Bearing Capacity of Bored Piles in Expansive Clays

Capacité portante de pieux forés dans une argile gonflante

by Dinesh Mohan, M. A.S.C.E., Head of Soil Engineering Division, Central Building Research Institute, Roorkee and
Giriraj Singh Jain, Junior Scientific Officer, Central Building Research Institute, Roorkee

Summary

The design of under-reamed pile foundations in expansive clays requires a knowledge of the anchorage and load carrying capacities of the piles. The authors describe a full scale loading and pull out tests on cast-in-situ straight and under-reamed piles of different sizes carried down to different depths in Indian black cotton soils. While the net point bearing value, after deducting the side friction for straight piles, is eight times the shear strength of the soil, in the case of under-reamed piles the point bearing is only half this value.

Sommaire

L'exécution des reprises en sous-œuvre par pieux forés dans des argiles expansives nécessite la connaissance des capacités d'ancrage et de force portante de ces pieux. La présente communication décrit des essais de chargement et d'arrachage de pieux moulés dans le sol, munis ou non d'un bulbe à la base, de différents diamètres, et de longueur différente dans le « Black Cotton » indien. Tandis que la contrainte nette de pointe (déduction faite de celle absorbée par frottement dans les pieux ordinaires) est de 8 fois la résistance au cisaillement du sol, on a constaté que celle-ci doit être réduite environ de moitié dans le cas de pieux à bulbe.

Introduction

Indian black cotton soils are highly expansive clays. Their liquid limit ranges from 46 to 97 and Plasticity Index from 22 to 49. They are not sensitive and have a sensitivity value close to unity. They are usually dark in colour and have a predominance of the mineral montmorillonite [1]. Under-reamed pile foundations have been suggested for buildings over deep layers of such soils [2]. These piles have their bases enlarged out by a special reaming tool to provide an anchorage and a greater bearing area in the stable zone where ground movements are negligible (Fig. 2). Full scale loading and pull out tests were carried out on piles of various sizes at different depths in order to obtain some idea of their load bearing capacity.

A loading and pull out test was carried out on bored piles at Poona in March 1957 [3]. The black cotton soil on the site had an average liquid limit 85, a plastic limit of 28, a natural moisture content 33 and a shrinkage limit of 12. About twenty one piles were tested and it was observed that the frictional resistance offered by the piles as obtained from the pull out tests was about one third of the shear strength of the soil, and that the net point bearing capacity as obtained from loading tests after deducting the side friction was about nine times the shearing strength for straight piles of uniform diameter and about four times the shear strength for underreamed piles.

In order to confirm the above findings and to fill in certain gaps in previous testing records a second test was carried out at Jabalpur (Madhya Pradesh), in July, 1958. Twenty three circular concrete piles, 9 to 12 in. diameter and 6 to 12 ft. long, both straight of uniform diameter and under-reamed, were cast in-situ in February 1958. Fig. 1 shows the layout plan and details are given in Table 1.

The layout of the piles was so arranged that the piles which were first tested by pulling could later be made to act as anchors for loading tests on intermediate piles. Pile No. 2 was cast in such a manner that a gap of one foot was left below the pile bottom, and the process is described later. The loading test on this pile gave the value of frictional resistance in loading alone. Piles 22 and 23 were subjected to a long term loading test with the help of bricks piled up on a loading platform eight feet square. Pile 22 had an outer sleeve of galvanised iron pipe which eliminated skin friction and only point load was recorded. The datum pipe which served as a bench mark for recording settlements was anchored at a depth of 25 feet.

The soil samples for test were obtained close to the piles at the same time as the loading and pull out tests were undertaken (July 1958). Due to the monsoon the ground was soft at the surface but was fairly firm below.

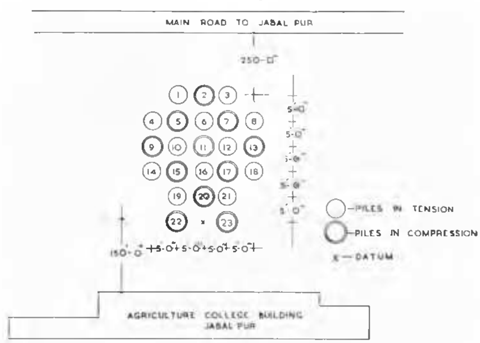

Fig. 1 Layout plan of piles.
Disposition de pieux.

Soil properties

The soil profile at the site showed clay of high compressibility down to a depth of 25 feet. Down to 13 feet it was black and then it turned yellow. Laboratory tests were carried out on soil samples from three boreholes, for consistency limits (Table 2). The average values were, liquid limit 55, plastic limit 15, shrinkage limit 12 and natural moisture content 19. Water table was struck at a depth of 15 feet and it usually went down to about 30 feet in summer.

Table 1

Pile No.	*Diameter of stem* (in.)	*Length* (feet)	*Diameter of under-reamed portion* (in.)	*Nature of test T-Tension, C-Compression*
1	9	6	—	T
*2	9	6	—	C
3	12	6	—	T
4	12	6	—	T
5	12	6	—	C
6	9	6¼	21½	T
7	12	12¼	—	C
8	12	12	—	T
9	9	6	—	T
10	9	12	22	T
11	12	12	30	C
12	12	12	30	T
13	9	12	—	C
14	9	6⅛	—	T
15	9	12	22	C
16	12	6	30	T
17	12	6	30	C
18	9	12	—	T
*19	12	6	28	T
20	9	6	22	C
*21	9¾	6	22	T
*22	9	12	30	C
*23	12	12	30	C

* Pile 2 had one foot air space below the bottom.
* Piles 19 and 21 had concrete in the under-reamed portion of the pile only.
* Piles 22 and 23 were subjected to long term loading test and pile 23 had outer sleeve to eliminate side friction.

Table 2

Depth (ft.)	3	6	9	12
Liquid Limit	54	58	61	50
Plastic Limit	16	16	15	14
Plasticity Index	38	42	46	36
Shrinkage Limit	12	12	12	10
Natural Moisture	19	20	19	19
Percent fines (silt+clay)	84	87	87	82

Shear strength of the soil

Unconfined compressive strength was determined from undisturbed soil samples from various depths and shearing strength was assumed to be half this value (Table 3).

Table 3

Depth (ft.)	*Moisture Content* (per cent)	*Dry Density* (lbs/cu.ft.)	*U.C.S.* (lbs/in.^{2})	*Shear strength* (tons/ft.^{2})
3	19·8	105	31	1·00
6	19·9	104	45	1·45
9	23·2	99	34	1·10
12	19·8	108	56	1·80

Shear strength increases uniformly with depth and has an average value of 1·34 tons sq. ft. The low value at 9 feet may be due to the fact that the borehole was sunk to 8 feet on the first day; it was wet and was left overnight. Water appears to have entered through vertical cracks which appeared after removal of the overburden, softening the next layer on the following day when the sample was obtained for testing.

Fig. 2 Under-reamed pile.
Pieux à bulbe.

A field vane 1 ½ in. dia. was also used to determine the shearing strength and results are shown in Table 4. Experience proved that this instrument was very useful for determining the in-situ shear strength of black cotton soil [4].

Table 4

Vane Shear Test

$$C = \frac{PR}{4\pi r^2 (h + 2/3\ r)}$$

(height of vane (h) = 3·0 in.; radius of vane (r) = 1·0 in.; radius of disc (R) = 10 in.)

Depth D (ft.)	*Load on Spring balance P* (lb)	*Torque PR* 2 (in. lb)	$2\pi\ ^2 (h + 2/3\ r)$	*Shear Strength*	
				C lb per sq. in.	tons per sq. ft.
3	52	260	23·0	11·3	0·74
6½	96	480	23·0	20·8	1·34
9¾	118	590	23·0	25·6	1·65
12	131	655	23·0	28·5	1·84

According to the field vane test shear strength increases uniformly with depth with an average value of 1·4 tons per sq. ft. The values are close to half the unconfined compressive strengths.

Setting down the piles

Straight holes were bored with spiral augers of 9 and 12 in. diameter because these were found to work better than the posthole or the plate type augers in clays. For under-reamed piles the base was enlarged by a portable under-reaming tool operated by hand (Fig. 3). The steel reinforcement cage was next lowered into the hole and 1 : 2 : 4 concrete poured in. The pile top was covered by wet soil and cured for a week.

In pile No. 2, a 9 in. diameter hole was first bored down to 7 feet. A $\frac{1}{4}$ in. thick steel plate of equal diameter was next lowered to a depth of 6 feet and held in position by a $\frac{1}{2}$ in. steel rod. The concrete was then poured into the hole and the steel rod released. Thus a one foot gap was secured below the pile bottom for testing the frictional resistance of the pile under load.

Fig. 3 Portable under-reamer.
Dispositif portatif pour réduire le bulbe.

In pile No. 22, a 12 in. diameter bore was sunk down to 12 feet and the base was enlarged to 30 in. diameter. Concrete was poured into the enlarged portion and a 9 in. diameter galvanised iron sheet pipe was lowered to act as a mould for the pile shaft. Concrete was next poured into this pipe. Another galvanised iron casing pipe 11 in. dia. was then slipped on the stem to serve as a sleeve and eliminate side friction. Since the pile was subjected to a long term loading test it prevented the sides from collapsing.

For pile Nos. 19 and 21 concrete was poured in the under-reamed portion only and steel bars were suitably anchored in the concrete and carried up to the ground level for testing only the anchorage value of these piles.

Testing of all the piles was carried out 3 months after casting the piles.

Pull out test

The equipment used for the pull out test consisted of a 30 ton hydraulic jack with pressure gauge and a suitable reaction frame of steel (Fig. 4). Movement of the piles was recorded on two dial gauges fixed to a horizontal bar lying across the pile and resting on fixed supports. The jack rested on a steel joist which in turn rested on two firm supports. Since the test was carried out during the monsoon the ground was soft at the surface. Bricks were first spread out and wooden sleepers laid over them to act as supports for the

Fig. 4 Pull out test assembly.
Essais d'arrachage.

concrete block which acted as the bearing for the steel joists. The load was applied in increments of 2 000 lb and failure was assumed to have taken place when there was a progressive movement of the pile. The results are shown in Tables 5 (a), 5 (b) and 5(c).

Table 5 (a)

Pull out test on straight piles

Pile No.	*Diameter* D (in.)	*Length* H (ft.)	*Pull* (tons)	*Resistance* (tons/ft)	*Resistance* (tons/ft.^{2})
14	9	$6\frac{1}{8}$	5·8	0·95	0·40
18	9	12	10·6	0·89	0·38
3	12	6	7·2	1·20	0·38
8	12	12	19·6	1·63	0·52
					Average 0·42

Tests on straight piles (Table 5 (a)) show an average frictional resistance of 0·42 tons per sq. ft. This is 30 per cent of the average shear strength of the soil as determined by the unconfined compression and vane shear tests.

Tests on under-reamed piles (Table 5 (b)) show an average anchorage force of 5·1 tons and 11·3 tons for 22 in. and 30 in. under-reaming respectively. This has been confirmed by pulling out under-reamed portion of the pile only (Table 5 (c)) which show a value of 6·5 and 9·4 tons respectively. The latter value is for 28 in. diameter reamed portion.

The values of the anchorage are close to those obtained by multiplying the shear strength of the soil by the curved surface area of the under-reamed portion (Table 5 (d)).

Table 5 (b)

Pull out test on under-reamed piles

Pile No.	*Diameter D* (in.)	*Length H* (ft.)	*Under-reamed diameter (Du)* (in.)	*Pull* (tons)	*Length of straight portion* (ft.)	*Curved surface of straight* (ft.²)	*Skin friction* (ton/ft.²)	*Total frictional resistance* (tons)	*Anchorage* (tons) (5∼9)
1	2	3	4	5	6	7	8	9	10
6	9	6¼	12⅛	8·9	5·00	11·8	0·42	5·0	3·9
16	12	6	30	16·1	4·75	14·9	0·42	6·3	9·8
10	9	12	22	16·9	10·75	25·2	0·42	10·6	6·3
12	12	12	30	26·8	10·75	33·6	0·42	14.1	12·7

Table 5 (c)

Pull out test on under-reamed portion only

Pile No.	*Upper diameter D* (in.)	*Depth H* (ft.)	*Under-reamed diameter (Du)* (in.)	*Pull* (tons)	*Length of straight portion (bucket)* (ft.)	*Curved surface of straight portion* (ft.²)	*Frictional resistance* (ton/ft.²)	*Total frictional resistance* (tons)	*Anchorage* (tons) (5∼9)
1	2	3	4	5	6	7	8	9	10
21	9¾	6	22	7·6	1·0	2·6	0·42	1·1	6·5
19	12	6	28	10·7	1·0	3·1	0·42	1·3	9·4

Table 5 (d)

Pile No.	*Upper dia.* (in.)	*Height* (in.)	*Lower dia.* (in.)	*Curved surface* (ft.²)	*Soil shearing strength* (tons/ft.²)	*Resistance or anchorage* (ton)
21	9·75	15	22	5·60	1·40	7·80
19	12	15	28	7·40	1·40	10·40

Fig. 5 Loading test assembly.
Essais de chargement.

Loading tests

The equipment for loading tests consisted of a heavy mild steel joist supported on and bolted down to anchor piles on each side. The hydraulic jack rested on the test piles and obtained its reaction from the joist above (Fig. 5). Additional soil anchors were used in case the anchor piles alone were not adequate. Load was applied in increments of 2 000 lb with a 30-ton jack for piles taking up to 20 tons, and in increments of 2½ tons, with a 50 ton jack for piles taking more than 20 tons. The settlement was read on dial gauges as in case of pull-out tests. Ultimate load was assumed to have been reached when progressive settlement of the pile started. The point load corresponding to each stage of settlement was worked out after deducting the frictional load (assuming 0·42 tons per sq. ft. to be the value of the skin friction), and a load settlement curve was plotted (Figs. 6 and 7).

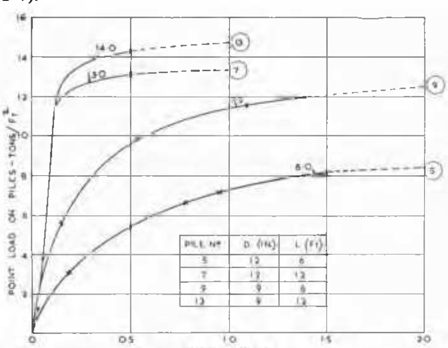

Fig. 6 Loading test on straight piles.
Essais de chargement sur pieux droits.

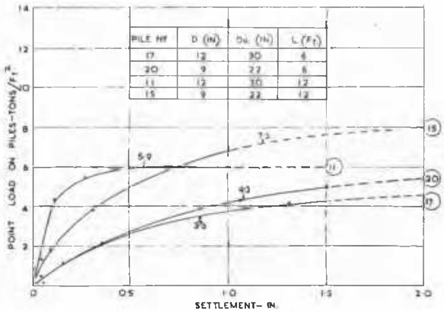

Fig. 7 Loading tests on under-reamed piles.
Essais de chargement sur pieux à bulbe.

It is not easy to pinpoint the value of the ultimate point load and this is assumed to be at the point when the curve finally rises at a uniform slope. The values are recorded in Table 6 (a).

Table 6 (a)

Loading tests on piles

Pile No.	*Dia. of stem* (in.)	*Dia. of base* (in.)	*Length* (ft)	*Ultimate point resistance* (tons/ft.²)	*Shearing strength of soil* (tons/ft.²)	*Bearing Capacity factor* (5/6)
1	2	3	4	5	6	7
			Straight piles			
9	9	—	6	11·5	1·40	8·2*
5	12	—	6	8·0	1·40	5·7
13	9	—	12	14·0	1·80	7·8
7	12	—	12¼	13·0	1·80	7·2
			Under-reamed piles			
20	9	22	6	4·3	1·40	3·1
17	12	30	6	3·6	1·40	2·6
15	9	22	12	7·6	1·80	4·2
11	12	30	12	5·9	1·80	3·3

* Pile went slightly out of plumb while casting.

The loading test on straight pile No. 2 which had an air gap of one foot below its base gave a value of 0·30 tons per sq. ft. as skin friction under load.

For straight piles, except for pile No. 5 which shows a low value, an average bearing capacity equal to 8 times the shear strength of the soil is indicated. For under-reamed piles, however, the value falls considerably and an average value of 3·3 times the shear strength is obtained. It has conformed to the earlier experience at Poona where a value of 4c was obtained. The reason for this exceptional drop is not clear. The possibility of the diameter of the enlarged base being less than estimated was ruled out by pulling out a few piles and measuring their base diameters.

Tests on straight pile No. 2 with an air gap below the base indicate a value of 0·39 tons per sq. ft. for skin friction which is nearly the same as for pulling. This proves that the frictional resistance in pulling and pushing has the same value.

Long term loading tests

Long term loading tests were carried on piles 22 and 23, both being under-reamed piles 12 ft. long and having a base diameter of 30 inches. In pile 22 the shaft was only 9 in. diameter and had an outer sleeve to eliminate the influence of skin friction. The loading platform on each pile was of reinforced concrete and weighed about 4 tons. There was no settlement under the weight of this platform. After an interval of three months (July 1958) pile 22 was loaded with an additional 7 tons and pile 23 with 11 tons weight. Settlement at the end of Dec. 1958 (after an interval of 6 months) was ¼ in. in each of the two piles.

A further load of 7 tons was then added (in all 18 tons on pile 22 and 22 tons on pile 23) and up to April 1960 (an interval of 2 years) there has been no further settlement.

Conclusions

1. The frictional resistance offered by the pile in pulling and pushing has nearly the same value and is about one third the average shear strength of the soil. This reduction does not appear to be due to the softening of the clay alone as the piles were tested after a period of three months.

2. The ultimate point bearing capacity of the straight pile upto 12 in. diameter is 8 times the shearing strength of the clay at the point of bearing. This value decreases to almost half for under-reamed piles of base diameter 22 to 30 inches and under-reaming ratio about 2·5. The reason for this marked drop is not clear. It cannot be attributed entirely to the softening of the clay from water in the wet concrete.

3. The anchorage offered by the under-reamed piles is close to a value obtained by multiplying the shear strength of the soil with the area of the curved surface of the enlarged portion which is a frustum of a cone.

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References

[1] Dinesh Mohan (1957). Consolidation and Strength characteristics of Indian Black Cotton Soils. *Proc. 4th Int. Conf. Soil Mech. and Found. Eng.*, London, *1*, 74.

[2] — and Jain, G. S. (1958). Under-reamed pile foundations in black cotton soils. Design and constructional aspects. *Ind. Conc. Jr.*, *32* (6), 203-7.

[3] — — (1958). Pile loading and pull out tests in black cotton soils. *Jr. Inst. Eng.* (India), pt. 1, *38* (5), 409-21.

[4] — — (1957). Field vane shear test in black cotton soil. *Civil Engineering and Public Works review*, London, *52* (618), 1 387.