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Estimating geotechnical capacity of bored cast-in-situ piles from penetration resistance

Estimation de la capacité géotechnique des pieux de fondation calibrés et moulés sur place à partir de la résistance à la pénétration

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ABSTRACT
The termination depth of bored cast in situ piles poses serious problem to the field engineers particularly on weak weathered rock, stiff clays and dense sands. Some sort of decision making tool is available for driven piles in the form of driving formulae. But for the termination of bored cast in situ piles no such guide is available for field engineers. The paper deals with a simple method based on penetration resistance to the advancement of bore and its relation with end bearing and frictional resistance offered by formation. The method shall serve a very useful purpose for estimation of time frame of piling jobs from the investigation data and serve as a good quality control tool for termination of piles in field.

RÉSUMÉ
L'interruption de la profondeur des pieux de fondation calibrés et moulés sur place présente un problème pour les ingénieurs de terrain surtout pour les rochers exposés aux intempéries, aux argiles raides et aux sables denses. Il existe un outil pour déterminer les formules de battage de pieux, mais pour déterminer l'interruption des pieux de fondation calibrés et moulés sur place, il n'existe aucun outil pour les ingénieurs de terrain. Cet article présente une méthode facile qui est basée sur la résistance à la pénétration dans l'avancement des forages par rapport au palier d'extrémité et la résistance de friction de la formation. Cette méthode sera très utile dans l'estimation du temps pour les travaux de pieux à partir des données de la recherche et servira comme un outil de contrôle de qualité pour l'interruption des pieux de fondation dans le terrain.

1 INTRODUCTION

Piles are designed using shear parameters of rock and soil samples recovered during the investigation on testing in the laboratory. In spite of a very elaborate soil investigation scheme that too carried out by very reliable agency under vigilant supervision the variation in formation characteristics both depth and strength wise during the execution is possible. In such circumstances the field engineers find it very difficult to take a rational decision while terminating the piles on a strata contemplated by the designers.

The paper presents a semi-rational method of evaluation of end bearing resistance and socket friction from the penetration energy required for developing the bore. The method is based on equivalence of energy principle. Use of Mayerhoff's analysis relating SPT to load carrying capacity of piles is extended to get the correlation between penetration resistance ratio and load carrying capacity of bored cast-in-situ piles. The procedure shall help in estimating required socket length from energy principle and shall help in easing out the burning issue.

2 ESTIMATION OF PENETRATION RESISTANCE

Pile bores are developed with the help of chisel / bailer in the conventional tripod type of piling rig. The penetration energy required to advance the bore is given by the product of weight of chisel/ bailer (in MT), drop of tool (in Mtr.) and no. of blows applied. Under the influence of the impact energy the pile of given cross section area in m^2 is advanced by certain distance (measured in cms for convenience). The ratio of energy required to that of work done or volume bored called hereafter as PRR therefore represents energy required to advance a pile of 1 m^2 ara by one cm in that strata.

Penetration Resistance Ratio (PRR) = ($TM/m^2/cm$)

$$\frac{\text{Weight of boring tool in tonnes x Fall in mtr. x No. of blows}}{\text{Area in } m^2 \text{ x Penetration in cms.}} \qquad \textbf{(1)}$$

Normally in ½ hour of chiseling 250 to 300 blows are counted.

Similarly for the auger piling where the auger is rotated by the engine mounted at the top of rig having certain HP. The torque is generated and auger blades cut the formation while rotating. The engine is running at constant speed and produces a torque. When the strata is difficult to penetrate the torque increases and the rpm reduces. The horse power of an engine is related to torque and revolution per minute by following relation.

$$\text{HP of the engine} = \frac{2\,\pi\,\text{NT}}{4.5} \qquad \textbf{(2)}$$

Where HP is horsepower

N = Revaluation per minute T = Torque in TM

The cutting action of formation takes place under the torque energy imparted per minute enabling the bore of certain area (m^2) advancing by certain distance (in cm) in a minute) The PRR therefore for auger pile can be given by following equation

$$\text{Penetration Resistance Ratio (PRR) (for Auger piling)} = \frac{2\,\pi\,\text{NT(M.T). x Time in minutes}}{\text{Area in } (m^2) \text{x Penetration (cm)}} \qquad \textbf{(3)}$$

Thus for both the type of pile boring methods the PRR can be worked out at any depth while developing the bore.

3 COMPARISON WITH DYNAMIC FORMULAE

All the pile driving formulae in reality represent the ratio of energy applied and work done.

These formulae are based on laws governing dynamic impact of elastic bodies. They equate the energy of hammer blow to the work done in overcoming the resistance of the ground to the penetration of pile. Allowance is made for losses of energy due to elastic contraction of pile caps and subsoil as well as the losses caused by inertia of the pile. The modified Hilly's formulae is popularly used for inferring a allowable load on a concrete piles. The Indian Standard Code I. S. 2911 (part 1 / Section 1) recommend the use of modified Hilly's formation for driven piles. It is in this background the method is outlined below.

4 COMPARISON WITH SPT

The Standard Penetration Test measures number of blows for 30 cm penetration under the application of standard energy per blow. It is felt that the concept of Standard Penetration Test has its origin in pile driving formulae. As a matter of fact the calculations of the load carrying capacity of the SPT shoe treating as a small size pile and substituting the relevant parameters in Hilley's modified formulae and then on correcting for the zone of influence for various footings widths and the small dia pile in the form of SPT shoe to account for settlement match closely to that of Tarzagi's curve relating SPT and SBC for shallow foundation.

In view of these observations the analysis was extended using Prof. Mayeroff's method for design of pile based on SPT values (A.S.C.E. 1956)

It is well known that SPT N = 50 is deemed as hard strata implying thereby the strata is approaching stage of a weathered formation. The PRR ratio for N = 50 is calculated below in the units of tm/m^2/cm.

$$\text{PPR}_{(N=50)} = \frac{\text{Wt of monkey x fall x no. of blows}}{\text{Area of split spoon Sampler}} \times \frac{\text{50 no. of blows}}{\text{30 cm.}}$$

$$= 36\,\text{tm/m}^2\text{/cm} \simeq 40\,\text{tm/m✧/cm.} \qquad (4)$$

By rule of three from the 'PRR' observed and the relation (4) the corresponding SPT value (projected) can be calculated.

$$\text{P.R.R.} = \frac{N}{1.25} \qquad (5)$$

Prof. Mayeroff has suggested a following relations

$$Q_{ult} = 40\,N\,A_p + \frac{\bar{N}}{5}\,A_S \text{ – (In Tonnes)} \qquad (6)$$

A_P = Base area in m✧ N = 'SPT' at base

$\bar{N}$ = Average 'N' on shaft portion offering frictional resistance.

As = Surface area of shaft in m✧

It is very essential to know the difference between the energy application during pile boring and SPT. In SPT the blows are given at the top while in piling executed by the conventional method the blow is right at the top of strata hence the energy imparted during pile boring is superior to that of SPT. This is also true for auger piles.

The other important aspect is the fact the during SPT the soil is offering resistance from inside of the sampler as well as from the outside of the sampler. In case of pile developed in either way the resistance is offered at outer face.

From the above discussion it can be said that piling energy is superior to that of SPT and to treat them as equivalent is quite safe while extending SPT analysis to bored cast in situ piles.

Now the relation can be used on modification to workout safe load on bored cast-in-situ piles. A modification is necessary due to difference in methodology of boring of driven piles and bored piles. The soil strata around the driven pile shaft gets densitified while in case of bored cast-in-situ piles it is not so.. The amount of densification is nearly 40 % and as such the SPT values have to be modified. Similarly Prof. Mayeroff has allowed a settlement of 20 mm while the I. S. Code permits 12 mm settlement for 1.5 times the allowable load. These two parameters can be accounted by assuming higher value of factor of safety than assumed by Prof. Mayeroff namely F. S. = 4. By increasing value of factor of safety to 6 the effect of densfication can be accounted and improving it further to 10 the variation between limits of permissible settlement could be tackled. Thus the pile capacity for bored cast-in-situ piles works out to be tackled. The relation therefore for bored piles as under

$$\text{Pile capacity} = 4\,N \times A_P + \frac{\bar{N} \times As}{30} \text{ (In Tonnes)} \qquad (7)$$

i.e. safe end bearing resistance = 4 N - t/m^2

The safe end bearing resistance on knowing PRR is given by relation (8)

$$\text{Safe end bearing resistance in t/m}^2 = 5 \times \text{P.P.R} \qquad (8)$$

The socket friction in rocks can be taken as 5 to 10 % of safe end bearing resistance.

The relation can be used in working out the pile capacities for bored cast-in-situ piles executed either by conventional method or by auguring. The relation is found to be reliable for weathered rocks and requires modification for clays and sand.

5 THE ESTIMATION OF PILING EFFORTS OF INVESTIGATION (WEATHERED ROCK)

The borelogs generally give the details of recovery, RQD and U.C.S. etc. pertaining to the rock cores depth wise. The unconfined compressive strength reported in the borelogs on a core pieces which are 10 cm and about in length. Naturally therefore it does not reflect the average characteristics of the rock mass. Author uses following relations to get characteristics strength from the using recovery and RQD data.

$$\text{Characteristics U.C.S.} = \underset{\text{(observed)}}{\text{U.C.S.}} \times \frac{\underset{(\%)}{\text{R.Q.D.}} + \underset{(\%)}{\text{Recovery}}}{2} \qquad (9)$$

It is well known that SBC of shallow foundation is 90% of U.C.S. On obtaining the characteristics U.C.S. from bore data as per equation (8) it can be concluded that safe end bearing resistance is equal to characteristics U.C.S. Dr. W. Flaming has suggested that U.C.S. is equal to Safe end bearing for piles. Thus on knowing the safe end bearing resistance the PRR can be worked out. Once the PRR is known the time and effort required for advancing the bore through the variation can be worked out. The method is very useful for estimating boring time for weathered rock for contracting agencies and a good guide.

The table below gives suitable relations for weak sand stones, cemented sands shale, tuff breccia and weatjered basalt and weathered rock in tabular form.

Weak Weathered Rocks

Chiselling Energy or Auguring Energy $Tm/m^2/cm$	Safe End Bearing Resistance (S. B. C.) T/m^2	Socket friction T/m^3	Characteristics U. C. S. of Rock
60 $Tm/m^2/cm$	300 T / m^2	15 T/m^2 to 20 T/m^2	30 kg/ cm^2
75 $Tm/m^2/cm$	375 T / m^2	20 T/m^2 to 25 T/m^2	37.5 kg/ cm^2
100 $Tm/m^2/cm$	500 T/ m^2	25 T/m^2 to 35 T/m^2	50 kg / cm^2

6 RELATION FOR SAND

The design of piles in sand is often done with SPT data. During the actual execution of pile bore what comes up is only sandy particles and the inferences regarding the strength characteristics of the formation can only be obtained form the resistance offered to the penetration. The relation given earlier by (5) is quite satisfactory for weathered rock but requires modification for sands and clays. It is so because if the sand does not have cementation the boring rate will be faster requiring less energy as compared to weathered rock. It is observed that the PRR for sands related the SPT by following relation

$$\text{P.R.R.} = \frac{N}{2 \text{ to } 2.5} \qquad \textbf{(10)}$$

Thus with relation above the field engineer can determine the N value of the strata (i.e. 'SPT" potential) is likely to possess and also the time required for advancing the bore can be estimated. On comparing with bore loggs of soil investigation suitable decision can be taken.

7 RELATION FOR CLAYS

Advancing bore in the clay necessitate extra energy to over come the stickyness of the clays. The bore can be quickly advanced but the withdrawal of the tool requires an extra energy because of stickiness of the clay. The cohesion values of the clay could be obtained by the relation given for weathered rock with some modification. The S.B.C. can be obtained and hence idea about cohesion can be obtained by following relations.

a) Soft clay. – very weak soils
b) Stiff clay (moist saturated) = P.R.R. = 0.6 N T/m^2
c) Very stiff clay not moist P.R.R. = N T/m^2 **(11)**

Using these relations of clay the cohesion of the formation can be obtained. The time required for advancing the bore can be estimated. It is in this light the PRR method shall serve a useful guiding tool for the field engineers. It shall be treated as a quality control tool and the actual termination can be done on inspecting the samples of the chisel pieces for weathered rock as well as comparing with bore data from the investigation for all types of foundation. The bailed samples of sand and clay should also be compared with bore loggs before deciding the termination of piles.

8 VALIDITY OF THE ANALYSIS

The author has been using method with caution for last 15 years. However the validity of same in terms of load tests could only be established recently. Recently the dynamic piling testing method using Hilley's formulae was conceived by the author. In this method the bored cast in situ piles is treated as driven preast pile while subjected to hammer blows during testing and deformation the pile undergoes is measured with help 'NOPTEL' equipment which makes use of inferred ray technology. The settlement record is substituted in Modified Hilley's formulae and ultimate load is worked out Adopting F.S. = 2.5 as per IS 2911 the safe load can be availed.

The data of above tests at the different sites in weathered rock is compared with safe pile load arrived by P.R.R. method. A glance at the safe load values obtained from dynamic testing using Hilley's formulae and the pile capacity worked out from record of penetration resistance kept at site show a good agreement with each other. The method was applied with success to the piles in sand and clays also on a limited sites. The data is not very large. (Refer Table 1 & 2 and figure 1 & 2)

9 CONCLUSION

From the comparison of pile dynamic data based on (modified Hilley's formulae) and penetration resistance worked out it can be seen that the method is fairly reliable for piles in weathered rock.

The author has been using method for working out time period for advancing the bore with the help of bore data for last decade with fair amount of success. The actual results match with predicted time fairly well. It can be very useful piling contractors and designers the estimation time frame particularly in weathered rock.

As regards sands and clays more data is required and then method can be perfected. However the applying the method for few cases in sand in clay a good agreement with dynamic test results is noted.

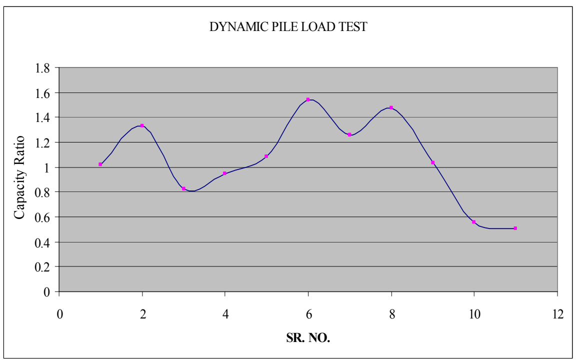

Figure 1. Ratio of safe test capacity & safe capacity from penetration resistance.

Dynamic Test v/s PRR results (Piles Founded On Tufficious Breccia)

Sr. No.	Safe Load Dynamic Test in Tonnes	Safe Load from Penetration Resistance in Tonnes
1	63.36	*N. A.
2	256	270
3	76.8	*N. A.
4	14.7	*N. A.
5	48.2	*N. A.
6	46	45
7	262	242
8	329	223
9	193	145
10	208	252
11	454	440
12	276.81	180
13	283.85	225.36
14	498.92	894.4
15	322.01	637.33

*N. A. = Not Available

Dynamic test/ PRR results
Piles Founded On Weathered Basalt

Sr. No.	Safe Load Dynamic Test in Tonnes	Safe Load from Penetration Resistance in Tonnes.
1	176	155
2	220	-
3	163	150
4	178	167
5	145	140
6	94	90
7	145	155
8	78.42	104.76
9	151.94	67.79
10	76.84	55.09
11	217.78	129.2
12	100.78	98.8
13	74.34	83.6
14	159.78	103.11
15	79.24	178.79
16	236.21	132
17	106.01	88
18	115.25	160
19	133.75	116
20	258.34	231
21	351.91	448.8
22	289.15	221
23	203.87	204
24	226.96	229.17
25	133.19	111.3
26	108.94	148.4
27	191.12	178
28	184.74	172.44
29	167.47	169.1
30	200.5	169.1
31	284.42	158.86
32	144.49	101.36

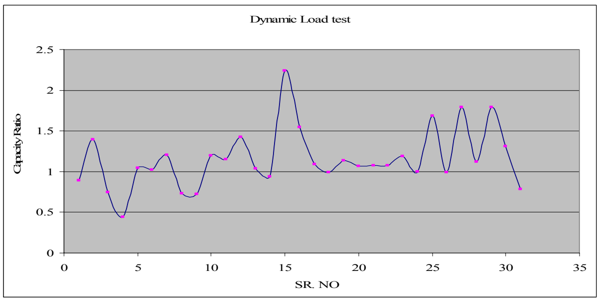

Figure 2. Ratio of safe test capacity & safe capacity from penetration resistance.

REFERENCES :

Fleming WGK, Weltman AJ, Randolph MF and Elson WK (1985) *Piling Engineering Surrey University Press*

Indian Standard Code of Practice for Design & Construction of Pile Foundation IS 2911 (Part I /Section) (1991) Dynamic Pile Formulae Appendix B

Mayerhoff G.G. (1956) *"Penetration Test and Bearing Capacity of Cohensionless Soil"*, A.S.C.E. Proceeding Paper No. 866.