BEARING CAPACITY OF FOUNDATIONS BY DIFFERENT METHODS: A CASE STUDY

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ABSTRACT: Field investigation has been carried out at Palatona, Agartala with a number of boreholes following standard codal provisions. Pressure meter tests have also been conducted at two locations at the site (twelve at each location at different depths) using Menard Pressuremeter Necessary laboratory tests have been also conducted on disturbed and undisturbed samples collected from the boreholes to characterize the subsoil and also to ascertain its strength and compressibility characteristics. Further, Bearing capacity of different shallow and deep (pile) foundations have been computed using standard codified procedures using laboratory test results. Bearing capacities of those shallow foundations and safe capacities of those piles are further estimated using Pressuremeter parameters, *viz*., Limit Pressure and Pressuremeter Modulus. A comparison of the bearing capacity of footings and pile capacities under compression obtained from Pressuremeter test with those computed from borelog data and laboratory test results reveal that the former consistently yields higher capacity particularly for shallow foundation. However, pile capacities appear to be of the same order when computed by both of them. This relative picture may be useful to the practising engineers to arrive at appropriate decisions in important projects.

1. INTRODUCTION

Feasibility of any practical project, to a large extent, depends on the geotechnical attributes of the proposed location as the superstructures, through different structural elements, transfer load to the sub-soil. Hence, choice and design of appropriate substructure elements compatible to the relevant structure is of overriding importance. Further, such decision is primarily regulated by the sub-soil characteristics as the structure to-be-constructed is usually planned beforehand. To accomplish such challenging end, it is practised to explore the sub-soil and reckon its strength and compressibility characteristics through standard laboratory tests. Subsequently, realizing the characteristics of sub-soil and requirement of the structure, bearing capacity of shallow and deep foundations, feasible for the proposed construction, is estimated using standard codified procedure.

Customarily, bearing capacity of shallow and pile foundations is estimated using codal provisions developed after Terzaghi & Meyerhoff (Terzaghi, 1943; Meyerhof, 1951) and static formula (Tomlinson, 1981; IS: 2911-Part1/Sec 2, 1979), respectively. However, in the recent times, sophisticated field tests, *viz.*, pressuremeter test have emerged to estimate the same. In this context, it seems necessary to examine the variation of results obtained from these tests in relation to the conventional one. An attempt has, therefore, been made in the present study to compare the bearing capacity of shallow and pile foundations obtained by codal procedure as well as pressuremeter tests. The results presented correspond to a site at Palatona, Agartala where a number of boreholes were sunk and two pressuremeter tests were conducted.

2. SUB-SOIL PROFILE

The average subsoil profile established on the basis of the range of SPT values (N) in conjunction with the results of routine laboratory tests, such as, grain size distribution, Atterberg limits, bulk density, natural moisture content as well as appropriate shear and consolidation tests is summarized in Table 1.

Table 1: Subsoil Properties

Layer details		Corrected N-Value	Unit weight, γ (t/m^3)	Cohesion c (t/m^2)	Angle of internal friction ϕ (in degree)	Coefficient of volume compressibility (kg/cm^2) *
No.	Thickness (m)					
*IA	4.0	16	1.952	8.3	-	0.015
*IB	2.5	19	1.967	8.7	10	-
+II	8.5	29	2.020	-	35	-
	15.2	22	1.950	-	33	-
*Very stiff clay; +Medium dense/dense silty sand						

* Pressure range: 0.5 to 1.0 kg/cm^2

Table 2: Limit Pressure (p_l) and Pressuremeter Modulus (E)

Depth (m)	N (BH-51)	PMT-1		N (BH-10)	PMT-2	
		E	p_l		E	p_l
3	20	70	12.3	19	144	10
5	20	130	11	14	122	15
7	38	200	18	39	200	17.9
9	22	132	20	24	136	23
11	18	139	22.5	31	155	26
13	25	141	24	30	163	28
15	18	99	25	28	146	31
17	19	112	27	28	147	34
19	23	114	31	25	142	36
21	23	102	33	24	125	39
23	21	98	36	24	123	40
25	20	80	38	23	105	40

3. PRESSUREMETER TEST

Pressuremeter test using Menard Pressuremeter has been carried out in two locations viz. PMT-1 and PMT-2 in the vicinity of the boreholes. The test involves expanding the pressure cell inside a borehole and measuring the expansion of its volume. The test data are interpreted on the basis of the theory of expansion of an infinitely thick cylinder of soil. A representative test results is presented in Figure 1 showing three different zones. Zone I represents the reloading portion, during which the soil around the borehole is pushed back to its initial state, i.e., at rest condition before drilling. Zone II represents pseudo-elastic zone in which cell volume vs. cell pressure is practically linear and Zone III is plastic zone. Pressuremeter parameters *viz*., limit pressure and pressuremeter modulus obtained at the locations of PMT-1 and PMT-2 are presented in Table 2.

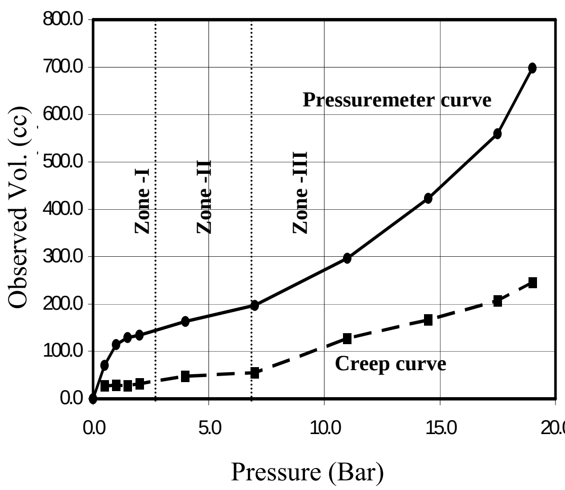

Fig. 1: Typical Pressuremeter Curve at PMT-1

4. LOAD CARRYING CAPACITY OF SHALLOW AND PILE FOUNDATIONS

Load carrying capacity of shallow and pile foundations have been estimated using codal formulation on the basis of subsoil properties as well as from pressuremeter parameters.

4.1 Computation Based on SPT and Laboratory Test Results

Net safe bearing capacity of shallow footings has been obtained as per IS 6403 (IS 6403: 1981) considering a factor of safety of 2.5. The allowable bearing capacities with respect to different values of allowable settlement have been computed in accordance with IS 8009 (Part-1) (IS 8009 (Part-1), 1976). A set of shallow footings of different shapes (*viz*., square, rectangular) and sizes placed at a depth of 2 m to 2.5 m are considered in the present study. The bearing capacities of such footings so obtained are furnished in Table 3.

Likewise, safe capacity of piles under compression has been estimated following static formula of IS 2911 (IS 2911-Part I/ Sec 2) using a factor of safety of 2.5. Bored-cast-in-situ piles of diameter varying from 0.45 m to 0.60 m having shaft length of 15m are considered. The pile capacities so estimated are presented in Table 4.

4.2 Computation from Pressuremeter Parameters

4.2.1 *Shallow Foundation*

Allowable bearing capacities of the footings mentioned in subsection 4.1 are computed using pressuremeter parameters as per the procedure outlined below:

$$Q_l = Q_0 + K \times (p_l - p_0) \quad (1)$$

where,

Q_1 = Bearing capacity at failure, Q_0 = Vertical overburden pressure at foundation level, p_1 = Limit pressure, p_0 = At rest horizontal pressure and K = Bearing factor expressible as a function of $D_f/(0.5B)$ and soil type (Soil is categorized on the basis of the p_l of soil).

Capacity of footings so estimated satisfying the shear failure criterion is checked against settlement restricting total settlement S within the specified limit as follows:

$S = S_1 + S_2$

$$= \frac{1.33}{3EB} pR_0 \left(\lambda_2 \frac{R}{R_0} \right)^{\alpha} + \frac{\alpha}{4.5EA} p\lambda_3 R \qquad (2)$$

Where,

- S_1 = Volumetric compression under the influence of the spherical component of stress field
- S_2 = Shear deformation due to deviatric component of stress field
- R_0 = A reference length equal to 30 cm
- p = Contact pressure
- λ_2, λ_3 = Coefficients of shape expressed in terms of aspect ratio of footing
- EB = Equivalent Pressuremeter modulus (considered a layer thickness equal to 8B)
- EA = Pressuremeter modulus of the founding strata
- α = A coefficient expressed as a function of E/p_1

The allowable bearing capacities obtained from pressuremeter parameters are presented in Table 3.

4.2.2 *Pile Foundation*

Pressuremeter parameters presented in Table 2 have been used to determine safe capacities of piles as follows:

$$Q_1 = Q_p + (Q_{f1} + Q_{f2}) \qquad (3)$$

Where,

- Q_1 = Bearing capacity at failure
- Q_p = Tip resistance = $K \times p_1 \times \pi \times d^2/4$
- K = Bearing factor
- Q_{f1} = Frictional resistance acting over a length of 3d of pile shaft from base of pile = $\pi \times d \times \sum S_i \times F_i$ in which, S_i : Thickness of L-i within 3d from base, F_i : Skin friction of L-i corresponding to relevant p_1 (within 3d)
- Q_{f2} = Frictional resistance acting over rest part of shaft (above 3d from pile base computed as stated above)

The safe pile capacities under compression so obtained from pressuremeter parameters are presented in Table 4.

5. RESULTS AND DISCUSSION

5.1 Verification of Pressuremeter Parameters

It is known that Pressuremeter test is very sensitive to the conditions of a borehole before the test. In this context, Pressuremeter parameters are compared to their standard correlations (Schultze & Biedermann, 1977) with SPT values for an indirect confirmation of reliability of the same. Pressuremter parameters derived from the standard correlations, though not presented for brevity, are found to be in good agreement with the observed values presented in Table 2.

5.2 Comparison of Estimated Bearing Capacity

5.2.1 *Shallow Foundation*

Table 3 suggests that allowable bearing capacities of shallow foundations obtained from pressuremeter tests overestimates those derived from codal procedure, in general. This may be due to the fact that the overall sub-soil characteristics have been used in estimating allowable bearing capacity with the help of method recommended in IS code, whereas pressuremeter test considers a zone-specific data. However, the percent variation is around 10% with respect to the values obtained from codal procedure.

Table 3: Bearing Capacity of Shallow Foundations

Footing size	*Depth of foundation*	*From SPT and laboratory test results*		*From pressuremeter parameters*	
		q_{llow} (S=25 mm)	*q_{llow} (S=40 mm)*	*q_{llow} (S=25 mm)*	*q_{llow} (S=40 mm)*
3 × 3	2.0	34.3	54.9	36.6	40
	2.5	34.6	55.3	37.5	60
6 × 3	2.0	29.8	47.7	32.1	40
	2.5	30.0	48.1	32.9	52.7
16 × 8	2.0	14.8	23.6	16.3	26.1
	2.5	16.0	25.6	17.7	28.3
20 × 10	2.0	14.2	22.8	15	24
	2.5	14.4	23.0	15	24
30 × 15	2.0	9.9	15.8	11	17.6
	2.5	10.0	16.0	11	17.6

5.2.2 *Pile Foundation*

It is observed from Table 4 that pressuremeter test yields higher values compared to those obtained from static formula recommended in IS 2911: Part I/ Sec 2. The variation in capacities is of the order of 5%.

Table 4: Safe Capacity of Pile Foundation

Pile diameter (mm)	*Cut-off depth (m)*	*Founding depth (m)*	*Safe vertical Pile capacity (ton)*	
			From SPT and laboratory test results	*From pressuremeter parameters*
450	3.4	18.4	95.6	100
500			105.9	110
600			146.8	155

5.3 Seismic Safety

Liquefaction susceptibility of the subsoil was also checked to examine the relevance of the comparison in a seismic-prone region (Kramer, 2007). It was found that the subsoil was not prone to liquefaction since the factor of safety against liquefaction at different depths are computed to be greater than unity as presented in Table 5.

Table 5: Factor of Safety Against Liquefaction

Layer details			*Corrected N-value*	*% Fines < 75μ*	*$CRR_{7.5}$*	*CSR*	*F.S.*
No.	*Description*	*Thickness (m)*					
II	Medium dense / dense silty sand	8.5	29	22.4	> 0.5	0.42	>1.19
		15.2	22	26.3	0.45	0.27	1.66

$CRR_{7.5}$: Cyclic Resistance Ratio is read from Figure (Kramer, CSR: Cyclic Stress Ratio = 0.65 $(a_{max}/g)\ r_d\ (\sigma_v/\sigma_v')$

where, a_{max} = peak horizontal ground acceleration;

r_d = (1.174 – 0.0267z) (for $9.15 < z \leq 23$ m);

σ_v = total stress, σ_v' = effective stress

It appears from Table 5 that the subsoil is not prone to liquefaction.

6. CONCLUSIONS

A large number of boreholes were sunk at Palatona, Agartala besides conducting two pressuremeter tests. The pressuremeter modulus and limit pressure for all the tests at different depths at the two locations were found to be close to those computed using their standard correlation with N value. The following conclusions may be drawn from the present study.

a) Load carrying capacities of both shallow and pile foundations obtained by pressuremeter tests slightly overestimates the values obtained from the procedure recommended in IS code using SPT and laboratory test results.
b) This indicates that the procedure used herein to estimate load carrying capacities on the basis of pressuremeter parameters is reasonable and may be used in practice.
c) Pressuremeter test yields zone specific results and hence they seem to be more relevant provided sufficient tests are carried out at a site.

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