A Comparative Study on Safe Pile Capacity as Shown in Table 1 of IS 2911 (Part III): 1980

Somdev Pakrashi¹

Received: 7 July 2016 / Accepted: 20 April 2017 / Published online: 8 May 2017
© The Institution of Engineers (India) 2017

Abstract Code of practice for design and construction of under reamed pile foundations: IS 2911 (Part-III)—1980 presents one table in respect of safe load for bored cast in situ under reamed piles in sandy and clayey soils including black cotton soils, stem dia. of pile ranging from 20 to 50 cm and its effective length being 3.50 m. A comparative study, was taken up by working out safe pile capacity for one 400 dia., 3.5 m long bored cast in situ under reamed pile based on subsoil properties obtained from soil investigation work as well as subsoil properties of different magnitudes of clayey, sandy soils and comparing the same with the safe pile capacity shown in Table 1 of that IS Code. The study reveals that safe pile capacity computed from subsoil properties, barring a very few cases, considerably differs from that shown in the afore-said code and looks forward for more research work and study to find out a conclusive explanation of this probable anomaly.

Keywords Under reamed pile · Safe pile capacity · Code of practice · Comparative study

Introduction

Under-reamed piles are special type of bored piles, in general, having one or more bulbs formed by suitable enlarging of the bore-hole for the pile stem. Considerable bearing is achievable with the formation of the bulb/bulbs.

Such piles are observed to be successful and economical in sandy, clayey as well as expansive soils.

Under reamed piles are also observed to be very useful as anchors having the special advantage of resisting uplift to a great extent.

Stem diameters of these piles generally vary from 200 to 500 mm while effective lengths usually vary from 3.00 to 10.00 m. IS 2911, Part-III: 1980 presents a table (Table 1) containing safe load for bored cast-in-situ under-reamed piles [1].

- under vertical downward loads,
- in uplift resistance as well as
- against lateral thrust.

A study has been taken up in this paper by working out safe pile capacity (compression) of 3.50 m long bored cast in situ single under reamed piles having 400 mm stem dia., based on subsoil properties obtained from site exploration work at different sites containing sandy and clayey soils including black cotton soils as well as layered soil, in order to compare the same with the safe pile capacity (compression) shown in Table 1 of IS 2911, Part-III: 1980—for 400 mm stem dia. under reamed piles. This study also includes comparison of

- safe pile capacity worked out in respect of cohesion values from very soft to very stiff clayey soils and
- sandy soils having Φ values from very loose to very dense sandy soils with the safe pile capacity (compression) shown in Table 1 of IS 2911, Part-III: 1980.

Objective of the Study

It has been observed quite a number of times by the author, as a geotechnical engineering expert, that safe pile capacity for single under reamed piles obtained from soil

✉ Somdev Pakrashi
s_pakrashi@rediffmail.com

¹ Consultants Engineers and Builders (Geotechnical Engineering Consultancy Firm), B 294, Lake Gardens, Kolkata 700045, India

Table 1 Clayey soil 10 nos. of sites have been selected

Consistency	No. of locations	Site location and project
Medium	3	(i) Haringhata, for University Campus of West Bengal University of Technology, West Bengal (ii) Haldia, for Naphtha Tankage foundation for BPCL (iii) Burdwan, for P&T Complex_Building under Postal Civil Divn. II, Yogayog Bhaban, Kolkata
Stiff	4	(i) Bharatpur, Murshidabad, for P.O. Building & SPM's Quarters under Postal Civil Divn, Yogayog Bhaban, Kolkata (ii) Panbazar, Guwahati, for LIC Office Building (iii) Dispur, Assam, for Telephone Exchange Building, BSNL (iv) Panbazar, Guwahati, for BSNL Admn. Building
Very stiff	3	(i) Royagada, Orissa, for IOCL Oil Storage Tanks (ii) Balasore, Orissa, for H.P.T.V. Centre under AIR, CCW, Kolkata (iii) Joranda, Orissa, for Radio Station under AIR, CCW, Kolkata

Table 2 Sandy soil 8 nos. of sites have been selected

Density	No. of locations	Site location and project
Loose	2	(i) Near Jiagunge, Murshidabad, for rehabilitation of washed Railway Bridge No. 82A (E. Railway) (ii) Lahil, Hatwar, W. Bengal, for ONGC Drill site Project
Moderately dense	6	(i) NIT, Durgapur, for Academic Complex (ii) Paradeep, Orissa, for BSNL S&M building (iii) Barauni, Bihar, for Additional Tankages for IOCL (iv) Pradhan Nagar, Siliguri, for residential building for M. Design Associates, Siliguri (v) Hakimpara, Siliguri for residential building complex for M. Design Associates, Siliguri (vi) Paradeep, Orissa, for SAIL Staff Quarters

Table 3 Layered soil 10 nos. of sites have been selected

Strength characteristics	No. of locations	Site location and project
<i>Clayey soil over clayey soil</i>		
A. Medium clayey soil underlain by soft clayey soil	3	(i) Haldia Installation, BPCL, for Tankage Foundation (ii) Brahmapur, Kolkata, for W.B.H. Board Residential Complex (iii) Haridevpur, 24 Parganas(S), for W.B.H.B. Housing Complex
B. Medium clayey soil followed by very soft clayey soil	1	(i) Dankuni Stock-Yard Complex, W. Bengal for SAIL
<i>Sandy soil over clayey soil</i>		
A. Loose sand over medium clayey soil	3	(i) Bhadrak, Orissa, for Heavy duty M.W. Tower under BSNL (ii) KMC Compound, Garden Reach, Kolkata, for New Building with Garage (iii) Eastern Rly. Colony, Liluah, Howrah, for 0.50 lac Gallon R.C.C. O.H. Tank
B. Loose sandy soil over soft clayey soil	1	(i) Salt Lake, Kolkata, for 8-Storied Office Building for SCERT under BSNL
C. Moderately dense sandy soil overlying medium clayey soil	1	(i) Near Govindapur Level Crossing, Kolkata in respect of Boundary Wall for E. Railway
<i>Clayey soil over sandy soil</i>		
A. Medium clayey soil followed by dense sandy soil	1	(i) NPT Institute, Durgapur, for Office cum Laboratory cum Auditorium Building under CPWD

Table 4 Safe pile capacity for the under reamed pile in the sites having clayey soil—comparative study

Sl. no.	Site location	Client/year of investigation	Sub-soil profile	Safe pile capacity as per calculation based on soil properties, ton	Safe pile capacity as per Table 1, Col. 8 of IS 2911, Part-III—1980, ton	Deviation of Col. (3) from Col. (4), %
(1)	(a)	(1b)	(2)	(3)	(4)	(5)
1.	Haringhata for Development of Campus for W. Bengal University of Technology	W.B. University of Technology, Salt Lake, Kolkata/2008	Medium silty clay; Av. $c = 3.8 \text{ t/m}^2$, $N = 4-5$	13	28	−53.57
2.	Haldia Installation for Naphtha Tankage	B.P.C.L., 15, Hemanta Basu Sarani, Kolkata/2001	Medium silty clay; $c = 2.75 \text{ t/m}^2$, $N = 2-3$	10.05	28	−64.11
3.	Bharatpur Murshidabad for P.O. Bldg. & SPM's Qtrs. for P.C. Divn.-1	Postal Civil Div. I, Bentinck Street, Kolkata/2001	Stiff silty clay; Av. $c = 9.85 \text{ t/m}^2$, $N = 9-18$	32.5	$1.25 \times 28 = 35$	−7.14
4.	Burdwan P&T Complex for Div. Office Building, Kolkata	Postal Civil Div. II, Bentinck Street/1997	Medium silty clay; Av. $c = 4.4 \text{ t/m}^2$, $N = 3-7$	15.05	28	−46.25
5.	Panbazar, Guwahati for LIC Divn. Office	LIC of India, Guwahati, Assam/1996	Stiff silty clay; Av. $c = 8.55 \text{ t/m}^2$, $N = 9-12$	28.2	$1.25 \times 28 = 35$	−19.43
6.	Royagada, Orissa for 2-nos. Oil Storage Tanks	IOCL, G.H. Road. (S), Kolkata/1995	Very stiff silty clay; Av. $c = 12.4 \text{ t/m}^2$, Av. $N = 15$	39.45	$1.25 \times 28 = 35$	12.71
7.	Balasore, Orissa for H.P.TV for AIR, CCW, Bhubaneswar	All India Radio Bhubaneswar Orissa/1994	Stiff silty clay; Av. $c = 11.25 \text{ t/m}^2$, $N = 13-32$; Av. c at pile tip/base = 9.90 t/m^2	33.25	$1.25 \times 28 = 35$	−4.71
8.	Joranda, Orissa for Radio Station	All India Radio Bhubaneswar/1994	Stiff silty clay; Av. $c = 10.7 \text{ t/m}^2$; Av. $N = 30$	35.3	$1.25 \times 28 = 35$	0.86
9.	Dispur, Assam for Telephone Exchange Building	Telecom Civil Divn., BSNL, Guwahati/1993	Stiff silty clay; Av. $c = 6.25 \text{ t/m}^2$, Av. $N = 8-9$; Av. c at pile tip/base = 6.9 t/m^2	22.5	28	−19.64
10.	Panbazar, Guwahati for Admn. Building for BSNL	Telecom Civil Divn. BSNL Guwahati/1993	Stiff silty clay; Av. $c = 7.5 \text{ t/m}^2$, $N = 10-12$	24.75	$1.25 \times 28 = 35$	−29.28

For this study a single under reamed pile with the dimensions [1, 2] as shown in Fig. 1 has been considered.

Comparative study, as detailed in Tables 4, 5 and 6, has been made in respect of safe capacity (compression) worked out from subsoil properties in different sandy and clayey soils including expansive black cotton soil with that shown in Table 1 of IS 2911, Part-III: 1980.

- very loose to very dense sandy soils with 'Φ' values ranging from 27° to 45° have been examined in this study in order to compare safe capacity (compression) of single under-reamed piles obtained on the basis of subsoil properties with that shown in Table 1 of IS 2911, Part-III: 1980 and presented in Tables 7 and 8 (Figs. 2, 3).

Results

Besides the above,

- very soft to very stiff clayey soils having cohesion values ranging from 0.75 to 16 t/m^2 as well as

Discussion and Observation

Following observations were made in respect of the present comparative study:

Table 5 Safe pile capacity for the under reamed pile in the sites having sandy soil—comparative study

Sl. no.	Site/location	Client/year of investigation	Sub-soil profile	Safe pile capacity as per calculation based on soil properties, ton	Safe pile capacity as per Table 1 Col. 8 of IS 2911, Part-III—1980, ton	Deviation of Col. (3) from Col. (4), %
(1)	(1a)	(1b)	(2)	(3)	(4)	(5)
1.	NIT, Durgapur for Academic Complex	Ex. Engr.(C), CPWD, KCD-VI, Nizam Palace, AJC Bose Rd., Kolkata/2007	Moderately dense sand; Av. $\Phi = 31^\circ$, N = 6–18	25.4	28	–9.29
2.	Near Jiagunge, Murshidabad for rehabilitation of Washed Bridge No. 82A (E. Rly.)	M/s. L.K. Industries 21/48, Karaya Road, Kolkata/2001	Loose silty fine to medium sand; Av. $\Phi = 29.5^\circ$, Av. N = 8–9	21.35	$28 \times 0.75 = 21$	1.67
3.	Paradeep, Orissa for S&M Building for BSNL	Telecom Civil Divn., Friends Colony, Nala Road, Cuttack/1999	Moderately dense fine sand; Av. $\Phi = 32^\circ$, Av. N = 16	29.4	28	5.00
4.	Barauni, Bihar for prop. 3-nos. Additional Tankage for IOCL	I.O.C.L., 2, G.H. Road (S) Kolkata/1997	Moderately dense silty fine sand; Av. $\Phi = 35^\circ$, N = 11–16	47.4	28	69.29
5.	Pradhan Nagar, Siliguri for residential Building	Modern Design Associates 149/97, Hill Cart Road, Pradhan Nagar, Siliguri/1996	Moderately dense silty fine sand; Av. $\Phi = 31^\circ.5$ Av. N = 13	27.35	28	–2.32
6.	Hakimpara, Siliguri for residential Building	Modern Design Associates, Sevoke Road, Siliguri/1996	Moderately dense silty fine sand; Av. $\Phi = 30.5^\circ$, N = 14–15; At pile tip/base: $\Phi = 31^\circ$	25.35	28	–9.46
7.	Paradeep, Orissa for SAIL Staff Quarters	SAIL. Rabindra Sarani, Kolkata/1990	Moderately dense fine to medium sand; Av. $\Phi = 33^\circ$, Av. N = 15; At pile tip/base: $\Phi = 34^\circ$	38.3	28	36.79
8.	Lahil Hatwar, W. Bengal Drill site for ONGC Project	ONGC, W.B. P-45, Taratala Road, Kolkata/1989	Loose fine to medium sand; Av. $\Phi = 29^\circ.5$, Av. N = 9	21.35	$28 \times 0.75 = 21$	1.67

When the Under Ream Pile is in Clayey Soil

- (a) For very soft to soft clayey soil ($c \leq 3.00 \text{ t/m}^2$) [3, 4], safe pile capacity values from subsoil properties are observed to be quite smaller in comparison to safe loads as per the IS Code, its deviation from safe loads as per IS 2911 (Part-III)—1980 varying between –80.37 and –47.86%.
- (b) For medium clayey soil (where cohesion, $c > 3.00 \text{ t/m}^2$ but $\leq 6.00 \text{ t/m}^2$) [3, 4], safe pile capacity obtained from subsoil properties is also much lower, its deviation from safe loads as per IS 2911 (Part-III)—1980 varying between –60.36 and –26.79%.
- (c) For a range from 6 to 9 t/m^2 of stiff clayey soil [3, 4], safe pile capacity as obtained from subsoil properties has also been observed to be considerably lower, its deviation from safe load as per the above IS Code varying between –41.09 and –15.14%.
- (d) Only for the next range of stiff to very stiff clayey soil [3, 4], having $c \geq 9.50 \text{ t/m}^2$ but $\leq 12.50 \text{ t/m}^2$, safe pile capacity obtained from subsoil properties is very close to the safe pile capacity as per the said IS Code, its deviation from the safe pile load as shown in the above IS Code varying between –10.43 and 13.71%.
- (e) For very stiff to hard clayey soils [3, 4] having $c > 12.50 \text{ t/m}^2$ but $\leq 16.00 \text{ t/m}^2$, safe pile capacity value as obtained from subsoil properties is more, in each case, than the safe pile capacity as per IS Code. Here deviation of safe pile capacity obtained from subsoil properties vary between 18.14 and 45.43%, from the safe pile load as per the above IS Code.
- (f) It is also observed that the safe pile capacity obtained on the basis of subsoil properties keeps on increasing with the increment of cohesion value. At $c = 0.75 \text{ t/m}^2$, safe pile capacity calculated on subsoil properties works out to 2.75 ton and for $c = 16 \text{ t/m}^2$, safe pile

Table 6 Safe pile capacity for the under reamed pile in the sites having layered soil—comparative study

Sl. No	Site/location	Client/year of investigation	Sub-soil profile	Safe pile capacity as per calculation based on soil properties, ton (3)	Safe pile capacity [1] as per Table 1 Col. 8 of IS 2911, Part-III—1980, ton (4)	Deviation of Col. (3) from Col. (4), % (5)
(1)	(1a)	(1b)	(2)	(3)	(4)	(5)
1.	N.P.T. Institute, Durgapur for Office cum Lab. cum Auditorium Bldg.	Ex. Engr.(C), CPWD, KCD-VI, Nizam Palace, AJC Bose Road, Kolkata/2010	First layer: up to -3.05 m Medium silty clay with some coarse sand; $c = 4.25$ t/m ² , $N = 10$ Second layer: below -3.05 m Dense coarse sand; $\Phi = 38.5^\circ$	88.2	$1.25 \times 28 = 35$	152.00
2.	Bhadrak, Orissa for Heavy Duty Microwave Tower	Telecom Civil Divn., B.S.N.L. Cuttack/1998	First layer: up to -2.25 m Loose fine to medium sand; Av. $\Phi = 29^\circ$, Av. $N = 5$ Second layer: below -2.25 m Medium to stiff silty clay; Av. $c = 4.95$ t/m ² , Av. $N = 7-8$; Av. c at pile tip/base = 5.75 t/m ² , $N = 8-11$	18.35	28	−34.46
3.	Near Govindapur Level Crossing, Kolkata for Boundary Wall	Eastern Rly, Sealdah/1998	First layer: up to -3 m Moderately dense silty fine sand; Av. $\Phi = 31^\circ$, Av. $N = 7$ Second Layer: below -3 m Medium silty clay; Av. $c = 3.1$ t/m ² , Av. $N = 4-6$	10.2	28	−63.57
4.	Haldia Installation BPCL for 4-nos. Tankage Foundation	BPCL, West Bengal, Kolkata/1998	First layer: up to -3.6 m Medium silty clay; Av. $c = 2.85$ t/m ² , $N = 3-5$ Second layer: from -3.6 m Soft silty clay with decayed and decomposed vegetation; Av. $c = 1.85$ t/m ² , $N = 1-3$	7.4	$28 \times 0.75 = 21$	−64.76
5.	Salt Lake, Kolkata for 8-Storied. Office Building for SCERT	PWD (C.Brd.), West Bengal, Kolkata/1998	First layer: up to -3 m Loose silty sand; Av. $\Phi = 29^\circ$, $N = 2-5$ Next layer: from -3 m Soft silty clay; Av. $c = 1.95$ t/m ² , Av. $N = 2-3$	6.65	$28 \times 0.75 = 21$	−68.33
6.	Garden Reach, CMC compound for New Building with Garage provision	Calcutta Municipal Corporation S.N. Banerjee Road, Kolkata/1998	First layer: up to -3.5 m Loose silty fine sand; Av. $\Phi = 29^\circ$, $N = 5$ Next layer: from -3.5 m Soft silty clay; Av. $c = 3$ t/m ² , Av. $N = 3-4$	9.8	$28 \times 0.75 = 21$	−53.33
7.	Brahmapur, Kolkata for Residential Complex	West Bengal Housing Board Kolkata/1997	First layer: up to -4 m Medium silty clay; Av. $c = 3.70$ t/m ² , $N = 3-8$ Second layer: below -4 m Soft silty clay with decayed and decomposed vegetation; Av. $c = 1.75$ t/m ² ; $N = 1-3$	6.95	$0.75 \times 28 = 21$	−66.90

Table 6 continued

Sl. No	Site/location	Client/year of investigation	Sub-soil profile	Safe pile capacity as per calculation based on soil properties, ton (3)	Safe pile capacity [1] as per Table 1 Col. 8 of IS 2911, Part-III—1980, ton (4)	Deviation of Col. (3) from Col. (4), % (5)
(1)	(1a)	(1b)	(2)			
8.	Liluah E. Rly. Colony Howrah for 0.50 Lac gallon RCC O.H. Tank	Eastern Rly. Strand Road, Howrah/1997	First layer: up to -3.35 m Loose silty fine sand; Av. $\Phi = 30^\circ$; Av. $N = 3$ Second layer: from -3.35 m Medium silty clay with decomposed vegetation; Av. $c = 2.25$ t/m ²	7.6	$0.75 \times 28 = 21$	-63.81
9.	Haridevpur, 24 Pgs.(S) for Housing Complex	W.B. Housing Board, 105, S.N. Banerjee Road, Kolkata/1995	First layer: up to -3.35 m Soft/medium silty clay; Av. $c = 2.45$ t/m ² , $N = 2-3$ Next layer: below -3.35 m Soft silty clay with decayed and decomposed vegetation; Av. $c = 2.01$ t/m ² , $N = 0-1$	7.6	$0.75 \times 28 = 21$	-63.81
10.	Dankuni Stockyard Complex, W. Bengal, for SAIL	SAIL, Rabindra Sarani, Kolkata/1989	First layer: up to -1.75 m Medium silty clay; Av. $c = 4$ t/m ² , $N = 5-6$ Second layer: below -1.75 m Very soft silty clay with decayed and decomposed vegetation; Av. $c = 0.9$ t/m ² , Av. $N = 1-2$	3.65	$0.5 \times 28 = 14$	-73.93

Table 7 Comparative study for safe pile capacity: under reamed pile in clayey soil

Consistency of sub soil [3, 4]	Sl. no. (1)	c, t/m ² (2)	Safe pile capacity as per calculation based on soil properties, ton (3)	Safe pile capacity [1] as per Table 1, Col-8 of IS 2911 (Part-III): 1980, ton (4)	Deviation of Col. (3) from Col. (4), % (5)
Very Soft	1.	0.75	2.75	$0.5 \times 28 = 14$	-80.37
	2.	1	3.65	$0.5 \times 28 = 14$	-73.93
	3.	1.25	4.55	$0.5 \times 28 = 14$	-67.50
	4.	1.5	5.5	$0.5 \times 28 = 14$	-60.71
Soft	1.	1.75	6.4	$0.75 \times 28 = 21$	-69.52
	2.	2	7.3	$0.75 \times 28 = 21$	-65.24
	3.	2.25	8.25	$0.75 \times 28 = 21$	-60.71
	4.	2.5	9.15	$0.75 \times 28 = 21$	-56.43
	5.	3	10.95	$0.75 \times 28 = 21$	-47.86
Medium	1.	3.25	11.1	28	-60.36
	2.	3.5	11.95	28	-57.32
	3.	3.75	12.8	28	-54.29
	4.	4	13.65	28	-51.25
	5.	4.25	14.5	28	-48.21
	6.	4.5	15.4	28	-45.00
	7.	4.75	16.25	28	-41.96
	8.	5	17.1	28	-38.93
	9.	5.25	17.95	28	-35.89
	10.	5.5	18.8	28	-32.85
	11.	5.75	19.65	28	-29.82
	12.	6	20.5	28	-26.79

Table 7 continued

Consistency of sub soil [3, 4]	Sl. no. (1)	c, t/m ² (2)	Safe pile capacity as per calculation based on soil properties, ton (3)	Safe pile capacity [1] as per Table 1, Col-8 of IS 2911 (Part-III): 1980, ton (4)	Deviation of Col. (3) from Col. (4), % (5)
Stiff	1.	6.25	20.65	$1.25 \times 28 = 35$	−41.09
	2.	6.5	21.45	$1.25 \times 28 = 35$	−38.71
	3.	7	23.1	$1.25 \times 28 = 35$	−34.00
	4.	7.5	24.75	$1.25 \times 28 = 35$	−29.29
	5.	8	26.4	$1.25 \times 28 = 35$	−24.57
	6.	8.5	28.05	$1.25 \times 28 = 35$	−19.86
	7.	9	29.7	$1.25 \times 28 = 35$	−15.14
	8.	9.5	31.35	$1.25 \times 28 = 35$	−10.43
	9.	10	33	$1.25 \times 28 = 35$	−5.71
	10.	10.5	34.65	$1.25 \times 28 = 35$	−1.00
	11.	11	36.3	$1.25 \times 28 = 35$	3.71
	12.	11.5	37.95	$1.25 \times 28 = 35$	8.43
	13.	12	39.6	$1.25 \times 28 = 35$	13.14
Very stiff to hard	1	12.25	39	$1.25 \times 28 = 35$	11.43
	2	12.5	39.8	$1.25 \times 28 = 35$	13.71
	3	13	41.35	$1.25 \times 28 = 35$	18.14
	4	13.5	42.95	$1.25 \times 28 = 35$	22.71
	5	14	44.55	$1.25 \times 28 = 35$	27.29
	6	14.5	46.15	$1.25 \times 28 = 35$	31.86
	7	15	47.75	$1.25 \times 28 = 35$	36.43
	8	15.5	49.3	$1.25 \times 28 = 35$	40.86
	9	16	50.9	$1.25 \times 28 = 35$	45.43

Table 8 Comparative study for safe pile capacity: under reamed pile in sandy soil

Density of sub soil [3, 5]	Sl. no. (1)	Φ , deg (2)	Safe pile capacity as per calculation based on soil properties, ton (3)	Safe pile capacity [1] as per Table 1 Col-8 of IS 2911 Part-III: 1980, ton (4)	Deviation of Col. (3) from Col. (4), % (5)
Very loose	1	27	14.15	$0.50 \times 28 = 14$	1.07
	2	27.5	16.2	$0.50 \times 28 = 14$	15.71
	3	28	17.2	$0.50 \times 28 = 14$	22.86
	4	28.5	18.7	$0.50 \times 28 = 14$	33.57
Loose	1	29	20.15	$0.75 \times 28 = 21$	−4.05
	2	29.5	21.35	$0.75 \times 28 = 21$	1.67
	3	30	22.75	$0.75 \times 28 = 21$	8.33
Moderately dense	1	30.5	24.5	28	−12.50
	2	31	25.4	28	−9.29
	3	31.5	27.35	28	−2.32
	4	32	29.4	28	5.00
	5	32.5	32.25	28	15.18
	6	33	34	28	21.43
	7	33.5	36.4	28	30.00
	8	34	38.35	28	36.96
	9	34.5	41.8	28	49.29
	10	35	47.4	28	69.29
	11	35.5	52.1	28	86.07
	12	36	56.7	28	102.50

Table 8 continued

Density of sub soil [3, 5]	Sl. no. (1)	Φ , deg (2)	Safe pile capacity as per calculation based on soil properties, ton (3)	Safe pile capacity [1] as per Table 1 Col-8 of IS 2911 Part-III: 1980, ton (4)	Deviation of Col. (3) from Col. (4), % (5)
Dense	1	36.5	63.05	$1.25 \times 28 = 35$	80.14
	2	37	67.2	$1.25 \times 28 = 35$	92.00
	3	37.5	75.65 ^a	$1.25 \times 28 = 35$	116.14
	4	38	80.05 ^a	$1.25 \times 28 = 35$	128.71
	5	38.5	89.95 ^a	$1.25 \times 28 = 35$	157.00
	6	39	101.1 ^a	$1.25 \times 28 = 35$	188.86
	7	39.5	106.4 ^a	$1.25 \times 28 = 35$	204.00
	8	40	121.15 ^a	$1.25 \times 28 = 35$	246.14
	9	40.5	130.8 ^a	$1.25 \times 28 = 35$	273.71
	10	41	147.65 ^a	$1.25 \times 28 = 35$	321.86
Very dense	1	41.5	165.65 ^a	$1.25 \times 28 = 35$	373.29
	2	42	180.2 ^a	$1.25 \times 28 = 35$	414.86
	3	42.5	186.3 ^a	$1.25 \times 28 = 35$	432.29
	4	43	192.35 ^a	$1.25 \times 28 = 35$	449.57
	5	43.5	210.4 ^a	$1.25 \times 28 = 35$	501.14
	6	44	228.5 ^a	$1.25 \times 28 = 35$	552.86
	7	44.5	268.9 ^a	$1.25 \times 28 = 35$	668.29
	8	45	309.3 ^a	$1.25 \times 28 = 35$	783.71

^a Structural safe capacity for the under reamed pile with M25 R.C.C. = 75 ton

capacity is observed to be 18.50 times high as it works out to 50.90 ton. But the safe pile capacity as per the said IS Code varies between a smaller range of 14–35 ton and the ratio between the maximum and the minimum value is 2.5 only.

When the Under Ream Pile is in Sandy Soil

1. For very loose/loose sandy soil ($27^\circ \leq \Phi \leq 30^\circ$) [3]

- Safe pile capacity as obtained from subsoil properties is observed to be more than that as per the above IS Code where, Φ values $\geq 27.5^\circ$ but $\leq 28.5^\circ$. Here deviation of safe pile capacity obtained from subsoil properties vary between 15.71 and 33.57%, from the safe pile load as per the above IS Code.
- Safe pile capacity obtained from subsoil properties and the same as per the said IS Code is almost equal or very close to each other for $\Phi = 27^\circ$ as well as where $29^\circ \leq \Phi \leq 30^\circ$, i.e., for a very small range. The deviation of safe pile capacity based on subsoil properties from that shown in the aforesaid IS Code are 1.07% and –4.05 to 8.33%, deviations being negligible or very small.

2. For moderately dense sandy soil ($30^\circ < \Phi \leq 36^\circ$) [3]

- Safe pile capacity obtained from subsoil properties and the same as per the said IS Code are very close to each other (% deviation varies from –9.29 to 5) where $31^\circ \leq \Phi \leq 32^\circ$.
- Safe pile capacity values obtained from subsoil properties are somewhat higher (% deviation varies from 15.18 to 30.00) than those shown in the above mentioned IS Code—for ϕ values $\geq 32.5^\circ$ but $\leq 33.5^\circ$, whereas, for $\phi = 30.5^\circ$, safe capacity obtained from subsoil properties is bit less (% deviation = –12.5) than that shown in the said IS Code.
- Safe pile capacity obtained from subsoil properties, having ϕ values $> 33.5^\circ$ but $\leq 36^\circ$, however, become considerably higher (% deviation = 36.96–102.5) than those as per the said IS Code.

3. For dense to very dense sandy soil ($36.5^\circ \leq \Phi \leq 45^\circ$) [3]

Percentage deviations of the safe pile capacity obtained from subsoil properties are observed to be very large varying between 80.14 and 783.71.

4. For sandy soil it is also observed that the safe pile capacity obtained on the basis of subsoil properties

Fig. 2 a Safe pile capacity versus cohesion curves. **b** Safe pile capacity versus angle of internal friction curves

keeps on increasing with the increment of ' Φ ' value. At $\Phi = 27^\circ$, safe pile capacity calculated from subsoil properties works out to 14.15 ton and for $\Phi = 45^\circ$, worked out safe pile capacity is 21.86 times of 14.15 ton, being 309.30 ton. It has, however, been observed that structural safe pile capacity (compression) for a 3.5 m long $\times$ 400 mm stem dia. under reamed pile with M20 and M25 R.C.C are 65 and 75 ton respectively. Accordingly these structural safe pile capacity values, respectively, are 4.59 and 5.3 times higher than 14.15 ton. But safe pile capacity as per IS Code, in comparison, varies between quite a smaller range of 14 and 35 ton for the same range of ' Φ ' values, i.e., between 27° and 45° . The ratio between the highest and the lowest value of safe pile load is 2.5 only.

When the Under Ream Pile is in Layered Soil

Safe pile capacity obtained from subsoil properties, as well, increases with the increment of ' c ' and/or ' Φ ' values of the subsoil whereas the safe pile capacity given in the IS Code is same for a wide range of strength parameters and variation range of the same is quite small being from 14 to 35 ton only.

Deviation (%) of Safe Pile Capacity Based on Subsoil Properties from the Safe Pile Load Shown in the IS 2911, Part-III: 1980

- (a) In case of clayey soils, aforesaid deviations are negative (from -80.37 to -1.00%) as well as diminishing with the increment of ' c ' values, from 0.75 to

Fig. 2 continued

10.5 t/m². With the increment of cohesion values from 11 to 16 t/m² said deviations go on increasing (3.71–45.43%) all values being positive.

- (b) In case of sandy soils, deviations (from 1.07% at ' Φ ' = 27° to 783.71% at ' Φ ' = 45°) are mostly positive and go on increasing with the increment of ' Φ '. However the deviations are negative only for ' Φ ' = 29°, 30.5°, 31° and 31.5°, the deviations being −4.05, −12.5, −9.29 and −2.32% respectively.
- (c) For layered soil, Table 6, shows large deviation of values based on subsoil properties from those as per the IS Code and the values are mostly negative.

Limitations

- (a) Influence of field and laboratory test procedures, some conditions and faults by manpower in carrying out soil investigation work etc. is not unlikely on study results.
- (b) This study has been carried out in respect of one particular length and diameter of one single under reamed pile. Quite a number of study/research work in respect of under reamed piles having different pile lengths and diameters in various sites with different

Fig. 3 a Deviation (%) of safe pile capacity based on subsoil properties from that shown in IS 2911, Part-III—1980.

b Deviation (%) of safe pile capacity based on subsoil properties from that shown in IS 2911, Part-III—1980

sub soil compositions/conditions etc. are necessary before any conclusive explanation/decision can be made in respect of this comparative study.

Conclusions

A comparative study on safe loads (compression) as shown in Table 1 of IS 2911 Part-III—1980 was taken up by working out safe pile capacity (compression) from soil properties of different subsurface deposits in respect of 3.5 m long bored cast in situ single under ream piles having 400 mm stem dia.—to examine whether the results are in conformity with the safe loads (compression) shown in the said table of the said IS Code.

Study results show that the safe pile capacity as obtained from subsoil properties differs, from the safe pile capacity shown in the said table of the said IS Code, in most of the cases to a great extent in sandy and clayey

soils including black cotton soil as well as in layered soil i.e., in all types of subsoils, except for the small range of values where $c \geq 9.5 \text{ t/m}^2$ but $\leq 12.5 \text{ t/m}^2$ as well as $\Phi = 27^\circ$, $\Phi \geq 29^\circ$ but $\leq 30^\circ$ and $\Phi \geq 31^\circ$ but $\leq 32^\circ$.

Safe pile capacity obtained on the basis of subsoil properties keeps on increasing with the increment of 'c' and/or 'Φ' values for all types of subsoils including layered soil and the increment is manifold from low ($c = 0.75 \text{ t/m}^2$ or $\Phi = 27^\circ$) to high ($c = 16 \text{ t/m}^2$ or $\Phi = 45^\circ$) shear strength parameters. Ratio between maximum and minimum safe pile capacity for clayey soil is 18.5 and for sandy soil it is 21.76. Safe capacity in terms of structural safety of this pile with M20 and M25 RCC are however 65 and 75 ton respectively. With a safe pile capacity value = 75 ton, aforesaid ratio of maximum to minimum safe pile capacity for sandy soil is to 5.30. But, safe pile capacity given in the said IS Code, for all types of subsoil including black cotton soil and layered soil is same for a wide range of strength parameters and its variation

Fig. 3 continued

range is also quite small (14–35 ton), the ratio between the values being as low as 2.5.

It is observed that some civil engineers refer to the aforesaid table of IS 2911, Part-III, 1980 as a ready means of obtaining safe load for under reamed piles in sandy/clayey soil including black cotton soil or layered subsoil i.e., for all types of subsoils. Under the light of the above findings and observations it appears, therefore, prudent to look forward to more study and research work in order to find out a conclusive explanation in regard to probable anomaly of the results arising out from the present study.

Appendix 1: Expression used for the determination of safe pile capacity for single under reamed pile [1]

For Clayey Soils

$$Q_a = Q_d F$$

$$= (A_p N_c c_p + A_a N_c c'_a + c'_{s1} A'_{s1} \alpha'_1 + c'_{s2} A'_{s2} \alpha'_2 + c'_{s3} A'_{s3} \alpha'_3) / F \quad (i)$$

where Q_a (t/m^2) = safe bearing capacity of pile; F = factor of safety = 2.5 (taken); Q_d (t/m^2) = ultimate bearing capacity of pile; $A_p = \pi/4 D^2$, cross-sectional area of pile stem at toe level; N_c = bearing capacity factor, taken as 9; c_p = cohesion of soil around toe; $A_a = \pi/4 (D_u^2 - D^2)$ where D_u and D are the under-reamed bulb and stem diameters respectively; c'_a = average cohesion of soil around under reamed bulb; $\alpha_1, \alpha_2, \alpha_3$ = reduction factors; c'_{s1} = average cohesion of soil along pile stem above under reamed bulb; A'_{s1} = surface area of the stem above under reamed bulb providing frictional resistance; c'_{s2} = cohesion of soil around the under-reamed bulb; $A'_{s2} = \pi D_u (D/4)$, surface area of the cylinder circumscribing the under reamed bulb; c'_{s3} = average cohesion of soil along pile stem below the under reamed bulb; and A'_{s3} = surface area of stem below the under reamed bulb.

- (I) First two terms of the above expression are for bearing and the last three are for friction components.
- (II) For uplift first term of expression (i) will not occur.
- (III) Frictional resistance for a length of $2D$ along the stem above the under reamed bulb has not been considered owing to disturbance of that part of

subsoil due to possible settlement of the under reamed bulb.

(IV) Where $c_p = c'a$ first two terms reduces to

$$(A_p + A_a)N_c \times c'a = \pi/4 D_u^2 N_c \times c'a \quad (\text{ia})$$

(V) Where $c_p = c'a = c'_{s1} = c'_{s2} = c'_{s3} = c$ = cohesion of soil between -1.25 and -4.75 m, we have, $\alpha_1 = \alpha_2 = \alpha_3 = \alpha$ and expression (i) becomes

$$Q_a = Q_d/F = \{(\pi/4)D_u^2 N_c c + c\alpha(A'_{s1} + A'_{s2} + A'_{s3})\}/F \quad (\text{ib})$$

From Fig. 1 we have, $L_{\text{eff}} = 3.50$ m; $D = 0.40$ m; $D_u = 2.5 \times 0.40 = 1.00$ m; $L_1 = 1.80$ m; $L_2 = 2.60$ m; $L_3 = 0.3$ m; $L' = D/4 = 0.10$ m.

$F = 2.5$, $\therefore$ from expression (ib) we have, $Q_a = Q_d/F = \{(\pi/4) \times (1)^2 \times c \times 9 + \pi \times 0.4 \times c\alpha(1.80 + 0.25 + 0.3)\}/F = (7.0686 + 2.9531\alpha)c/F$.

For $\alpha = 0.7$ ($c \leq 3 \text{ t/m}^2$) [6], $Q_a = 3.654c$; for $\alpha = 0.5$ ($c > 3 \text{ t/m}^2$ but $\leq 6.0 \text{ t/m}^2$) [6], $Q_a = 3.418c$; for $\alpha = 0.4$ ($c > 6.0 \text{ t/m}^2$ but $\leq 12.0 \text{ t/m}^2$) [6], $Q_a = 3.300c$; for $\alpha = 0.3$ ($c > 12.0 \text{ t/m}^2$) [6], $Q_a = 3.182c$.

For Sandy Soils

$$Q_a = Q_d/F = \{A_p\{1/2\gamma DN\gamma + \gamma d_f N_q\} + A_a\{1/2\gamma D_u N\gamma + \gamma d_r N_q\} + A'_{s1} K \tan \delta p_{d1} + A'_{s2} K \tan \delta p_{d2} + A'_{s3} K \tan \delta p_{d3}\}/F \quad (\text{ii})$$

where Q_a (t/m^2) = safe bearing capacity of pile; F = factor of safety = 2.5 (taken); Q_d (t/m^2) = ultimate bearing capacity of pile; $A_p = \pi/4 D^2$; $A_a = \pi/4 (D_u^2 - D^2)$; p_{d1} = average effective overburden pressure along stem above under reamed bulb; p_{d2} = average effective overburden pressure at the cylinder circumscribing the under reamed bulb; p_{d3} = average effective overburden pressure at stem below under reamed bulb; A'_{s1} = surface area of the stem above under reamed bulb providing frictional resistance; $A'_{s2} = \pi D_u \cdot (D/4)$, surface area of the cylinder circumscribing the under reamed bulb; A'_{s3} = surface area of stem below the under reamed bulb; γ = average effective unit weight of soil; N_γ and N_q = bearing capacity factors depending upon the angle of internal friction; d_f = total depth of pile below ground level; d_r = depth of the centre of under-reamed bulb below ground level; K = earth pressure coefficient; δ = angle of wall friction (taken equal to $0.85 \times$ angle of internal friction Φ) [3, 5]; L_1 = length of stem above under reamed bulb providing frictional resistance where a length = $2D$ above the under reamed bulb [3] has not been considered for frictional

resistance = 1.80 m; L_2 = entire length of the stem above under reamed bulb = 2.60 m; L_3 = length of stem below under reamed bulb = 0.30 m.

- (1) First two terms of the above expression are for bearing and the last three are for friction components
- (2) For uplift, bearing on tip, A_p will not occur. Where Φ is same throughout the subsoil from cut off to tip of the pile expression (ii) becomes

$$Q_a = Q_d/F = \{A_p(1/2\gamma DN\gamma + \gamma d_f N_q) + A_a(1/2\gamma D_u N\gamma + \gamma d_r N_q) + K \tan \delta (A'_{s1} p_{d1} + A'_{s2} p_{d2} + A'_{s3} p_{d3})\}/F \quad (\text{iii})$$

For very loose to moderately dense sandy soils ($\Phi \geq 27^\circ$ but $\leq 36^\circ$) [3, 7], frictional resistance along the stem for a length of $2D$ above the under ream has not been considered.

Now, with $\gamma = 0.85$, $L_1 = 1.80$ m, $L_3 = 0.30$ m, $D = 0.40$ m, $D_u = 1.00$ m, $d_f = 4.75$ m and $d_r = 4.20$ m, the above expression becomes,

$$\begin{aligned} Q_a = Q_d/F &= [(\pi/4) \times 0.16(0.5 \times 0.85 \times 0.4 \times N_\gamma + 0.85 \times 4.75 \times N_q) \\ &+ (\pi/4) \times 0.84(0.5 \times 0.85 \times 1 \times N_\gamma + 0.85 \times 4.2 \times N_q) \\ &+ \pi \times 0.4 \times K \tan \delta \times 0.85 \\ &\{1.80 \times 2.15 + (1/4) \times 4.2 + 0.3 \times 4.60\}]/F \\ &= [0.02136N_\gamma + 0.50737N_q + 0.28039N_\gamma + 2.3553N_q \\ &+ \pi \times 0.4 \times K \tan \delta \times 0.85 \\ &\times \{1.80 \times 2.15 + (1/4) \times 4.2 + 0.3 \times 4.60\}]/2.5 \\ &= (0.30175N_\gamma + 2.86267N_q + 6.7293K \tan \delta) / 2.5 = 0.1207N_\gamma + 1.1451N_q \\ &+ 2.6917K \tan \delta \end{aligned} \quad (\text{iib})$$

For dense to very dense sandy soils ($\Phi > 36^\circ$) [3, 7] entire length above the under ream is considered to provide frictional resistance.

Here, with $\gamma = 0.85$, $L_1 = 2.60$ m, $L_3 = 0.30$ m, $D = 0.40$ m, $D_u = 1.00$ m, $d_f = 4.75$ m and $d_r = 4.20$ m expression (iii) reduces to

$$\begin{aligned} Q_a = Q_d/F &= [\pi/4 \times 0.16 \times (1/2 \times 0.85 \times 0.4N_\gamma + 0.85 \times 4.75N_q) \\ &+ \pi/4 \times 0.84 \times (1/2 \times 0.85N_\gamma + 0.85 \times 4.2 \times N_q) \\ &+ \pi \times 0.4 \times K \tan \delta \times 0.85 \\ &\times \{2.60 \times 2.55 + (1/4) \times 4.2 + 0.3 \times 4.60\}]/F \\ &= (0.30175N_\gamma + 2.86237N_q + 9.6774K \tan \delta)/2.5 \\ &= 0.1207N_\gamma + 1.1451N_q + 3.871K \tan \delta \end{aligned} \quad (\text{iic})$$

Taken, $K = 1$ for $\Phi \leq 30^\circ$; $K = 1.25$ for $\Phi > 30^\circ$ but $\leq 32^\circ$; $K = 1.50$ for $\Phi > 32^\circ$ but $\leq 36^\circ$; $K = 1.75$ for $\Phi > 36^\circ$ but $\leq 38^\circ$; $K = 2.00$ for $\Phi > 38^\circ$ [3].

Appendix 2: Values of N_q and N_γ as per relevant IS Code ($\Phi' = \Phi - 2$, considering loosening of subsoil at pile tip)

Φ'	N_q [1]	N_γ [7]	Φ'	N_q [1]	N_γ [7]
25	10.20	10.88	35	50	48.03
25.5	11.85	12.032	35.5	56.7	54.168
26	12.60	13.184	36	59.8	60.306
26.5	13.75	14.336	36.5	67.2	66.444
27	14.9	15.488	37	76.2	72.582
27.5	15.8	16.64	37.5	80.1	78.72
28	16.85	17.792	38	92.3	84.858
28.5	17.95	18.944	38.5	100	90.996
29	18.6	20.096	39	114	97.13
29.5	20.15	21.218	39.5	129	103.27
30	21.8	22.40	40	141	109.41
30.5	23.7	24.963	40.5	144.5	125.645
31	24.9	27.526	41	148	141.88
31.5	26.7	30.089	41.5	162	158.115
32.0	28.10	32.652	42	176	174.35
32.5	30.8	35.215	42.5	209.5	190.585
33	35.4	37.778	43	243	206.82
33.5	39.2	40.341	43.5	271	223.055
34	42.9	42.904	44	299	239.29
34.5	46.7	45.467	45	345	271.76

Appendix 3: Sample Calculation

Determination of safe pile capacity (compression) from necessary subsoil parameters for the single under reamed pile

A. Clayey soil Let, $c = 4.4$ t/ m^2 ; Here, $\alpha = 0.5$

$\therefore$ Safe pile capacity $= 3.418c = 3.418 \times 4.4 = 15.0392$ ton say, 15.05 ton

B. Sandy soil Let, $\Phi = 31^\circ$ $\therefore \Phi' = 31 - 2 = 29^\circ$ (considering loosening effect at pile tip). Here, $K = 1.25$, $N_\gamma = 20.096$ and $N_q = 18.6$ for $\Phi' = 29^\circ$
 $\delta = 0.85$ (taken) [1, 3]

$\therefore$ Safe pile capacity $= 0.1207N_\gamma + 1.1451N_q + 2.6917 K \tan \delta = 2.4256 + 21.2989 + 1.6666 = 25.391$ ton say, 25.40 ton

Estimate of safe capacity in respect of structural safely of the single under reamed pile

Safe capacity (compression)	Use M20 RCC [8]
$= 1372.79 \times 51 \times 10^{-3}$	$f_{sc} = 51$ kg/cm ² ; $m = 13.33$
$= 70.01$ ton	$\Phi = 40$ cm;
$\therefore$ Use safe capacity $= 65$ ton	$A_s = A_g + (m - 1) \times A_s$
Now, $65 \times 10^3 / 1372.79$	$= (\pi/4) \times 40^2 + 12.33 \times 9.42$
$= 47.35$ kg/cm ² < 51 ton $\therefore$ O.K.	$= 1372.79$ cm ²
	Used 3 nos. 16 mm Φ and 3 nos. 12 mm Φ , area $= 09.42$ cm ² $>$ min. steel @0.4% of $(\pi/4) \times (40)^2 = 5.03$ cm ² $\therefore$ O.K.
Safe capacity (compression)	Use M25 RCC [8]
$= 1350.65 \times 10^{-3} \times 61.2 = 82.66$ ton	$f_{sc} = 61.2$ N kg/cm ² ; $m = 10.98$
$\therefore$ Use safe capacity $= 75$ ton	$\Phi = 40$ cm;
Now, $75 \times 10^3 / 1350.65 = 55.53$ kg/cm ² < 61.2 ton $\therefore$ O.K.	$A_s = A_g + (m - 1)A_s$
	$= (\pi/4) \times 40^2 + 9.98 \times 9.42 = 1350.65$ cm ²
	Use, 3 nos. 16 mm Φ + 3 nos. 12 Φ , area $= 09.42$ cm ² $>$ min. steel@0.4% of $(\pi/4) \times 40^2 = 5.03$ cm ² $\therefore$ O.K.

References

1. IS: 2911 (Part-III)—1980, Indian Standard Code of Practice for Design and Construction of Pile Foundations, Part-III, Under-Reamed Piles (First Revision). Indian Standard Institution, Manak Bhavan, 9, Bahadur Shah Zafar Marg, New Delhi 110002, February (1981)
2. SP 7(2005), National Building Code Of India 2005, Second Reprint 2007, Bureau of Indian Standards, Manak Bhavan, New Delhi 110002, Part 6, Section 2, Fig. 7, p. 30
3. M.J. Tomlinson, *Foundation Design and Construction*, 4th edn. The English Language Book Society and Pitman, ELBS edition reprinted (1981)
4. K. Terzaghi, R.B. Peck, *Soil Mechanics in Engineering Practice, First Indian Edition, Eleventh Printing, August 1960* (Asia Publishing House, Calcutta, 1962)
5. R.B. Peck, W.E. Hanson, T.H. Thornburn, *Foundation Engineering, 2nd. Edition, John Wiley and Sons, New York, USA, 1974*
6. IS: 2911 (Part I/Sec 2) – 2010, Indian Standard Code of Practice for Design and Construction of Pile Foundations, Part I: Concrete Piles, Section 2: Bored Cast In Situ Concrete Piles (Second Revision). Bureau of Indian Standards, Manak Bhavan, 9, Bahadur Shah Zafar Marg, New Delhi 110002, May 2011, p. 25
7. IS: 6403 – 1981, Indian Standard Code of Practice for Determination of Bearing Capacity of Shallow Foundations. Indian Standard Institution, Manak Bhavan, 9, Bahadur Shah Zafar Marg, New Delhi 110002, November 1981
8. IS 456-2000, Indian Standard Plain and Reinforced Concrete—Code of Practice (Fourth Revision) Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002, July 2000