recommended that δ should be based on loose conditions for precast piles



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Scheme Design (Rocks)

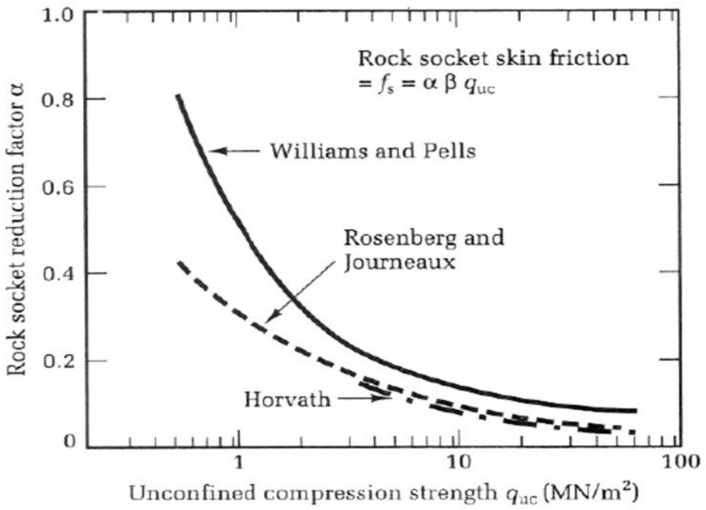

Figure 1 Rock Socket Reduction Factor, α, w.r.t. Unconfined Compressive Strength (after Tomlinson, 1995)

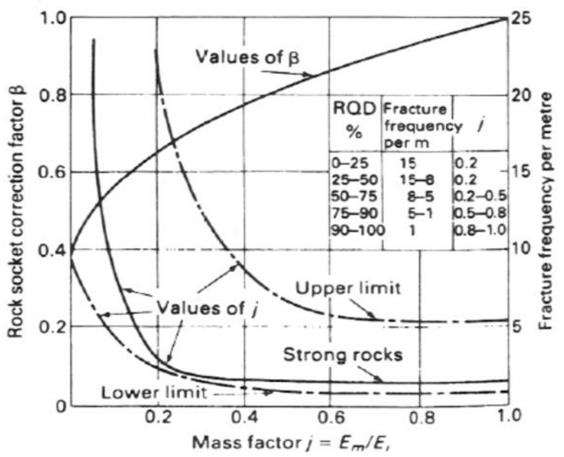

Figure 2 Rock Socket Reduction Factor, β, w.r.t. Rock Mass Discontinuity (after Tomlinson, 1995)

During borehole exploration, statistics of q_{uc} can be established for different weathering grade of bedrock and the rock fracture can be assessed through the Rock Quality Designation on the rock core recovered or by interpretation of pressuremeter modulus in the rock mass against the elastic modulus of intact rock, which is equivalent to mass factor j, which is the ratio of elastic modulus of rock mass to that of intact rock, as in Figure 2. Alternatively, Figure 3 can provide some indications of the modulus ratio of the rock mass. In the some cases, at very small cost, point load test equipment is used to assess and verify the rock strength on the recovered rock fragment during bored pile drilling after proper calibration with borehole results.

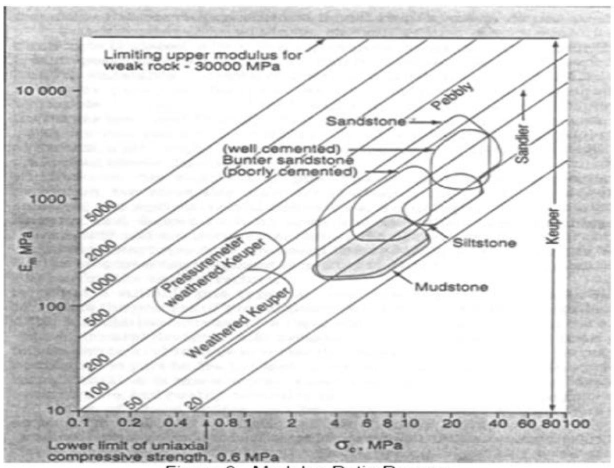

Figure 3 Modulus Ratio Ranges (after Hobbs,1974)

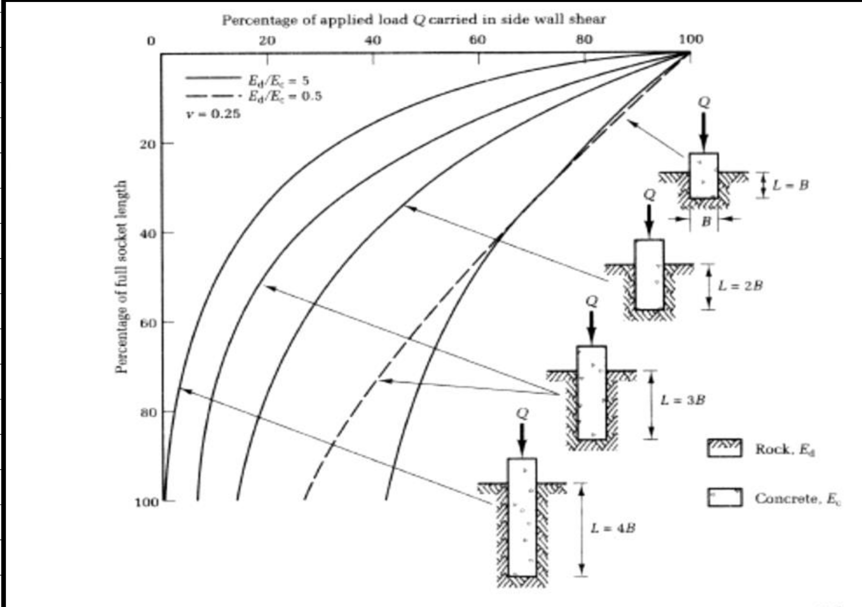

Fig. 7.16 Distribution of side wall shear stress in relation to socket length and modulus ratio (after Osterberg and Gill[7.39]).

It is also important to optimise rock socket design with due consideration of the load transfer behaviour of the socket. Figure 5 shows the analytical results of the socket load transfer behaviour for modulus ratio, E_p/E_r ranging from 0.25 to 1000. As shown in the figure, it is obvious that there is really no reason to extend the socket beyond 5 times the pile diameter for E_p/E_r =0.25 (very competent intact rock) as no load will be transferred below this socket length.

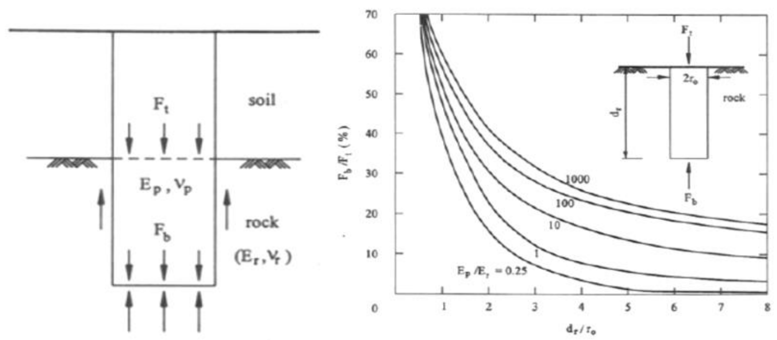

Figure 5 Distribution of Socket Resistance w.r.t. Socket Length and Modulus Ratio (after Pells & Tuner, 1979)

Standard Pile Structural Dimensions and Capacities

Precast Driven Square RC Pile or Insitu Bored Circular RC Pile

JKR STANDARD PRECAST SQUARE PILES
(Grade 45 Concrete)

Size (mm)	Structural Capacity (kN)	Main Reinforcement	End Plate Thickness (mm)	Anchorage Length (mm)	Available Lengths (m)
150 x 150	250	4Y10	10	450	6, 3
175 x 175	340	4Y12	10	450	6, 3
200 x 200	450	4Y12	12	480	6, 3
250 x 250	700	4Y16	12	640	12, 9, 6, 3
300 x 300	1,000	4Y20	15	800	12, 9, 6, 3
350 x 350	1,350	4Y20	15	800	12, 9, 6, 3
400 x 400	1,800	4Y25	15	1000	12, 9, 6, 3

PKM standard design & capacity

0.275 fcu • Ac + fs • As

0.55 fy but not greater than 175N/mm^2

Nominal Pile Size	Dimension			Weight of Pile	Main Bars	Pile Shoe Thickness	Joint Plate Thickness	Stirrup Size	Max. Axial Load	Recommended Working Load *	Pile Length
	a	b	c								
mm x mm	mm	mm	mm	kg/m	No. x dia.	mm	mm	mm	tonne	tonne	m
150 x 150	155	145	150	54	4T10	3	6	4.0	33	25	3, 6
175 x 175	180	170	175	74	4T10	3	6	4.0	43	35	3, 6
200 x 200	205	195	200	96	4T12	3	8	4.5	57	45	3, 6, 9
225 x 225	230	220	225	122	4T12	3	8	5.0	70	60	3, 6, 9
250 x 250	255	245	250	150	8T10	3	9	5.0	88	75	3, 6, 9, 12
275 x 275	280	270	275	182	4T16	4	9	5.0	107	85	3, 6, 9, 12
300 x 300	305	295	300	216	8T12	4	9	5.0	126	105	3, 6, 9, 12
325 x 325	330	320	325	254	8T12	4	12	6.0	145	125	3, 6, 9, 12
350 x 350	355	345	350	294	4T20	4	12	6.0	172	145	3, 6, 9, 12
375 x 375	380	370	375	338	4T22	4	12	6.0	199	175	3, 6, 9, 12
400 x 400	405	395	400	384	8T16	4	12	6.0	224	190	3, 6, 9, 12
450 x 450	455	445	450	486	4T25	4	15	6.0	283	240	3, 6, 9, 12

(Subject to change without prior notification)

* Recommended working load is subject to the geotechnical capacity of the pile at each individual location

Euro-pile standard design & capacity

Nominal Pile Size	Dimension			Weight of Pile	Main Bars	Pile Shoe Thickness	Joint Plate Thickness	Stirrup Size	Max. Axial Load	Max. Pile Length
	a	b	c							
mm x mm	mm	mm	mm	kg/m	No. x dia.	mm	mm	mm	tonne	m
250 x 250	255	245	250	150	8T10	3	9	5.0	113	12
300 x 300	305	295	300	216	4T12 + 4T10	4	9	5.0	161	15
350 x 350	355	345	350	294	4T12 + 8T10	4	12	5.0	219	15
375 x 375	380	370	375	338	4T10 + 8T12	4	12	5.0	251	15
400 x 400	405	395	400	384	12T12	4	12	5.0	286	15
450 x 450	455	445	450	486	16T12	4	15	5.0	363	15

(Subject to change without prior notification)

BORED PILE STRUCTURAL CAPACITY

Dia	Concrete Grade (MPa)				
	30	35	40	45	50
mm	Bored Pile Structural Capacity (kN)				
450	1,100	1,300	1,500	1,700	1,900
600	2,100	2,400	2,800	3,100	3,500
900	4,700	5,500	6,300	7,100	7,900
1,050	6,400	7,500	8,600	9,700	10,800
1,200	8,400	9,800	11,300	12,700	14,100
1,350	10,700	12,500	14,300	16,100	17,800
1,500	13,200	15,400	17,600	19,800	22,000
1,800	19,000	22,200	25,400	28,600	31,800

MAVERICK ENGINEERS	Maverick United Consulting Engineers	Job No.	Sheet No.	Rev.
		jXXX	37	
		Member/Location		
Job Title	Structure, Member Design - Geotechnics Piles v2024.02	Drg. Ref.		
Structure, Member Design - Geotechnics Piles		Made by XX	Date 18/08/2025	Chd.

Precast (Pretensioned Spun) Driven Circular RC Pile

PROPERTIES OF ICP PILES - STANDARD PRODUCTS

CLASS A (EFFECTIVE PRESTRESS = 4.0 N/mm²)

Nominal Diameter mm	Nominal Thickness mm	Length m	Nominal Weight kg/m	Prestressing Bar 7.1mm no.	Prestressing Bar 9.0 mm no.	Prestressing Bar 10.7 mm no.	Area of Concrete mm²	Section Modulus x 1000 mm³	Bending Moment Cracking KNm	Bending Moment Ultimate KNm	Recommended Max Structural Axial Working Load (For a short strut) ton	Effective Prestress N/mm²
300	60	6-12	118	6	-	-	45,239	2,373	20.4	34.8	85	4.6
350	60	6-12	142	6	-	-	54,664	3,506	28.1	40.6	104	4.0
400	65	6-12	178	8	-	-	68,408	5,106	41.0	61.8	130	4.0
450	70	6-12	217	10	-	-	83,566	7,113	57.8	86.9	158	4.1
450	90	6-12	265	-	8	-	101,788	7,996	69.5	111.2	191	4.7
500	80	6-12	274	12	-	-	105,558	9,888	79.1	115.9	200	4.0
600	90	6-12	375	-	12	-	144,199	16,586	148.3	222.5	270	4.9

CLASS B (EFFECTIVE PRESTRESS = 5.0 N/mm²)

Nominal Diameter mm	Nominal Thickness mm	Length m	Nominal Weight kg/m	Prestressing Bar 7.1mm no.	Prestressing Bar 9.0 mm no.	Prestressing Bar 10.7 mm no.	Area of Concrete mm²	Section Modulus x 1000 mm³	Bending Moment Cracking KNm	Bending Moment Ultimate KNm	Recommended Max Structural Axial Working Load (For a short strut) ton	Effective Prestress N/mm²
250	55	6-12	88	6	-	-	33,694	1,435	14.9	29.0	62	6.3
300	60	6-12	118	7	-	-	45,239	2,383	23.0	40.6	84	5.6
350	70	6-15	160	9	-	-	61,575	3,778	35.4	60.8	115	5.3
400	80	6-15	209	12	-	-	80,425	5,643	53.4	92.7	150	5.4
450	80	6-15	242	-	8	-	92,991	7,624	69.3	111.2	174	5.1
500	90	6-20	301	-	10	-	115,925	10,518	95.7	154.5	217	5.1
600	100	6-20	408	-	14	-	157,080	17,546	162.3	259.6	293	5.2
700	110	6-46	530	-	20	-	203,889	27,131	263.4	432.6	378	5.7
800	120	6-46	667	-	24	-	256,354	39,455	374.1	593.3	477	5.4
900	130	6-46	818	-	28	-	314,473	54,942	508.0	778.7	587	5.2
1000	140	6-46	983	-	-	24	378,248	74,056	685.4	1042.8	706	5.2
1200	150	6-36	1286	-	-	36	494,801	120,188	1143.6	1877.1	920	5.5

CLASS C (EFFECTIVE PRESTRESS = 7.0 N/mm²)

Nominal Diameter mm	Nominal Thickness mm	Length m	Nominal Weight kg/m	Prestressing Bar 7.1mm no.	Prestressing Bar 9.0 mm no.	Prestressing Bar 10.7 mm no.	Area of Concrete mm²	Section Modulus x 1000 mm³	Bending Moment Cracking KNm	Bending Moment Ultimate KNm	Recommended Max Structural Axial Working Load (For a short strut) ton	Effective Prestress N/mm²
400	80	6-15	209	-	12	-	80,425	5,747	69.0	148.3	145	7.6
450	80	6-15	242	-	12	-	92,991	7,734	86.5	166.9	169	7.2
500	90	6-20	301	-	15	-	115,925	10,670	119.6	231.7	210	7.2
600	100	6-20	408	-	-	14	157,080	17,761	195.7	365.0	286	7.0
700	110	6-46	530	-	-	20	203,889	27,497	318.6	608.3	368	7.6
800	120	6-46	667	-	-	24	256,354	39,966	451.9	834.3	465	7.3
900	130	6-46	818	-	-	28	314,473	55,622	612.6	1095.0	572	7.0
1000	140	6-46	983	-	-	36	378,248	75,188	857.4	1564.3	685	7.4
1200	150	6-36	1286	-	-	46	494,801	121,360	1335.3	2398.6	901	7.0

(Subject to change without prior notice)

FORMULA FOR AXIAL LOAD

Based on BS 8004: 1986, the maximum allowable axial stress that may be applied to a pile acting as a short strut should be one quarter of (specified works cube strength at 28 days less the prestress after losses)

$$N = f_{ca} \times A$$
$$= 1/4(f_{cu} - f_{pe}) \times A$$

Where, N = maximum allowable axial load
A = cross section area of concrete
f_{ca} = permissible compressive strength of concrete
f_{cu} = specified compressive strength of concrete
f_{pe} = effective prestress in concrete

Concrete Strength

Minimum concrete cube strength:

at transfer of prestress	28 days
30 N/mm²	78.5 N/mm²

CEPCO SPUN PILES

Dia mm	Nominal Thickness mm	Class	Nominal Weight (kg/m)	Length	Max Axial Working Load kN G80	PC Bar 7.1mm no.	PC Bar 9.0mm no.	PC Bar 10.7mm no.	Concrete Area cm2	Moment of Inertia Concrete x1000 mm3	Bmd Crack t-m	Bmd Ult t-m	Effective PreStress N/mm2	Ultimate Tension Capacity kN
250	55	A	87	6 - 12	620	6			337	17,940	1.9	3.0	6.0	
300	60	A	117	6 - 12	840	7			452	35,760	3.0	4.1	5.3	
350	70	A	160	6 - 15	1,150	9			616	66,260	4.7	6.2	5.0	
400	80	A	209	6 - 15	1,500		8		804	113,110	7.2	10.1	5.4	
		B			1,450		12			114,980	8.7	15.1	7.7	
450	80	A	242	6 - 15	1,740		8		930	171,570	9.5	11.4	5.1	
		B			1,690		12			174,060	11.4	17.0	7.3	
500	90	A	301	6 - 15	2,170		10		1,159	262,990	13.1	15.8	5.1	
		B			2,100		16			267,590	15.6	25.2	7.2	
600	100	A	408	6 - 30	2,930		14		1,571	526,470	22.1	26.5	5.3	
		B			2,860		20	14		533,019	25.8	37.3	7.1	
700	110	A	530	6 - 36	3,800		20	14	2,039	949,760	34.4	44.2	5.4	
		B			3,700		28	20		962,460	40.0	61.8	7.2	
800	120	A	666	10 - 36	4,770			18	2,564	1,581,240	50.3	63.9	5.4	
		B			4,660			24		1,599,030	58.4	85.2	7.2	
900	130	A	818	10 - 36	5,870			24	3,145	2,480,720	69.3	79.9	5.3	
		B			5,710			36		2,503,530	80.1	111.8	7.0	

Insitu Micropile Bored Circular RC Pile

API PIPE SIZES			FOS_{str} =	2.0
Grade N80 (f_y = 80,000 PSI / 552 MPa)				
OD (mm)	ickness (m	ID (mm)	Q_{ult} (kN)	Q_{all} (kN)
114.3	**7.37**	99.56	1,367	**683**
127.0	**7.52**	111.96	1,558	**779**
	9.19	108.62	1,878	**939**
	11.19	104.62	2,247	**1,124**
	12.7	101.6	2,517	**1,259**
139.7	**7.72**	124.26	1,767	**883**
	9.17	121.36	2,076	**1,038**
	10.54	118.62	2,361	**1,180**
168.3	**8.94**	150.42	2,471	**1,235**
	10.59	147.12	2,896	**1,448**
	12.06	144.18	3,268	**1,634**
177.8	**8.05**	161.7	2,370	**1,185**
	9.19	159.42	2,687	**1,344**
	10.36	157.08	3,008	**1,504**
	11.51	154.78	3,319	**1,660**
	12.65	152.5	3,623	**1,811**
	13.72	150.36	3,904	**1,952**
193.7	**9.52**	174.66	3,041	**1,520**
	10.92	171.86	3,461	**1,731**
	12.7	168.3	3,986	**1,993**
	14.27	165.16	4,440	**2,220**
	15.86	161.98	4,891	**2,446**
219.1	**11.43**	196.24	4,116	**2,058**
	12.7	193.7	4,546	**2,273**
	14.15	190.8	5,029	**2,515**
244.5	**10.03**	224.44	4,078	**2,039**
	11.05	222.4	4,473	**2,237**
	11.89	220.72	4,796	**2,398**
	13.84	216.82	5,536	**2,768**
273.0	**11.43**	250.14	5,185	**2,592**
	12.57	247.86	5,677	**2,838**
298.4	**12.42**	273.56	6,160	**3,080**
339.7	**13.06**	313.58	7,398	**3,699**