# Cast in Situ Driven Piles Through Deep Soft Clay at Visakhapatnam

*by*

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## Introduction

The civil engineers are compiling and analysing the driving and load test records since over a century. The evaluation of bearing capacity of pile is still one of the most controversial subjects in foundation engineering. As far back as in 1755, John Muller wrote :

> "As the foundations of all buildings in general are of the utmost importance, in respect of the strength and duration of the work, we shall enter into all the most material particulars, which may happen in different soils, in order to execute works with all the security possible, because many great buildings have been rent to pieces, and some have fallen down, for want of having taken proper care in laying the foundations."

On this approach the authors have conducted their study to evaluate the reliability of driven piles passing through deep, highly compressible strata in the area of Naval Project, Visakhapatnam. The study has been made on driven cast-in-situ concrete piles which range in length from 25 m to 32 m. In majority of the cases, 70 to 90% of the shaft length is embedded in soft clay whose N-value is less than 2.

No data is available about the behaviour of such piles when loaded to failure. It will not be an exaggeration to say that no where in India, driven piles of this length passing through deep layer of soft clay have been built and load-tested to destruction/failure.

## Geology of the Area

The site of Naval Project, Visakhapatnam is in the central sector of Eastern Ghat Ranges in Peninsular India. It is essentially covered by Khondolites. The basement rock has suffered extensive weathering which is overlain by a zone containing both residual products and transported materials which in turn is overlain by recent marine deposits. The marine deposits consists of fine grained sand, silt and clay, micro shell fragments. This is overlain by dredged material containing fine sand, silt and clay. From the bore-logs, the subsoil stratums in the order of their occurrence, and their average properties are given in Table I. From this Table it may

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TABLE I

Average Properties of the Stratas

| | Stratum Description | L.L % | P.L % | Natural moisture content | C kg/cm² | N Value | $\phi$ | Bulk density | Specific Gravity | Thickness |
|---|---|---|---|---|---|---|---|---|---|---|
| I | Fine sand, silt and clay | 8.) | 25 | 24 | 0.15 to 0.28 | 2 to 7 | 26° to 30° | 1.61 T/m³ | 2.59 | Nil to 9.5 m. generally 2m. |
| II | Soft to very soft clay | 80 to 100 | 41 | 85 | 0.14 | 0 to 2 | 0 | 1.44 | 2.55 | 5 to 25 m. generally. 15 to 20 m. |
| III | Stiff to very stiff silty/sandy clay | 50 | 20 | 35 | 0.8 | 21 | 0 | 1.82 | 2.69 | Nil to 16. 5 m. generally 5 m. |
| IV | Dense sand mixed with pebbles, weathered rock pieces, and conglomerate pieces | Non-plastic | — | 17 | — | 30 to 50 (30 av) | 30° | 2.2 T/m³ | 2.69 | Nil to 13 m. generally 2 to 4 m. |
| V | Weathered rock and basement rock | — | — | — | — | — | — | 2.3 T/m³ | 2.9 | Weathered rock varies from Nil to 8 m. |

be noticed that stratum II forms the predominant and important deposit of the area. The water table is struck at about 1.5 m below the general ground level.

### Type of piles studied

Cast-in-situ, reinforced concrete, driven piles of 45 and 50 cm diameter, Simplex type, have been used for the foundations of ship-building workshop structures at Naval Project Visakhapatnam.

The size of these structures can be assessed from the column loads which on the average work out to 300t, 100 tm and 20t, as vertical load, moment and the horizontal thrust respectively. The pile is formed by driving steel tube with detachable double rimmed cast-iron shoe. The driving is continued till a 'set' of 6 mm for ten blows is achieved. The steel tube is extracted after the concrete is cast. The capacity of 45 cm and 50 cm dia pile, constructed as stated above, is given by the firm as 60 tons and 90 tons respectively.

Driving and load test records of five tests piles and the driving record of an adjacent pile to the test pile have been analysed by several methods.

### Estimation of capacity of driven piles

*Estimation of capacity by dynamic formulae*

Much emphasis has been placed on dynamic formulae (Tschebotariff 1951 & IS Code 1964) to predict the bearing capacity of driven piles. The bearing power is estimated from the energy required to drive it; the penetration per blow can be used as a measures of the load carrying capacity. The particulars of the pile driver used for the construction of piles are given in Table II.

**TABLE II**

**Particulars of the Pile Drivers**

| Date | 45 cm dia | 50 cm dia |
|---|---|---|
| Weight of hammer (W) | 2.5 tons | 3.5 tons |
| Weight of mandrel (M) | 6.3 ,, | 6.95 ,, |
| Fall of hammer (H) | 1 m | 1 m |
| Length of mandrel (including follower) | 32.5 m | 32.35 m |

The driving records of the test piles (TP) are tabulated below :—

| Description | TP 1 | TP 2 | TP 3 | TP 4 | TP 5 | TP 6 |
|---|---|---|---|---|---|---|
| Nos of blows (B) | 1172 | 799 | 919 | 1174 | 1051 | 1226 |
| Length of pile (L) (metres) | 31.4 | 29.566 | 30.7 | 29.566 | 29.87 | 27.43 |

The capacities are worked out by Engineering News formula, Hiley formula (IS Code, 1964) and Simplex formula (1970) and are given in Table III. To arrive at the safe capacities, factor of safety 3 has been adopted.

TABLE III

**Safe capacities by Dynamic Formulae**

| Formula Used | Safe Capacity (P) | | Remarks |
|---|---|---|---|
| | 45 cm dia piles | 50 cm dia piles | |
| ENGINEERING NEWS FORMULA $P = \frac{32\,WH}{s+2.5}\left(1 - \frac{M}{10\,W}\right)$ | 23.4t | 35t | The capacities are worked out without neglecting the resistence offered by the compressible soil. It is not possible to work out the part energy absorbed by this strata. |
| HILEY FORMULA $P = 1/3\ \frac{w\,h\,n}{s+c/2}$ | 41.6t | 57.3t | |
| SIMPLEX FORMULA (1970) $P = \frac{B}{3\,L}\ \frac{2.5\,WH}{s+2.5}\sqrt{\frac{L}{15.24}}$ | TP1=43.3t; TP4=63.0t<br>TP2=30.5t; TP5=68.0t<br>TP3=34.0t; TP6=56.3t | | |

Where s = set per blow in cm; c = the sum of temporary elastic compression in cm of pile, dolly and ground etc; h = height of free fall of hammer in cm = 0.8 H in case of winch operated drop hammer; n = efficiency of the blow; B = Total number of blows; L = Length of pile in metres; rest of the symbols as given in Table II.

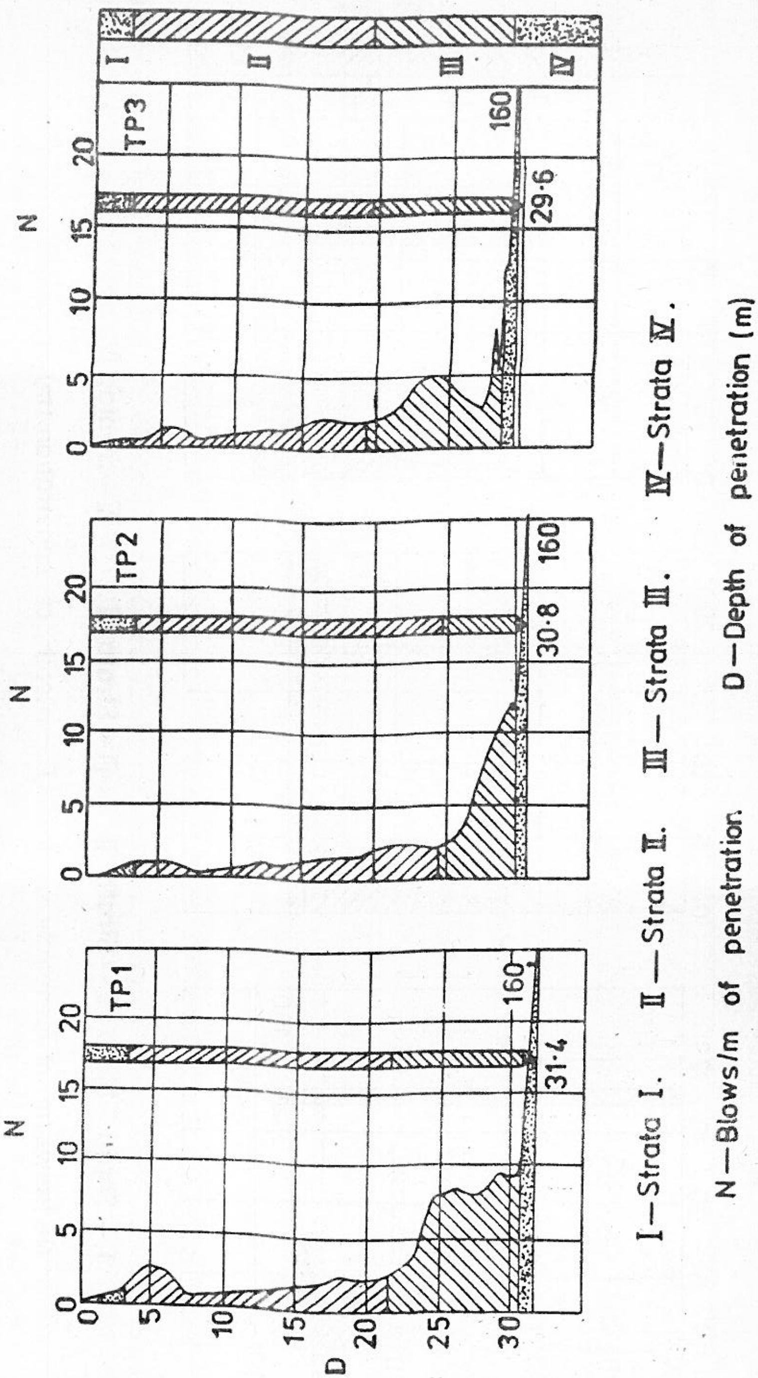
**Estimation of Capacity by Method of Soil Mechanics**

The figures 1 and 2 tell the entire story of penetration effort required to drive these piles to the desired set. The superposition of these over the bore-logs indicate the strata through which the piles are passing, and over which they are founded. From the penetration effort, it may be inferred that the piles are founded in strata IV and the maximum penetration in the founding strata is 0.5 to 2.0 m.

The major length of the pile is in the strata II which is very sensitive and a considerable drop in its shear strength is observed while driving the piles.

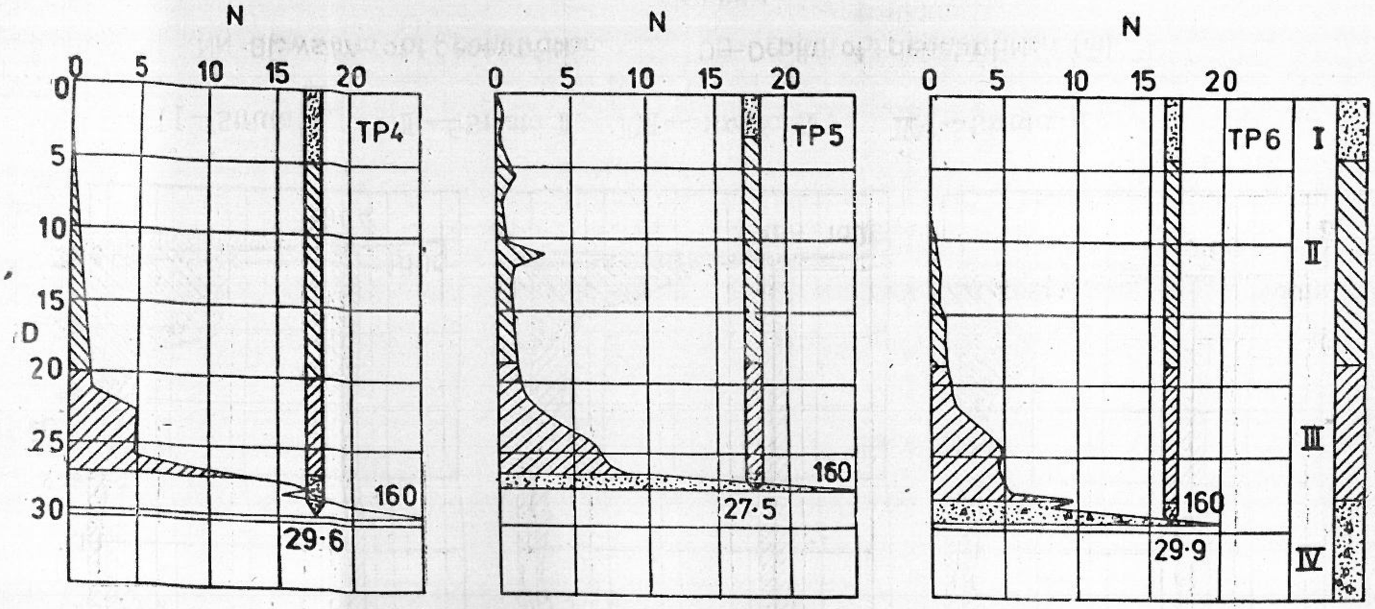
It may be of interest to note that the depth and characteristics of the soft clay under consideration are similar to that reported by Golder (1957) for a site in British Guiana. Golder pointed out that such soft clays suffer a great drop in their shear strength while driving the piles and there is no further regain in the strength.

In the light of this also, field experiments have been carried out and Golder's contention is not found to be correct. Full regain in shear strength has been observed after about four weeks.



TP1
TP2
TP3
N
D
0
5
10
15
20
25
30
31·4
30·8
29·6
160
I
II
III
IV
I—Strata I. II — Strata II. III — Strata III. IV—Strata IV.
N—Blows/m of penetration. D —Depth of penetration (m)


FIGURE 1.




I.— Strata I. II – Strata II. III – Strata III. IV – Strata IV

N—Blows/m of penetration. D—Depth of penetration (m).

FIGURE 2.

The ultimate capacity of the pile is taken as per Tomlinson (1969):

$$Q_u = Q_s + Q_b$$
$$= \int \alpha\ s\ c\ A_s + \int k_s\ p_d\ A_s\ \tan\delta + A_b\ p_d\ N_q$$

Where : $Q_b$=Ultimate bearing resistance, $Q_s$=ultimate frictional resistance; $\alpha$=adhesion factor for clay; $s$=shape factor; $c$=average undisturbed shear strength of clay adjacent to shaft; $A_s$=surface of shaft; $p_d$=effective overburden pressure at pile base; $\delta$=angle of wall friction; $k_s$=Rankines co-efficient of active pressure; $N_q$=bearing capacity factor depending upon the $\phi$ value; $A_b$=area of cross-section of pile.

To evaluate the capacities of the test piles the length of different stratas around the piles have been taken as shown in figures 1 and 2 and the properties of the soil have been taken as per Table I.

The capacity of each pile has been worked out for two different cases. In the first case the friction offered by the compressible strata (upto the top of strata III) is not ignored, therefore, the results obtained should be comparable to those obtained by Dynamic formulae. In the second case the friction offered by the strata upto the bottom of strata II is ignored because it is likely to be converted to drag after some time. This should give the realistic capacity as per IS : 2911 (Pt I)—1964. A factor of safety 3 for point bearing and 2.5 for skin friction has been adopted to arrive at safe capacities. The results of computations are presented in Table IV.

TABLE IV

Safe Capacities

| Test pile | $Q_s$ (Tons) | $Q_b$ (Tons) | $Q_u$ (Tons) | *Safe Capacity* Case I | Case II |
|---|---|---|---|---|---|
| 1 | 112.44 | 62 | 174.44 | 65.7 | 48.76 |
| 2 | 85.01 | 62 | 147.01 | 54.7 | 35.4 |
| 3 | 104.87 | 62 | 166.87 | 62.7 | 45.73 |
| 4 | 109.6 | 77.5 | 187.1 | 69.67 | 50.87 |
| 5 | 93.97 | 77.5 | 171.47 | 63.4 | 44.63 |
| 6 | 112.94 | 77.5 | 189.54 | 70.65 | 51.84 |

### Estimation of Capacity by Load Tests

Five load tests on cast-in-situ driven test piles, three of 45 cm dia and two of 50 cm dia have been conducted as per IS : 2911 (Pt I)—1964.

*Test Pile 1 (45 cm dia)*

The pile is load tested upto one and a half times the anticipated safe capacity. The load vs gross and net settlement observations are plotted in Figure 3.

The anticipated capacity of this pile as sixty tons is verified from this test. However, what would be the actual capacity of the pile, deducting the positive friction offered by the compressible strata (liable to consolidate) at the time of load-test, cannot be evaluated. For that end in view this test has very limited or no meaning for a foundation designer.

*Test Pile 2 (45 cm dia)*

This pile has been load tested upto two times the anticipated safe capacity as advocated by several authors. The conduct of the test is the same as for the 'Initial Test (IS Code, 1964)'. The load vs settlement observations are in Figure 3.

The behaviour of this pile is similar to that of Tp 1. It may be observed that the settlements are of very small order upto a load of 90 to 100 tons and with further increase in load the settlements shoot up largely. As per the criteria of 6 mm net settlement and 12 mm gross settlement the apparent safe capacity of the pile can be said to be 76 tons because the magnitude of positive friction offered by the compressible strata is not deducted from it. This load-test suffers from similar drawbacks as the preceding test, hence it is of no significant use for a foundation designer.

*Test Pile 3 (45 cm dia)*

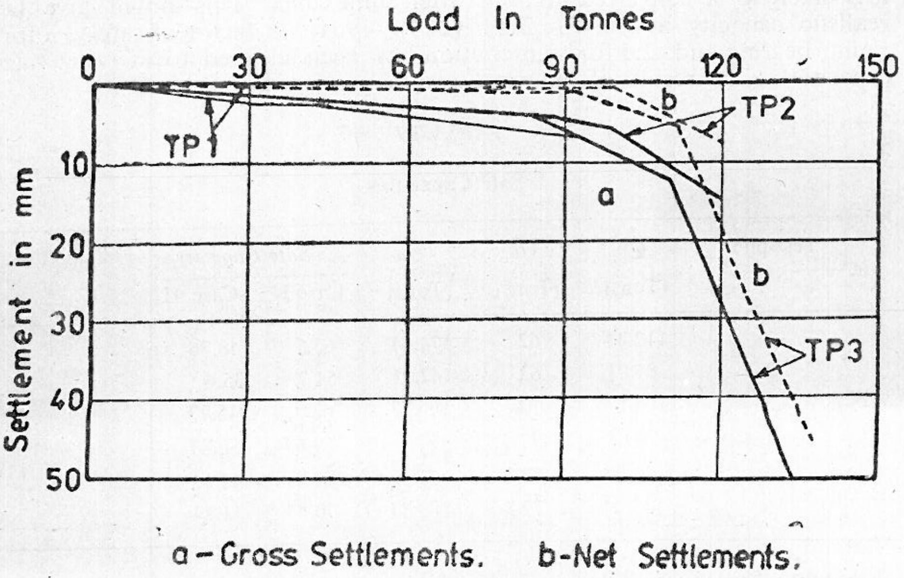



FIGURE 3.

The test pile is cyclic load-tested till failure, the criteria being to load till the settlement of the pile top equals one-tenth of the dia of pile stem. The load vs settlement observations are plotted in figure 3. The pile has behaved similar to the first two test piles upto the loads to which those were tested. The interesting point to observe is the behaviour of this pile between 100 and 140 tons of load. There is practically no sign of distress to the pile upto about 100 tons of load but after that the settlements increase rapidly.

From this test it is possible to separate the skin friction and point bearing. From the load-settlement plot the failure is observed to have taken place at 132 tons. By the method of iteration as suggested in the IS-Code (1964) ultimate skin friction and the point-bearing work out to 90 and 42 tons respectively. The safe capacities of this pile worked out by different criterias are tabulated in Table V.

This load test gives the desired information to the foundation designer.

*Test Pile 4 (50 cm dia)*

This pile is cyclic load-tested till failure similar to test pile 3. The load vs settlement observations are plotted in Figure 4. It may be observed that the criteria of 6 mm net and 12 mm gross settlement errs on the wrong side. Instead of taking safe load as two-third of the load at these settlements it should be taken as three-fifth of the load at these settlements.

*Test Pile 5 (50 cm dia)*

Similar to the test piles 3 and 4, this pile is also cyclic-load-tested till failure. The load vs settlement observations are plotted in Figure 4.

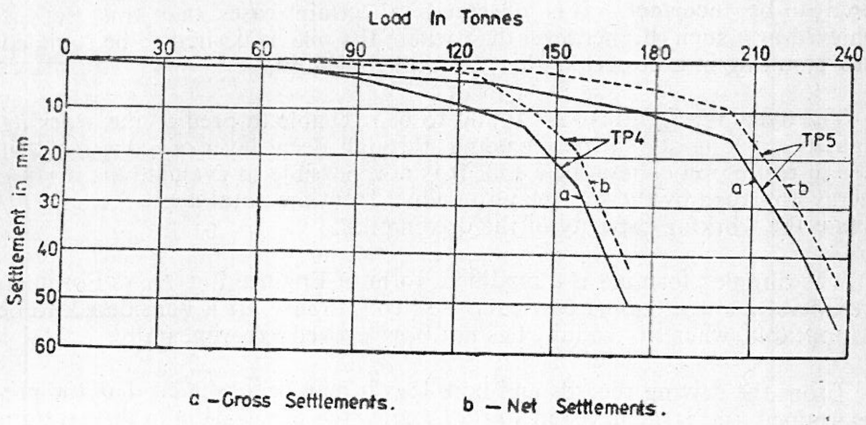



FIGURE 4.

This pile is though driven in close proximity to Tp 4 and cast under the similar conditions has failed at a relatively higher load. This may be attributed to the probability of the pile toe resting on a better founding strata. The uncertainity of the pile resting on the desired founding strata is one of the major drawbacks of the driven piles. The safe capacities worked out by different criterias are tabulated in Table V.

**Discussions**

Piles driven through soft clay to reach hard strata, hardly need any driving effort; even with the increase in depth the driving effort remains the same till harder strata is struck.

The soft clay of Visakhapatnam is similar to that of British Guiana. It is sensitive, and considerable drop in its shear strength is observed while driving the piles. Full regain in shear strength has been observed after about

TABLE V

**Safe capacities of Load Tested Piles by various criteria**

| Criteria | Safe Capacity (Tons) TP 3 | TP 4 | TP 5 | Remarks |
|---|---|---|---|---|
| 6 mm net settelment | 74 | 88 | 120 | Capacity is worked out without neglecting the positive friction offered by compressible strata at the time of load-test. |
| 12 mm gross settlement | 73 | 99.6 | 118 | —do— |
| Cyclic load test | 61.8 | 81.6 | 112.8 | —do— |
| Cyclic load test | 40.8 | 58.1 | 89.3 | Capacity is worked out deducting the friction offered by compressible strata from the ultimate friction. |

four weeks of disturbance; this is contrary to Golder's (1957) observations.

The termination of driving effort in the case of long piles driven through deep layer of cohesive soil, on reaching the pre-determined 'set', is considered to be incorrect. It is observed in certain cases that this 'set' is achieved at a such higher level than where the pile is desired to be founded thus resulting in excessive settlements under such piles.

The dynamic formulae are found to be irreliable to predict the working capacity of long driven pile passing through deep layer of cohesive soil though resting on cohesionless soil. It is not possible to evaluate the driving energy absorbed by the soft clay to deduct from the total applied energy to obtain the working capacity of the driven piles.

The Simplex formula is a modified form of Engineering News Formula, presumably to suit some particular soil conditions. It is considered to be inapplicable, where its validity has not been proved experimentally.

From the driving records and bore logs it may be observed that the predetermined 'set' is achieved in strata IV and the penetration in this strata is of the order of half a metre to two metres approximately. The founding could be on Strata V in certain cases if strata IV is absent, however, this cannot be saidiwith certainity in case of driven piles. If the depth of Strata III is large in some cases, the possibility of the pile achieving the 'set' in Strata III cannot be ruled out. The evaluation of pile capacity on the theory of Soil Mechanics is very much susceptible to the bearing capacity of the founding strata.

It is observed that if soil properties are well understood in their original and remoulded state, the pile capacity on the basis of theory of Soil Mechanics can be computed with reasonable accuracy for practical purposes.

The settlements, when loaded upto 1.5 to 2 times the safe loads, are observed to be of very small magnitude which may lead to deceptive estimation of working capacity of pile.

The conventional method of load tests, i.e. upto 1.5 to 2 times the safe capacity serve no purpose for long piles passing through deep compressible strata. Small increments of load within the range of two to three times the safe capacity have shown large plastic settlements. The requirement to extend load during the load test such that to cause yield point should be inlcuded in future revision of codes and specifications.

The estimation of safe capacity on the basis of 6 mm net or 12 mm gross settlement as per IS : 2911 (Pt I)—1964 is observed to err on the wrong side. The multiplying factor of 2/3 is recommended to be changed to 3/5.

To separate the point bearing from skin friction, the two methods available are 'Cyclic Load Test' and 'Tell-tale device'. The cyclic-load test is widely accepted and inexpensive.

Though cyclic-load test is the recognised test to separate skin friction and point bearing, its validity for long piles is doubtful. The author is conducting some field tests to ascertain the same.

There is a lot of ambiguity in working out the magnitude of drag and the code is silent on it. Different authors have different opinions on this subject, as such there is a lot of scope of research in this field. Till such time any detailed treatment for this can be defined it is recommended that its magnitude may be taken as $A_s \times c$ (where $A_s$=surface area of the shaft embedded in compressible soil and $C$=average undisturbed shear strength of the soil).

It is considered that the friction piles are not suitable in areas laid with deep layer of soft sensitive clays. The future loading on these soils cause extensive amount of drag which must be taken into account while designing the piles.

It is very expensive to carry out sufficient number of load tests to reduce the acceptable risk. It would, therefore, be desirable to have built-in factor of safety in working out the loads on piles.

For piles designed to carry heavy working loads, factor of safety 2 to 2.5 is not considered adequate, particularly where the load is expected to reach the founding strata. A factor of safety 3 for point bearing, and 2.5 for skin friction is recommended.

**Conclusions**

The conventional methods of one and one-half to two times safe capacity load tests on piles driven through deep compressible strata yield no purposeful results. The requirement to extend load tests sufficient enough to reach yield points shall be included in the future revision of codes and specifications.

The estimation of safe capacity on the basis of 6 mm net or 12 mm gross settlement as per IS 2911 (Pt I)—1964 is observed to err on wrong side. The multiplying factor 2/3 is recommended to be changed to 3/5.

The termination of driving effort on the basis of pre-determined 'set' can lead to serious difficulties in case of long piles. Driven piles are not recommended to be used in deep, soft sensitive clays as the magnitude of drag exceed the capacity of the pile.

To reduce the acceptable risk, statistically a large number of load tests are required which involve prohibitive cost. It would be desirable to have built in factor of safety in working out either the loads on the piles or the capacity of the piles. When the pile is designed to carry heavy working loads, and the loads are expected to reach the founding strata, a factor of safety 3 for point bearing and 2.5 for skin friction is recommended.

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