Prediction of Load Bearing Capacity of a Bored Pile During Its Construction

by

S.K. Naithani*

Introduction

Routine load test (IS.-2911) is specified for assessing the load carrying capacity of a working pile. The method of testing is quite expensive and time consuming, therefore an extremely small percentage of working piles are tested. Further there is no way of increasing the load carrying capacity of the pile, if it is found that the pile capacity is less than specified. Therefore there is a need to develop a method of assessing the pile capacity before it is cast so that any adjustment in the capacity can be made during its boring. Such methods already exist for driven piles wherein pile capacities can be determined by field measurement of energy required for driving. No such method has been reported for bored piles.

In this paper the author has attempted to develop an expression for determining the load carrying capacity of bored piles in terms of the rate of penetration of a DMC chisel and an index called chisel constant. A brief description of the equipment used in boring and its operation is explained in Appendix A. It can be seen from the same that the rate of penetration of the chisel mainly depends upon the shear properties of soil or rock. The method explained in this paper will be useful in a large piling project.

Determination of Chisel Constant

Before the construction of working piles commences, erect two piles for each size of DMC chisel. Record the rate of penetration of DMC chisel for each pile bore @ every 30 minutes of boring till the founding level is reached. The founding level may be pre-determined on the basis of sub-soil investigation carried out in the area or decided on the basis of a *minimum penetration resistance*. The author has observed that a chisel of 1000 kg having a drop of 70 cm @ 1100 drops per hour gives a rate of penetration of 0.20 to 0.25 meter per hour in a rock of crushing strength 500 kg/cm^2 (Quartzite and hard charnokite).

Four weeks after the casting of the piles, subject them to cyclic load test till failure. The cyclic load test results may be analysed by Naithani's method (Alam Singh, 1981) which is incidentally the only method at present to determine the contribution of different layers of soils in a stratified deposits towards mobilization of skin resistance. A brief description of the same is given in appendix B. Calculate the unit skin resistance

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* SO I Dry Dock, Office of the Chief Engineer, Dry Dock and Visakhapatnam zone, Visakhapatnam-530008, India.

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offered by different sub-soil layers and determine the chisel constant for the particular chisel as the ratio of unit skin resistance and rate of penetration. In a multilayer system different values of chisel constant may be calculated for different layers of soil. Thus the chisel constant for layer '*n*' can be expressed as :

$$C_n = \frac{P_n}{H_n\, r_n}$$

Experimental Investigations

Two piles were chosen for study, one was 430 mm in diameter and the other 500 mm diameter. They were constructed by bentonite displacement method, using a 1000 Kg DMC chisel with a drop of 70 cm @ 1100 drops per hour. The rate of penetration of the chisel was recorded in each pile bore @ every 30 minutes, till founding level was reached, One pile was founded on dense sand when the rate of penetration of the chisel was 0.10 meter per hour, thinking that hard rock was reached, while the other pile was founded on hard rock which was existing below the sand layer. At this stage the rate of penetration of the chisel was 0.25 meter per hour. The existance of hard rock was confirmed by taking bailor samples. The average rate of penetration recorded for different layers of soil for each bore are given in Table I.

TABLE 1

Rate of Penetration of Chisel

Sl. No.	Description of Strata	Rate of penetration (meter/hr)	
		430 mm dia pile	500 mm dia pile
1.	Moorum or fine sand	0.92	1.66
2.	Soft Clay	13.11	7.78
3.	Stiff Clay	1.65	1.54
4.	Conglomerate	0.28	0.33
5.	Dense Sand	0.11	0.10
6.	Rock	0.25	—

Both the piles were subjected to cyclic load test four weeks after casting till failure. The test results are given in Table 2. The load test results were analysed by Naithani's method for calculating skin friction offered by different soil layers to each pile. The load on pile top vs. elastic rebound of pile top, curves are given in Fig. 1. The pile bore logs are given in Fig. 2. Chisel constants for different layers have been calculated in Table 3.

TABLE 2

Load Test Record for Piles

Sl. No.	430 mm dia pile				500 mm dia pile			
	Load on pile top (tonne)	Gross settle-ment (mm)	Net settle-ment (mm)	Elastic reco-very (mm)	Load on pile top (tonne)	Gross settle-ment (mm)	Net settle-ment (mm)	Elastic recovery (mm)
1	2	3	4	5	6	7	8	9
1.	0	0.00	0.00	0.00	0	0.00	0.00	0.00
2.	38	0.81	0.00	0.81	29	0.36	0.01	0.35
3.	48	0.84	0.00	0.84	47	2.40	1.74	0.66
4.	68	1.55	0.00	1.55	66	3.65	2.35	1.30
5.	90	2.54	0.00	2.54	84	4.50	2.56	1.94
6.	114	3.31	0.00	3.31	102	4.93	2.63	2.30
7.	139	4.31	0.00	4.31	121	5.55	2.65	2.90
8.	152	4.94	0.00	4.94	139	6.28	2.68	3.60
9.	178	6.05	0.03	6.02	157	6,57	2.75	3.82
10.	191	7.07	0.12	6.95	175	6.86	2.75	4.11
11.	220	8.17	0.26	7.91	193	7.48	2.94	4.54
12.	235	8.98	0.31	8.67	211	7.82	3.03	4.79
13.	267	17.77	0 54	17.23	229	9.71	4.46	5.25
14.	283	18.62	0.64	17.98	248	12.98	7.25	5.73
15.					266	30.55	24.40	6.15
16.					284	68.85	61.15	7.70

Sub-Soil Profile at Test Site

The site where test piles were constructed was developed by reclamation of a tidal river bed with dredged material obtained during the deepening of the adjoining water area. The typical soil profile therefore consists of a layer of fine silty sand deposited over a thick layer of soft marine clay. The lower half of the soft marine clay is partly consolidated. Under the marine clay layer residual soil deposits formed by in-situ weathering of rock exist. These deposits consists of layers of yellow stiff clay, conglomerate, dense sand and weathered rock (khondolites) over fissured or jointed rock (Hard charnokites and quartzite). The characteristic properties of these layers are given in Table 4.

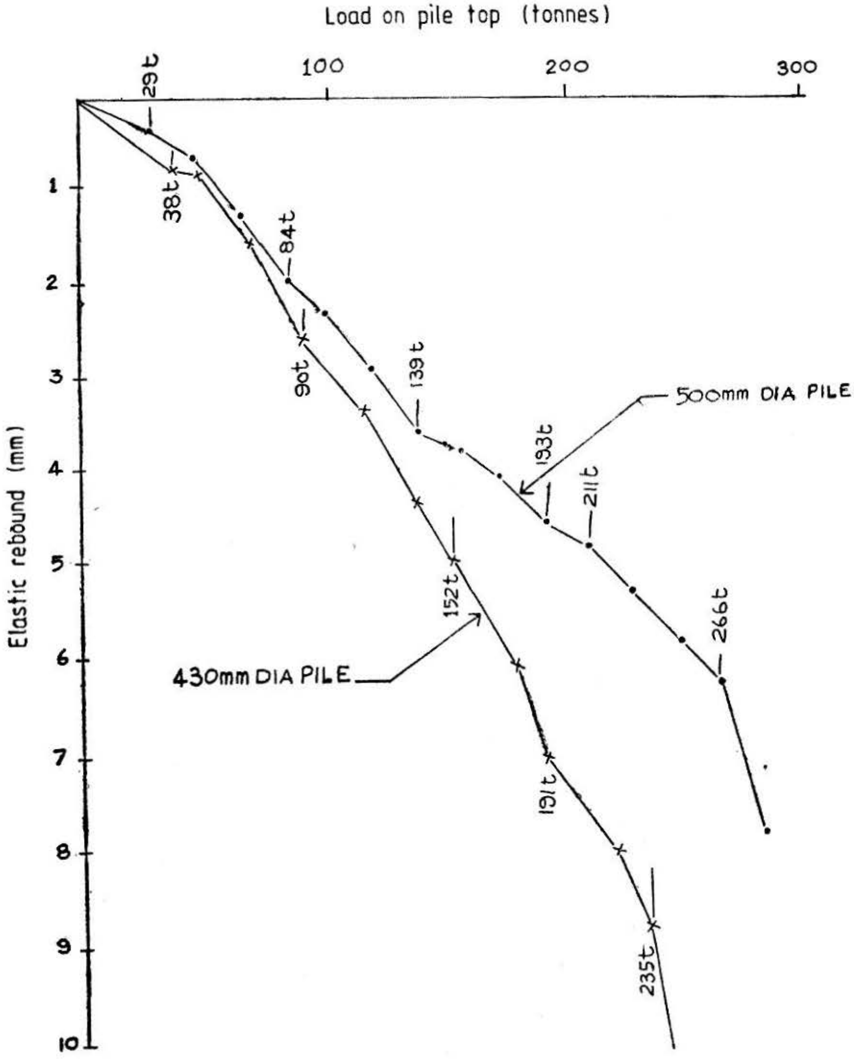

FIGURE 1 Separation of Skin Friction Offered by Different Layers

Observations and Discussion

It will be observed from Table 3 that the chisel constant follows a definite pattern having the least value in soft clay and the highest value in sand layer. In hard rock the value of chisel constant observed is about one fifth of that for sand. Although there is variation in the values of

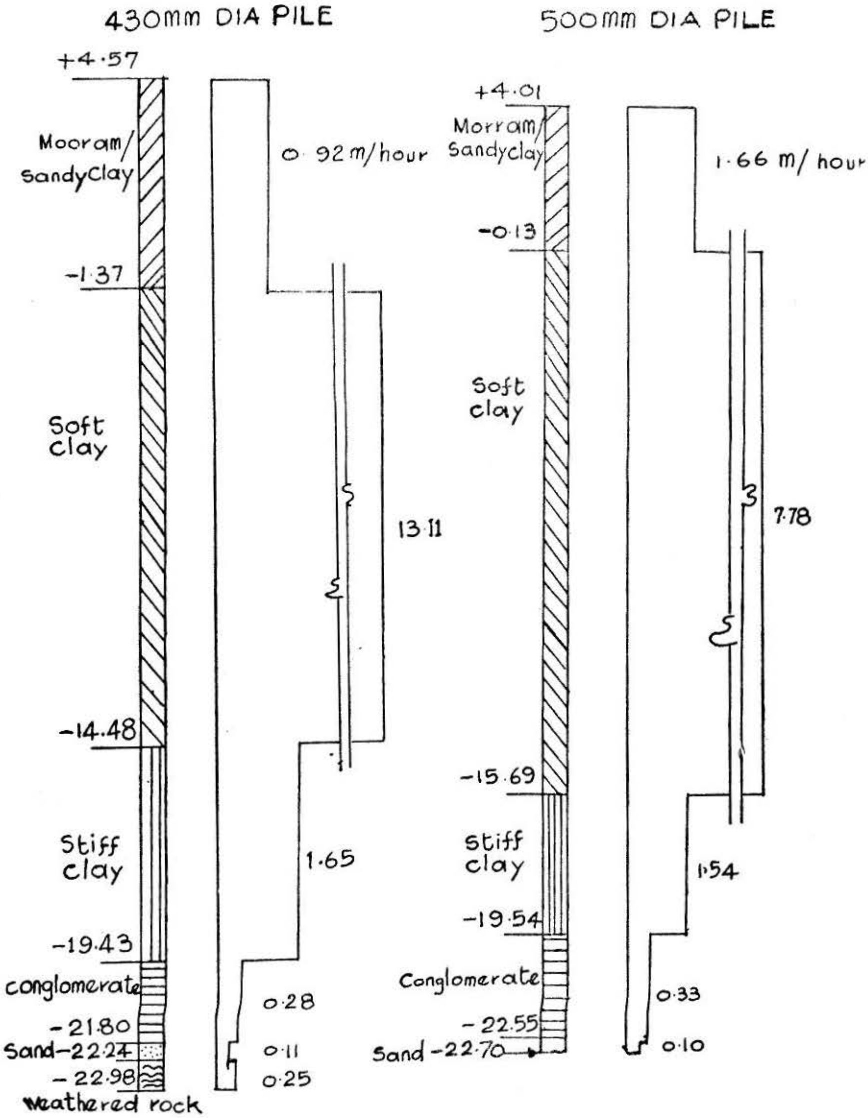

FIGURE 2 Pile Bores and Penetration Record of DMC Chisel

chisel constant obtained from the two test piles for the same soil strata, but there is a marked variation between chisel constants for different soil layers in each pile bore. Except for soft clay layer the chisel constants are seen to be quite consistent.

TABLE 3

Chisel Constant

Sl. No.	Description of Strata	430 mm dia pile					500 mm dia pile				
		Skin resistance (tonne)	Strata thickness (m)	Unit Skin resistance (ton/m)	Rate of penetration (m/hr)	C_n	Skin resistance (tonne)	Strata thickness (m)	Unit skin resistance (ton/m)	Rate of penetration (m/hr)	C_n
1.	Moorum or fine sand	38	6.94	5.28	0.92	6.0	29	4.70	6.17	1.66	3.72
2.	Soft clay	52	13.11	3.97	13.11	0.3	55	15.56	3.53	7.78	0.45
3.	Stiff clay	62	4.95	12.53	1.65	7.6	55	3.85	14.29	1.54	9.30
4.	Conglomerate	39	2.37	16.46	0.28	58.8	54	2.98	18.12	0.33	54.90
5.	Dense sand	44	0.44	100.00	0.11	909.0	18	0.20	90.00	0.10	900.00
6.	Rock	32	0.72	44.44	0.25	178.0	—	—	—	—	—

TABLE 4

Soil Properties

Sl. No.	Description of Strata	Soil properties			
		Dry density (ton/m³)	Bulk density (ton/m³)	Cohesion (kg/cm²)	Angle of friction (Degrees)
1.	Moorum or fine sand	1.78	2.10	0.00	31
2.	Soft clay	0.80	1.52	0.08	3
3.	Stiff clay	1.80	2.13	0.30	8
4.	Conglomerate	1.80	2.07	0.00	28
5.	Dense Sand	1.90	2.20	0.00	38
6.	Rock (Quartzite)	Average Crushing Strength 500 kg/cm² (Specific gravity 3.00)			

As explained in Appendix A the chisel constant should depend upon the shear characteristics of a soil layer, but the values observed for sand layer does not follow this logic. The most plausible explanation seems to be the reduction in rate of penetration of chisel due to sand flow into the pile bore, particularly where the sand strata is sloping towards the bore. Thus this constant can vary appreciably in sands.

There are a number of variables which effect the chisel constant viz., the shear properties of soil, weight, diameter, magnitude and frequency of drop for the chisel etc., Therefore no universal value can be suggested for the chisel constant but for a particular chisel and a particular soil strata the variation in chisel constant may not be appreciable. Hence for a particular site, chisel constants can be predetermined by carrying out some cyclic load tests and the values obtained may be used in assessing the load carrying capacity of the working piles.

The frictional resistance of the pile shaft can then be calculated from the following expression :

$$P_f = W \sum_{i=1}^{i=n} H_i \gamma_i C_i$$

Using the above formula the value of Pf should be calculated for each working pile as soon as the founding level is reached. If its value is found less than that obtained for test pile, the bore can be taken still deeper till the desired value of Pf is achieved. The average values recorded for chisel constant at test site are as follows :

Moorum or fine sand	5.0	tonne×hour/meter²
Soft Clay ($c \leqslant 0.1$ kg/cm²)	0.4	,,
Stiff Clay ($c \geqslant 0.3$ kg/cm²)	9.0	,,
Conglomerate	60.0	,,
Dense Sand	900.0	,,
Rock	180.0	,,

This method can be best explained by an example. In a bore for 430 mm dia working piles the following rates of penetration were recorded. Determine how much more boring may be done to achieve same skin resistance as for 430 mm dia test piles

Levels (m)		Thickness (m)	Rate of penetration (m/hr)
From	*To*		
+ 4.50	– 0.30	4.80	1.00
– 0.30	–14.50	14.20	11.50
–14.50	–16.30	1.80	1.50
–16.30	–18.25	1.95	0.30
–18.25	–20.25	2.00	0.25

The frictional resistance of the 430 mm dia test pile (reference Table 3) = 267 tonne

The frictional resistance of working pile

$$= (4.8\times1.0\times5.0)+(14.20\times11.5\times0.4)+(1.8\times1.5\times9.0)+(1.95\times0.3\times60)+(2.0\times0.25\times180)$$

$$= 24+65.32+24.3+35.1+90$$

$$= 238.72 \text{ tonne}$$

Additional capacity required $= 267-238.72$

$$= 28.28 \text{ MT}$$

$$= x\times0.25\times180$$

$$\therefore x = \frac{28}{45} = 0.62 \text{ m}$$

Take the pile 0.65 m deeper in the last layer.

Conclusion and Recommendations

A fairly good assessment of skin friction resistance of a bored pile can be made with the help of chisel constant and rate of penetration of the chisel observed in a particular pile bore.

This assessment will be much useful at sites where the sub-soil profile is variable, because the length of the pile can be varied while boring so that the skin frictional resistance remains unchanged. Otherwise it is practically impossible for the executive to decide how deep the pile should go whenever the bore log of a working pile is different than that of the test pile.

The recording of the rate of penetration of a DMC chisel is quite easy and does not involve any extra expenditure.

The present paper is based on the data obtained by testing two piles only. A series of tests are needed to arrive at a correlation between the chisel constant and the variables like shear parameters of soil and characteristics of chisel used.

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Notations

C_n Chisel constant for the layer n

H_n thickness of the layer n

P_f frictional resistance of pile shaft

P_n frictional resistance offered by layer n

r_n rate of penetration of DMC chisel in layer n

W weight of the chisel

APPENDIX A

Brief Description of the Boring Operation

The boring equipment essentially consists of a round steel chisel about a meter high and weighing between 500 to 1000 kg, hung from a tripod and connected to winch. By operating the winch the chisel can be raised or lowered. A fixed height of drop and a constant rate of fall of the chisel (number of hits per hour) can be maintained by this way. A vertical pipe passes concentrically through the chisel which is connected to the mud pump at one end and cutting edge of the chisel at the other end. The mud pump maintains a constant rate of flow of bentonite fluid through this pipe.

The fall of the chisel and jet of bentonite slurry cuts the soil or rock in small fragments which are lifted up by the upward current in the bentonite fluid contained in bore hole and deposited outside the bore hole. The rock fragments are obtained in the form of grit. The size of the grit depends upon the velocity of the upward current in the bentonite fluid. As the height of drop and rate of fall of the chisel is kept constant, the soil or rock strata receive energy from the chisel at a constant rate.

In case of granular soils this energy is used up mainly in over coming the penetration resistance offered by the soil to the chisel. This effect is