PILE LOAD CAPACITY FROM LOW STRAIN INTEGRITY TESTS

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ABSTRACT: The paper presents an approach to predict the load carrying capacity of piles from the non-destructive low-strain integrity test data. The data from low-strain integrity tests conducted on piles of different types, dimensions installed in variety of soil conditions is analyzed in both time and frequency domain to obtain the pile head stiffness. Simultaneously, the load - settlement response of piles is analyzed through a 3D FE model treating the pile as linear elastic and the elasto - plastic soil continuum is idealized by using a Drucker-Prager constitutive model. From the load - settlement curves, a relationship coefficient, defined as the ratio of failure load to initial stiffness of piles is estimated. For prediction of load capacity of piles, the head stiffness of piles from integrity tests could be taken same as that of the initial stiffness from load - settlement curves. The load capacities of piles predicted from the present methodology vis-à-vis those observed in pile-load tests from a few published works are found to be in good agreement.

1. INTRODUCTION

The evaluation of characteristics of service piles with super structure already atop is not a simple and feasible task. But, it is essential to assess the same to review the overall safety and service life of the pile-supported structures. Thus, it is becoming a pressing concern as in many cases; there are no information/records available regarding the soundness, quality and load carrying capacity of service piles. The load carrying capacity of piles is evaluated by conventional methods such as static formulae, dynamic formulae, field load tests etc. The static formulae always provide conservative estimates as the values of parameters in the formulae are assigned empirically. Dynamic formulae are based on the assumption that the total downward energy is consumed by the work done in penetrating the pile. The main objection is the uncertainty about the correlation between the dynamic and static resistances of soil. Also these static and dynamic formulae do not yield load – settlement response along the depth of pile. In view of these facts, the pile capacity computed by these formulae can deviate as much as 100% from that assessed from the field load test data. Thus, an appropriate methodology could be based on non-destructive testing techniques. Of late, with the advent of non-destructive testing methods in piling (Seitz, 1992), it is now possible to check the soundness, quality and dimensions of the piles through low strain integrity tests and determine the load carrying capacity by high strain dynamic testing or kinetic/statnamic testing (Holeyman, 1992). A few attempts have also been initiated to assess load carrying capacity of free headed piles using initial head stiffness obtained by low strain vibration testing (Shisheng, 1988 and Shisheng et. al. 1992). The present paper discusses a simple methodology to predict the load carrying capacity of piles using low strain integrity test data by making correlations between the initial stiffness obtained from frequency domain spectra and that from the conventional load - settlement response profiles of piles.

2. LOW STRAIN INTEGRITY TESTING

Low strain integrity tests are conducted by either in time domain or in frequency domain depending on the specific application. In time domain reflectometry, the wave is generated by a small hand held hammer blow impact and the response as a function of time is picked up by an accelerometer, placed on pile head/ shaft, close to the location of hammer blow. Monitoring and analysis of these reflections form the basis of integrity testing. After integration and converting the monitored signals, the pile particle velocity traces are available along the pile length. For obtaining frequency domain data, the test (Fig. 1) is conducted by using an instrumented hammer for giving impact such that force of impact is also measured.

Fig.1. Low strain integrity test set-up

The measured force multiplied by mechanical admittance of pile provides the velocity. This test provides initial pile stiffness under an extremely small dynamic load, which can be taken equivalent to initial static stiffness, as shown in Fig.2.

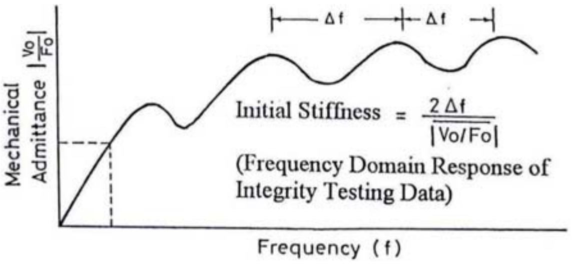


Fig.2. Frequency domain reflectometry of integrity test data

3. 3D FE MODEL

Pile-soil interaction analysis has been performed to predict the load-settlement response by using a three dimensional finite element program. In the analysis, solid 8-noded brick elements have been used to model both pile and soil medium. The pile has been treated as a linear elastic material and the soil has been idealized as a non-linear/elasto-plastic material based on Drucker-Prager constitutive model. The yield surface for this model has the form,

$$\mathbf{F} = \alpha \mathbf{J}_1 + \sqrt{\mathbf{J}_{2d}} - \mathbf{k} \qquad \dots\dots\dots\dots \quad (1)$$

where, J_1 is the first invariant of the stress tensor, J_{2d} is the second invariant of the deviatric stress tensor and α, k are the material constants expressed in terms of the well-known shear strength parameters of soil viz. c and ϕ. The schematic of 3-dimensional finite element mesh used for the analysis is shown in Fig.3.

The finite element analysis has been performed in two stages. In the first stage, the self-weight analysis of the soil has been performed with a Poisson's ratio equal to $K_o/(1+K_o)$ in which K_o is the lateral earth pressure coefficient at-rest. During this stage, both the pile and soil elements have been assigned the same material properties (Young's modulus, Poisson's ratio and unit weight) so as not to generate any extraneous shear stresses. All the nodal deformations and strains in the elements are set to zero at the end of this stage of analysis. During the second stage of analysis, the relevant properties for pile and soil have been assigned to the corresponding elements. In this stage, the external loads are applied in small increments consisting of several load steps with a maximum of 50 iterations. The iterations have been continued at each load step until the norms of out-of-balance force and incremental displacements decrease to less than 0.5% or until 50 iterations completed.

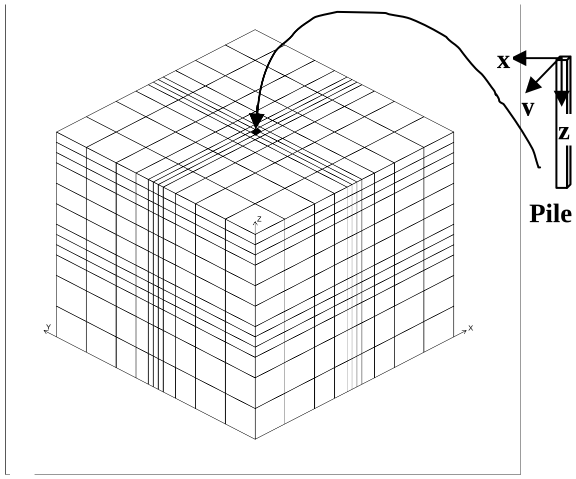
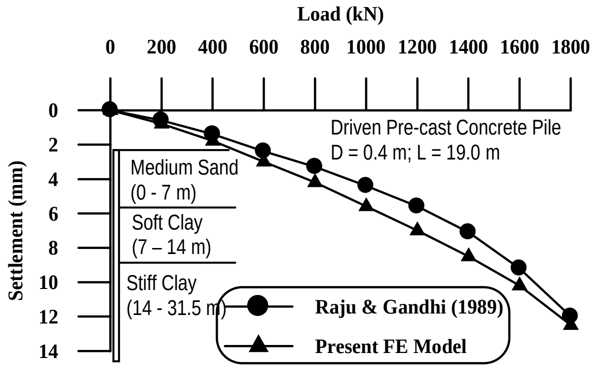
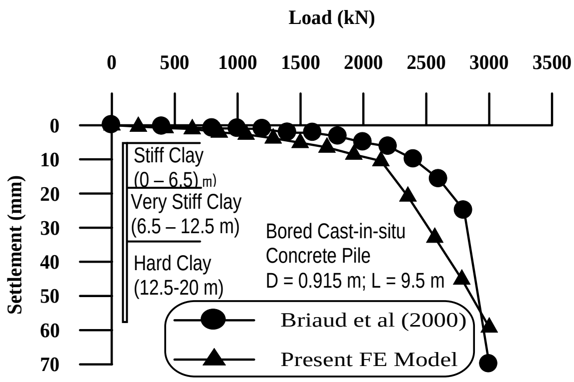


Fig.3. 3D Finite element mesh discretization of Pile-Soil system

The efficacy of the finite element model program has been verified against good number of load-settlement response curves of field load tests and typical comparison against two published works of Raju & Gandhi (1989) and Briaud et al. (2000) is presented in Figs. 4(a) and 4(b) respectively.



(a) Raju & Gandhi (1989)



(b) Briaud et al. (2000)

Fig. 4 Verification of the model against the Published works

4. METHODOLGY

The proposed methodology to predict the pile load capacity involves the following steps:

(i) Prediction of load-settlement (L~s) response of piles by considering the variations in pile type, dimensions and the soil strata.
(ii) Establishing a relationship (K_r) between initial stiffness (slope of initial portion of L~s curve) and the load corresponding to a specified ment from L~s curves.

$$\mathbf{K_r} = \frac{\text{Load corresponding to specified displacement level } (P_u)}{\text{Initial stiffness } (K_i)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \; (2)$$

(iii) Evaluation of initial stiffness $(k_i)_{int}$ from frequency domain spectra of low strain integrity test data for a few piles.
(iv) Using the relationship (K_r) and initial stiffness $(k_i)_{int}$ the load carrying capacity of piles is estimated using the equation:

$$\mathbf{P} = [\mathbf{K_r}].[\mathbf{k_i}]_{int} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \; (3)$$

4.1 Parametric Study for K_r

The relationship, K_r depends on the parameters, viz., diameter and length of pile as well as on type of soil strata. Accordingly, the following ranges have been considered in the analysis:

- Pile diameter :300mm - 1200mm
- Pile length :10m, 15m, 20m and 25m
- Soil strata: Uniform clay, Uniform sand and layered soil

The loads corresponding to specified displacement level (P_u), initial stiffness (k_i) and the relationship (K_r) have been obtained for different diameters and lengths of piles. In general, the K_r values increased with diameter upto pile lengths of 20m and in case of L = 25m, K_r values decreased with pile diameter upto 600mm dia. and became almost constant for larger diameters. The trends are almost same irrespective of soil strata condition. Accordingly a regression analysis has been carried out by incorporating the influence of all the three parameters and the following equation could be arrived at : $K_r = A + B.(D) + C.(D)^2$ ……… (4)

(Where, *A, B, C are the regression coefficients presented as functions of length of pile and type of soil strata as given in Fig.4 and D is the diameter of pile in mm*).

4.2 Load Carrying Capacity of Piles

The low-strain integrity test data of seven piles as presented in Table 1 has been analysed in frequency domain to obtain the head stiffness, $(k_i)_{int}$ of the piles. Then, the load carrying capacity is predicted using the eq. (3) above. The procedure is further illustrated through Table 1. The failure loads as observed from published reports are also presented in the same table. Though the predicted values are slightly on the lower side, there is a fairly reasonable agreement between the predicted and observed capacities are seen from table.

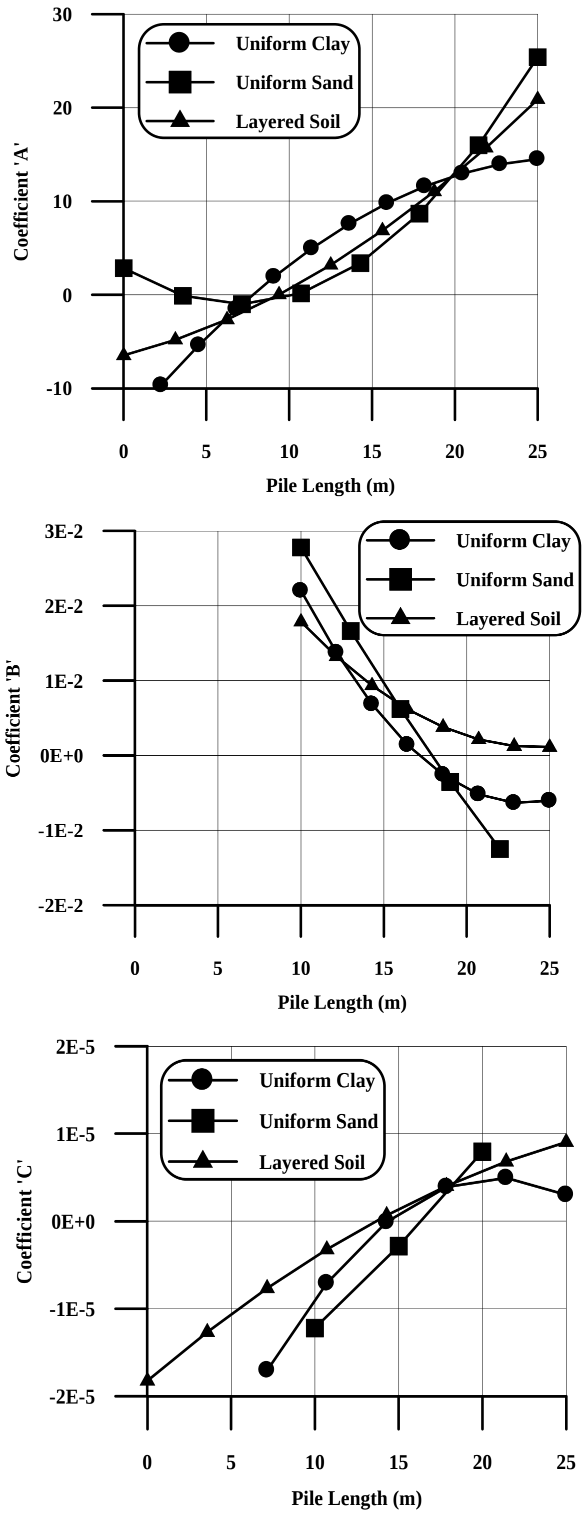


Fig.5 Regression Coefficients for Kr

5. CONCLUSIONS

The load carrying capacity of piles can be evaluated by using low strain integrity test data to a reasonable accuracy by using the suggested methodology considering that the initial head stiffness obtained from low–strain integrity test data and that estimated from static load settlement response curves is same. The accuracy of predictions can be further improved by verification of the proposed methodology against more number of field data and with the experience of analysing the pile integrity test data.

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REFERENCES

Briaud, J.L, Ballouz, M. and Nasr,G. (2000). Static capacity prediction by dynamic methods for three bored piles. *Journal of Geotechnical and Geoenvironmental engineering*, ASCE, Vol: 126, No. 7, pp 640-649.

Holeyman, A.E. (1992). Keynote lecture: Technology of pile dynamic testing. *Proc. 4th Int. Conf. Application of Stress Wave Theory to Piles*, The Hague, The Netherlands, 21-24 September, pp 195-216.

Raju, V.S. and Gandhi, S.R. (1989). Ultimate capacity of precast driven piles in stiff clay. *Indian Geotechnical Journal*, Vol. 19, No. 4, pp 273-289.

Shisheng, P.(1988). Quality control and determination of bearing capacity of piles from vibration testing. *Proc. 3rd Int. Conf. Application of Stress Wave Theory to Piles*, *Ottawa*, May 25-27, pp 271-284.

Shisheng, P., Jingzhang, Z and Changqing, J. (1992). Relationship between capacity and head stiffness of piles. *Proc. 4th Int. Conf. Application of stress wave theory to piles*, The Hague, The Netherlands 21-24 September, pp 639-643.

Seitz, J.M. (1992). Pile integrity by low strain impacts-A state of art", *Proc. 4th Int. Conf. Application of stress wave theory to piles*, The Hague, The Netherlands 21-24 September, pp 627-638.

Table 1: Illustrative procedure to evaluate load carrying capacity from the suggested methodology

Sl. No	Pile dimensions		Soil type	Regression Coefficients from Fig. 5			Kr	$[k_i]_{int}$	$P_{pre.}$	$P_{obs.}$
	D	L		A	B	C				
1	500	15.5	Predominantly sandy site	4.20	0.8e-2	-0.16e-5	7.8	149	1162	1300
2	500	11.0	Predominantly clayey site	3.67	1.9e-2	-0.70e-5	11.42	65	742	1200
3	500	11.0	Predominantly clayey site	3.67	1.9e-2	-0.70e-5	11.42	64	730	1150
4	1000	10.5	Layered <clay, dense sand, very dense sand>	1.50	1.65e-2	-0.03e-5	17.7	390	6903	7300
5	1000	12.8	Layered <clay, dense sand, very dense sand>	3.33	1.4e-2	-0.01e-5	16.23	440	7140	8300
6	1000	12.0	Layered <clay, dense sand, very dense sand>	2.13	1.44e-2	-0.13e-5	15.23	375	5710	7300
7	1000	12.0	Layered <clay, dense sand, very dense sand>	2.13	1.44e-2	-0.13e-5	15.23	370	5630	6800

Note:

D = Pile diameter in 'mm'; L = Pile length in 'm';
Kr = A + B*D + C*D^2 in 'mm'
$[k_i]_{int}$ = Pile head stiffness from integrity test data
P_{pre}. = Predicted load capacity in' kN' = Kr. $[k_i]_{int}$
$P_{obs.}$ = Observed failure load from the reports in 'kN'