Pile testing using raked under-reamed piles

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A SIMPLE set-up for conducting high capacity pile load tests, using raker under-reamed piles as anchors, is described. The technique requires little space and eliminates the need for heavy joists and kentledge in addition to giving safety benefits and effecting savings in cost and time. The Paper also highlights the load-carrying capacity of multi-under-reamed piles in compression and as anchors.

Introduction

Carrying capacities of piles are best determined by pile load tests that require the use of hydraulic jacks and heavy joists, suitably anchored. Large amounts of kentledge are also needed sometimes or, if this is to be eliminated, the provision of adequate anchorage. Single or multi-under-reamed piles, which have been successfully used as foundations for various structures including towers, have been used as anchors.

This Paper presents a typical set-up for conducting a pile load test employing two-bulbed under-reamed piles cast at a batter to serve as anchors. The observed ultimate uplift capacity of the reaction arrangement is compared with computed values. Carrying capacity of the multi-under-reamed test pile in compression is also discussed.

Test set-up

The set-up was first used in the campus of a college in Indore (Fig 1). It consisted of a loading frame provided with universal joint seatings for each anchor bolt, extension rods, packing column, couplers and turnbuckles (Figs. 2 & 3).

The frame, designed to carry a load of 400 tons, was made of two circular steel plates welded centrally on each end of a 100mm diameter steel bar. Fins were provided between the plates for further stiffening. In the upper plate twelve 55mm dia. holes were made, inclined at 30° to the vertical, to hold the anchor bolts extending from the anchor piles. The anchor bolts, threaded at both ends, were 50mm dia. and 3.5m long. A square plate was screwed at the lower end of each anchor bolt for obtaining reaction from the base.

The assembly

Anchor bolts, well greased and wrapped in hessian cloth, were lowered into each of the inclined bore holes and concreting was carried out after positioning the bolts in the centre of the inclined holes. A slight rotational movement was

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concrete was still green; this helped in their retrieval after completion of the test.

Between the hydraulic jack and the loading frame, a stiff packing column was introduced. Two 25mm thick steel plates, each 37.5cm dia. were welded one on each end of this column to obtain an increased support area.

The anchor bolts protruding from the inclined piles were connected with the loading frame using extension rods, couplers and turnbuckles. Universal joint seatings facilitated easy connections between the anchor bolts and the loading frame and proved helpful in making slight adjustment while assembling the set-up (Fig. 3).

Datum bar supports

Datum bar supports consisted of steel tubes, with cones at their ends, each driven separately into boreholes of 15cm dia. and 8m deep arranged in a triangular pattern. These tubes were driven into a hard stratum met at 10m. Sleeves were provided on the outside of each tube so as to prevent any disturbance to the datum support from ground movement.

A 500ton hydraulic jack was used for applying loads on the test pile and incremental loading was adopted. Settlement observations were recorded using three dial gauges each of 0.02mm sensitivity positioned symmetrically on the pile top.

Soil strata

The soil at the test site comprised a medium to stiff black clay having an undrained cohesion varying from 0.9 to 1.45kg/cm², liquid limit from 55 to 70% and a plasticity index from 35 to 50%. The variations of natural moisture content, Atterberg limits, bulk densities, Standard Penetration test values, undrained cohesion etc. are shown in Fig. 4. The ground water table was met at about 12m depth.

Anchor piles

The specifications of each of the twelve anchor piles used in the testing arrangement were: length, 3.5m; rake, 30°; diameter, 30cm; number of bulbs, 2; bulb diameter, 75cm. Fig. 5 shows the construction of a typical anchor pile in progress and Fig. 3 illustrates a sectional view of the pile load test set-up.

Safe uplift capacity of the anchor piles was worked out to be 15tons each (factor of safety 2) in accordance with IS:2911, Part III (Table I), which is based on a very large number of field pile load tests.

The capacity of the anchor piles was also checked by using static formula:

$$Q_u = A_a N_c C_u' + C_u' A_s' + \alpha C_a A_s \quad \ldots (1)$$

where Q_u = Ultimate bearing capacity of the pile,

A_a = $\pi/4$ $(D_u^2 - D^2)$, where D_u and D are under-reamed bulb and the stem diameter respectively,

N_c = Bearing capacity factor usually taken as 9

C_u' = Average undrained cohesion of soil around the under-reamed bulbs taken as 0.875kg/cm²

A_s' = Surface area of the cylinder circumscribing the under-reams,

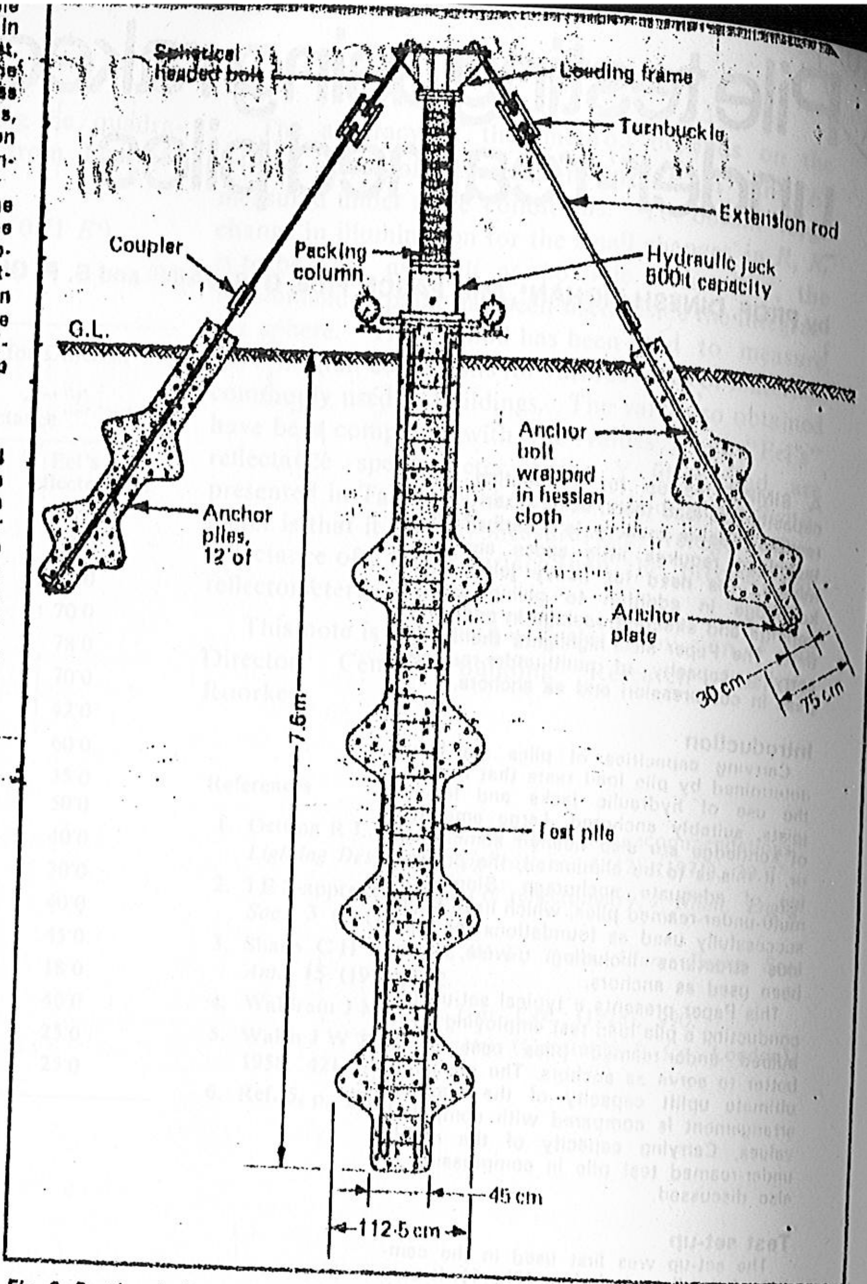

Fig. 3. Sectional view of the pile load test set-up

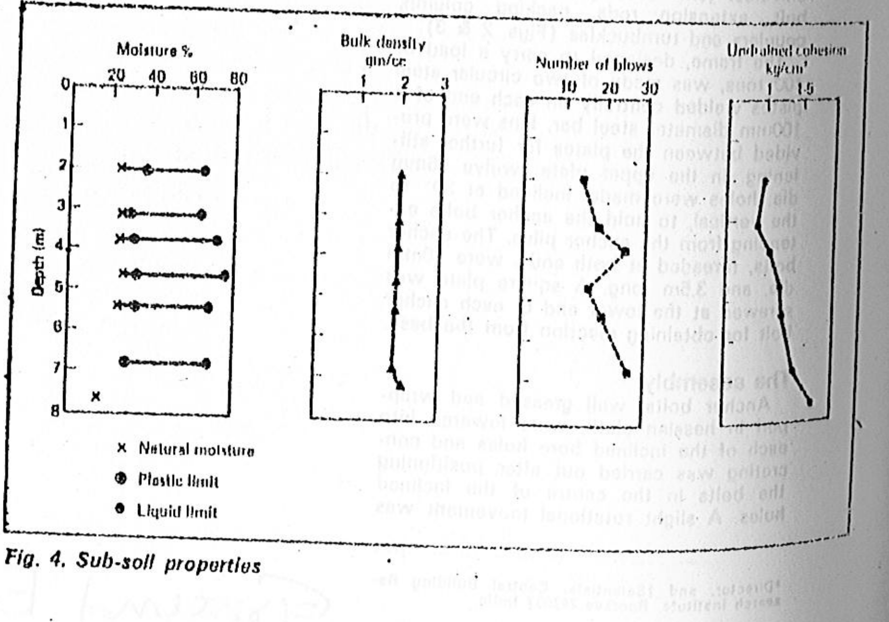

Fig. 4. Sub-soil properties

TABLE I. SAFE LOAD FOR VERTICAL UNDER-REAMED PILES IN SANDY AND CLAYEY SOILS INCLUDING BLACK COTTON SOILS

Dia. of pile	Under-reamed dia.	No. of bars	Dia.	Ring spacing of 6mm dia. rings	Single under-reamed	Double under-reamed	Increase per 30cm length	Decrease per 30cm length	Single under-reamed	Double under-reamed	Increase per 30cm length	Decrease per 30cm length	Single under-reamed	Double under-reamed
		REINFORCEMENT: Longitudinal reinforcement			SAFE LOADS: Bearing resistance				Uplift resistance				Lateral thrust	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
cm	cm		mm	cm	t	t	t	t	t	t	t	t	t	t
20	50	3	10	18	8	12	0.9	0.7	4	6	0.65	0.55	1.0	1.2
25	62.5	4	10	22	12	18	1.15	0.9	6	9	0.85	0.70	1.5	1.8
30	75	4	12	25	16	24	1.4	1.1	8	12	1.05	0.85	2.0	2.4
37.5	94	5	12	30	24	36	1.8	1.4	12	18	1.35	1.10	3.0	3.6
40	100	6	12	30	28	42	1.9	1.5	14	21	1.45	1.15	3.4	4.0
45	112.5	7	12	30	35	52.5	2.15	1.7	17.5	25.75	1.60	1.30	4.0	4.8
50	125	9	12	30	42	63	2.4	1.9	21	31.5	1.80	1.45	4.5	5.4

Notes

1 The safe loads given in Table I apply to both medium compact sandy soils and clayey soils of medium consistency. For dense sandy ($N > 30$) and stiff clayey ($N > 8$) soils, the loads may be increased by 25%. However, the values of lateral thrust should not be increased unless stability of the top soil (strata to a depth of about 3 times the stem diameter) is ascertained. On the other hand a 25% reduction should be made in the case of loose sandy ($N < 10$) and soft clayey ($N < 4$) soils [For determining the average N values (the standard penetration test values) a weighted average shall be taken and correction for fineness under water shall be applied where applicable].

2 Longitudinal bars should normally be provided with a clear cover of 4cm and may be curtailed or eliminated towards the toe depending upon the stresses in pile section.

3 For under-reamed piles subjected to a pull and/or lateral thrust the requisite amount of steel should be provided.

4 Values given in cols. *14* and *15* for lateral thrusts may not be reduced for changes in pile lengths and are fairly conservative. Higher values may be adopted after conducting lateral load tests on single or groups of piles.

5 In 25 and 30cm dia. normal under-reamed piles when the concreting is done by tremie, equivalent reinforcement in the shape of single angle iron piece placed centrally may be used.

6 When a pile designed for a certain safe load is found to be just short of the load required to be carried by it, an overload of 10% should be allowed on it.

7 For working out the safe load for a group of piles the safe load of individual piles is multiplied by the number of piles in the group. This would be applicable for piles taking lateral thrusts also.

8 Only 75% of the above safe loads should be taken for piles in which the boreholes are full of sub-soil water during concreting. When water is confined to the bucket portion only, no such reduction need be made. For bored compaction piles safe loads up to 85% of the values given in the table may be taken before applying a multiplying factor of 1.5.

9 In sandy soils when boring and under-reaming under water the minimum size of pile recommended is 25cm.

10 In multi-under-reamed piles the depth of the centre of upper bulb below ground level shall be kept a minimum of two times the diameter of the under-ream bulb.

11 The values given should be increased by 50% for a broken wire condition in the design of transmission line tower footings.

12 Safe loads for multi-under-reamed piles may be worked out from the table by allowing 50% of the loads as per col. 6 for each additional bulb. Increase in capacity due to increase in length will be as per col. 8.

13 For taking very high loads, the pile shaft above the topmost under-ream should be either increased in diameter and/or additional reinforcement provided as in the short column design technique.

14 The values of bearing resistance, uplift resistance and lateral thrust given in the table are for a minimum pile length of 3.5m except in double under-reamed piles. In double under-reamed piles the minimum recommended lengths for 37.5cm, 40cm and 50cm piles will normally be 3.75m, 4.0m, 4.5m and 5.0m respectively so as to suitably accommodate the bulbs at specified distances.

α = Reduction factor usually taken as 0.5,

C_u = Average cohesion of the soil along the pile stem

A_s = surface area of the stem,

$$Q_u = \pi/4(75^2-30^2) \times 9 \times 0.875 + 0.075 \times \pi/4 \times 75 \times 112.5 + 0.5 \times 0.875 \times \pi/4 \times 30^2 \times 1.7$$
$$= 35 \text{ tons}$$

Applying a factor of safety of 2.5, the safe uplift resistance works out to 14tons which is in fair agreement with the values recommended in the Indian Standards.

The ultimate uplift capacity of all the twelve anchor pile works out to be 360 tons according to the IS Code and 420tons according to the static formula. The anchor piles, however, started yielding at 300tons. The difference in predicted and the observed uplift capacity may be attributed to the closer spacing of the piles.

Test pile

The test pile was 7.6m long, 45cm dia., four-bulb multi-under-reamed pile with 112.5cm dia. bulbs. Load carrying capacity [illegible] under-reamed test pile [illegible] was also calculated using the following static formula:

$$Q_u = A_p N_c C_p + A_a N_c C_a' + C_a' A_s' + \alpha C_a' A_s \quad \ldots(2)$$

where A_p = Cross-sectional area of the pile stem at its toe,

C_p = Cohesion of the soil around the toe.

Other notations have the same significance as the symbols for eqn. *1*.

$$Q_u = \pi/4 \times 45^2 \times 9 \times 1.45 + \pi/4(112.5^2-45^2) \times 9 \times 1.45 + 1.23 \times \pi \times 112.5 \times 450 + 0.5 \times 0.875 \times 45 \times 200$$
$$= 328 \text{tons}$$

The load-settlement curve of the test pile is shown in Fig. 6. The pile could only be tested up to 300 tons and did not reach its ultimate due to yielding of the anchor piles.

Discussion and concluding remarks

The pile load test set-up described is [illegible] to assemble and has many [illegible] It also eliminates handling of large kentledge and heavy frame work.

The system as a whole is robust and tidy. It is safe against toppling due to eccentricity and load deflection readings can be taken from any convenient distance.

The entire test set-up could be covered by a temporary shed or hut to provide protection against bad weather during testing. Use of small datum bars is an additional advantage.

The set-up described in this Paper behaved extremely well on test loads up to 300tons. A slight eccentricity, noticed on one occasion, was corrected by adjusting the turnbuckles.

Load carrying capacity of double under-reamed piles in uplift obtained from the Indian Standard 2911 (Part III) 1973 provided reasonably close agreement with the pile capacities worked out from the soil properties.

Single or multi-under-reamed piles, vertical or raked, can be effectively used as anchors as well as for carrying vertical loads. The assembly can be easily dismantled and reused for any number of [illegible]

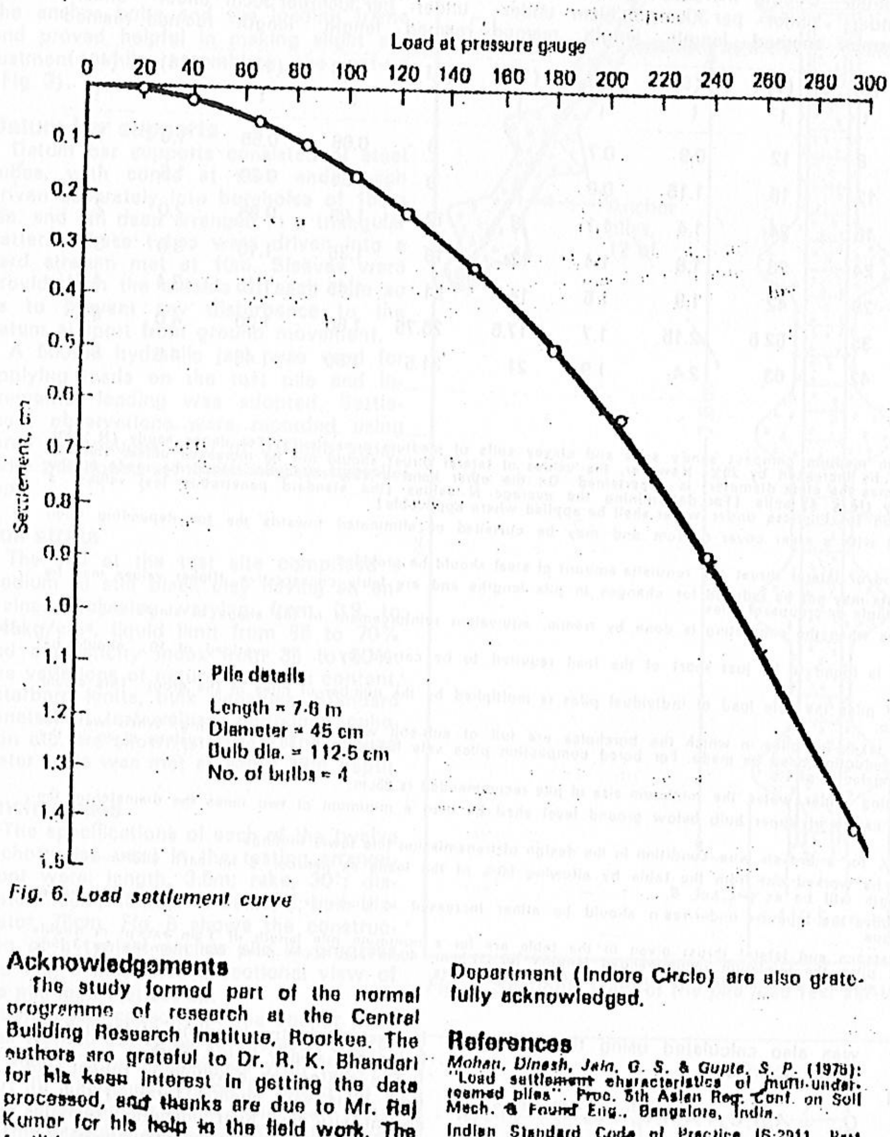

Fig. 6. Load settlement curve

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Indian Standard Code of Practice IS:2911, Part III, 1973 Design and construction of under-reamed pile foundations.