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A STUDY ON THE RELATIVE SUITABILITY OF DIFFERENT TYPES OF PILE FOUNDATIONS ON COHESIVE SUB-SOIL

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Abstract: Foundations are the initial components of construction of any civil engineering structure. They are therefore incredibly important from the point of view of safety and durability of structures. Hence, if not selected and constructed judiciously, they may eventually adversely affect the strength and resilience of the building, once completed. The foundation of a structure is a somewhat invisible and sometimes ignored component of the building. It is increasingly evident however that attention to good foundation design and construction has significant benefits to the builder and can avoid some serious future problems. Selection of an appropriate foundation depends upon the type of the proposed super-structure, type of the sub-soil encountered at the site, groundwater conditions, financial and other constrains like allotted time etc. The fact that the type of sub-soil encountered at the site significantly affects the performance of the foundation is quite evident from this study. It has been observed that for the clay type sub-soil (as encountered in the present study); load carrying capacity of piles is significantly enhanced with under-reamed c/s as compared to those with uniform c/s, with other dimensions remaining the same. Also, it was observed that with the increase in the stem diameter of the pile, the enhancement in load carrying capacity of under-reamed piles as compared to piles with uniform c/s also gets appreciated. Thus, in principle; it can be stated that under-reamed piles are the most optimal foundation type for cohesive type of sub-soil.

Keywords: Sub-structure, Cohesive Sub-soil, Pile foundation, Load capacity.

I. INTRODUCTION

Foundation is the sub-structure constructed to withstand the load of the superstructure. The sustainability of the super-structure mainly depends on the bearing capacity of the soil and the selection of the appropriate type of foundation. For this purpose, detailed sub-soil investigation and site exploration is required. In general, the purpose of a site investigation is to obtain necessary information about the soil and hydrological conditions at the site and to know the engineering properties of soil which will be affected. A timely and intelligently planned site investigation should be considered a pre-requisite for efficient, safe, economical design and construction.

The safe bearing capacity of any proposed sub-structure can be determined with the help of shear parameter of the soil underneath, extending up to the significant depth below the proposed founding level for shallow foundation or up to the depth of extend of the proposed deep foundation. Similarly, the probable settlement of the foundation soil below any proposed structure is determined from the consolidation parameter of the sub-soil within the significant depth. The field test that is the most commonly used one in any sub-soil investigation work is the Standard Penetration Test. The sample collected from the standard penetration test is tested later in the laboratory to obtain required engineering data.

II. NEED OF THE STUDY

The comparison of performances of different types of pile foundations vis.-a-viz. their load carrying capacities are concerned, is very much essential for the selection of a suitable type of sub-structure for a particular type of sub-soil that may be encountered in the field. Thus embarking on such a comparative study is the need of the hour and is quite justified.

III. METHODOLOGY

In this work, standard penetration test up to 10m is done and the penetration resistances (N-value) at every 1.0m interval were recorded. Simultaneously soil samples collected during this operation were tested in the laboratory for identification and classification purpose as well as for evaluating shear parameters. The results obtained from the laboratory test are then used to calculate the safe load for bored and cast in-situ pile foundation with uniform c/s and also for piles with under reamed sections as well. These results are then compared to check the relative suitability of these foundations, for the type of the sub-soil encountered as far as the load carrying capacities are concerned.

Since the sub-soil encountered in the field (explored with a single borehole) mainly consisted of fine grained soil (clay), hence only plasticity properties (Liquid limit, Plastic limit & plasticity index) of the samples extracted in the field were explored in the laboratory using relevant tests. Then the plasticity chart was used to classify the various layers of the sub-soil encountered using the specified graph as per I. S. 1498, 1970. Similarly, only unconfined compressive test was conducted on those samples going by the fact that they all fell under clay category. Hence, un-drained cohesion value is used to determine the unconfined shear strength of those soil samples.

IV. RESULTS AND DISCUSSION

4.1 Laboratory Results Summary

Table 4.1: Identification & Classification of the sub-Soil encountered
(W.T: 1m Below E.G.L.)

Depth in m	Consistency Limit		Classification
	Liquid limit (%)	Plasticity index	
1	32	21	CL
2	29	3	ML
3	37.6	19.2	CI
4	41.7	14.4	MI
5	38.2	2.7	MI
6	44.2	20	CI
7	41	20	CI
8	46	24	CI
9	42	23	CI
10	43	27	CI

Note:

CL: Clay with low plasticity

ML: Silt with low plasticity

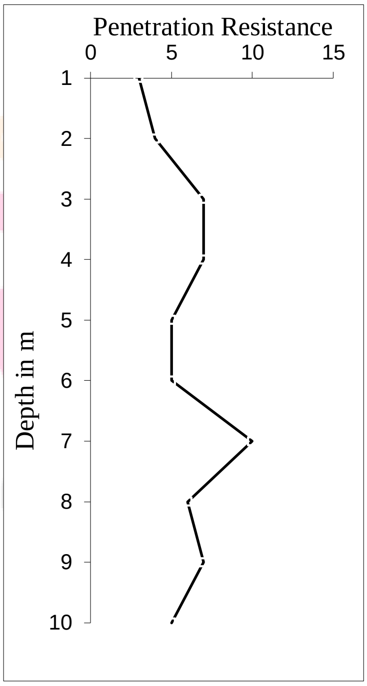
MI: Silt with medium plasticity

CI: Clay with medium plasticity

Table 4.2: Shear Parameters

Depth in meter	Core Cutter Results		Unconfined Compression Test
	Bulk Density (γ) t/ m^3	Field water content (%)	C_u t/ m^2
1.0 –1.3	1.61	22.47 %	1.676
2.0 –2.3	0.61		1.006
3.0 –3.3	0.61		1.509
4.0 –4.3	0.61		1.9
5.0 –5.3	0.61		1.676
6.0 –6.3	0.61		1.732
7.0 –7.3	0.61		1.621
8.0 –8.3	0.61		1.173
9.0 –9.3	0.61		1.397
10.0-10.3	0.61		1.509

Table 4.3: Bore-log (W.T: 1m below E.G.L.)

Depth in meter	Observed Penetration Resistance	Effective unit wt. of soil, γ; (In t/m^3) (Bulk density above W.T. and submerged density below W.T.)	Effective overburden pressure, (σ) (In t/m^2)	Corrected Penetration Resistance (Applicable for sand only)	Graphical representation of SPT data
1–1.3	3	1.61	1.61	3	
2 –2.3	4	0.61	2.22	4	
3 –3.3	7	0.61	2.83	7	
4 –4.3	7	0.61	3.44	7	
5 –5.3	5	0.61	4.05	5	
6 –6.3	5	0.61	4.66	5	
7 –7.3	10	0.61	5.27	10	
8 –8.3	6	0.61	5.88	6	
9 –9.3	7	0.61	6.49	7	
10-10.3	5	0.61	7.1	5	

4.2 Calculation Of Safe Load On Bored And Cast-In-Situ Concrete Pile Of Uniform Cross Section As Suggested In IS: 2911(Part I/Sec2) –2010

Since the soil is cohesive, so the ultimate load carrying capacity (Q_u) of R.C.C. bored, cast in – situ piles of circular cross-section are is given by the following formula:

$$Q_u = A_P \times N_C \times C_P + \alpha \times C_{av} \times A_S \text{ ----------- } (1)$$

Where;

A_p= C/S area of the pile toe in cm^2
N_C= Bearing capacity factor usually taken as 9, for cohesive soil
C_P=unit cohesion at the pile toe.
α = Reduction factor = 0.5, for bored & cast in-situ piles.
C_{av}= Average Cohesion throughout the stem of the pile.
(Considering the whole of the pile is embedded in the ground)
A_s = Surface area of the pile stem

Now, since the present sub-soil profile is of cohesive type, hence the relevant equation only (Eqn. 1) is considered in calculating the ultimate load carrying capacity (Q_u) of the pile.Now calculations of safe load for cast in situ concrete pile of uniform cross section at 9 m depth of diameter 0.3m, 0.4m and 0.6 m are illustrated below.
Since the specific gravity of concrete mix is more than that of soil slurry, so the concrete mix stays at bottom and the soil slurry rises up. So 1m below EGL the pile is broken and this 1m is considered as a cut-off length because it contains soil slurry.

Thus, for a total length of 9.0 m below the EGL, the effective length of the pile becomes L_e = 8.0m

Now, for pile diameter of 0.3 m;

$A_p = \frac{\pi}{4} \times 0.3^2$=0.07 m^2
$C_{av}= \frac{1.006+1.509+1.9+1.676+1.732+1.621+1.173+1.397}{8}$ = 1.5 t/m^2 , C_p= 1.397 t/m^2, Nc=9
$A_s = \pi \times 0.3 \times 9$= 8.48 m^2
Q_u ,=$A_p \times N_c \times C_p + \alpha \times C_{av} \times A_s$
=0.07x9x1.397+0.5x1.5x8.48
=7.24t

Therefore, $Q_s = \frac{7.24}{2.5}$= 2.89t

Similarly, for pile diameter of 0.4 m;

$A_p = \frac{\pi}{4} \times 0.4^2$ = 0.126 m^2
C_{av}= 1.5t/$m^2$$C_p$= 1.397 t/$m^2$
N_c = 9
$A_s = \pi \times 0.4 \times 9$= 11.309 m^2
$Q_u = A_p \times N_c \times C_p + \alpha \times C_{av} \times A_s$
= 0.126x9x1.397+0.5x1.5x11.309
= 10.06t

Therefore, $Q_s = \frac{10.06}{2.5}$ = 4.02t

And, for pile diameter of 0.6 m;

$A_p = \frac{\pi}{4} \times 0.6^2$ = 0.283m^2
C_{av}= 1.5 t/m^2, C_p= 1.397 t/m^2
N_c = 9
$A_s = \pi \times 0.6 \times 9$= 16.964 m^2
$Q_u = A_p \times N_c \times C_p + \alpha_i \times C_{av} \times A_s$
= 0.283x9x1.397+0.5x1.5x16.964
= 16.28t

Therefore, $Q_s = \frac{16.28}{2.5}$ = 6.51t

Table 4.4: Safe Load On Single Pile Of Uniform C/S

Pile type	Stem diameter (in m)	Length of pile (in m)	Effective length (in m)	Ultimate load on single pile (in tonnes)	Safe load on single pile (in tonnes)
Bored & cast in-situ	0.3	9	8	7.24	2.89
	0.4			10.06	4.02
	0.6			16.28	6.51

4.3 Calculation for Safe Load of Bored & Cast-In-Situ Concrete Piles with Under-reaming.

As per Cl. No. 5.2.3.1 of IS:2911 (Part III) - 1980; the ultimate bearing capacity (Q_u) of under- reamed piles (in kg) for clayey soil using Static formula can be calculated as under,

$$Q_u = A_p N_c C_p + A_a N_c C_a' + C_a' A_S' + \alpha C_a A_s$$

As per note 2 under Cl 5.2.3.1 since the pile is with one bulb only, the third term will not occur.

where,

A_P = Cross sectional area of the pile toe in cm^2,
N_C = Bearing capacity factor = 9, for cohesive soil,
C_P = Unit cohesion at the pile toe (kg/cm^2),
$A_a(cm^2) = \pi(D_U^2 - D^2)/4$,
where D_U and D are the diameters of the bulb and the pile stem respectively.
C_a' = Av. Cohesion of the soil around the under- reamed bulb (kg/cm^2),
α = Reduction factor = 0.5 for clay,
C_a = Av. Cohesion throughout the stem of the pile other than the under- reamed portion .
A_S = Surface area of the pile stem other than the under – reamed portion.
A_S' = Surface area of the cylinder circumscribing the under – reamed bulb.
= $2\pi r(r+h)$, where r and h are radius and height of the bulb respectively.

Calculation of safe load of a under reamed pile at 9 m depth-
Effective length of under reamed pile=8m
(Since 1m below EGL is considered as cut-off length)
Diameter of the pile, D = 0.3 m
Diameter of bulb, $D_U = 2.5\times D = 2.5 \times 0.3 = 0.75$ m

$A_P = \frac{\pi}{4} D^2 = \frac{\pi}{4}(0.3)^2 = 0.07m^2$
$N_C = 9$
$C_P = 1.397\ t/m^2$

$C_a = \frac{1.006+1.509+1.9+1.676+1.732+1.621}{6} = 1.574\ t/m^2$
$C_a' = 1.173\ t/m^2$

$A_a = \frac{\pi}{4}(D_u^2 - D^2) = 0.37m^2$
$A_S = \pi\times 0.3 \times 7 = 6.6m^2$
Now, ultimate bearing capacity,
$Q_u = 0.07\times9\times1.397 + 0.37\times9\times1.173 + 0.5\times1.574\times6.6$
$= 9.98$ t

Safe load on single pile, $Qs = \frac{Qu}{F.O.S} = \frac{9.98}{2..5} = 3.99t$
Similarly, calculations are made for other different options of pile diameters and the results are summarized in the Table 4.5

Table 4.5: Safe Load of Bored & Cast-In-Situ Concrete Piles with Under-reaming

Pile type	Stem diameter (in m)	Bulb diameter (in m)	Length of pile (in m)	Effective length (in m)	Ultimateload on single pile (in tonnes)	Safe load on single pile (in tonnes)
Under-reamedpile	0.3	0.75	9	8	9.98	3.99
	0.4	1			15.46	6.18
	0.6	1.5			29.52	11.81

4.4 Interpretations of Results and Discussions:

The various results obtained from the calculations made with the explored engineering properties of the foundation soil, can be rearranged in the following tables 4.6 and 4.7 for better representation and interpretation.

Table 4.6: Comparison of safe load between uniform c/s pile and under-reamed pile

Stem diameter (in m)	Length of the pile in meter		Safe load for pile with uniform c/s (in tonnes)	Safe load for under-reamed pile (in tonnes)	Percent increase in Safe load from pile with uniform c/s to pile with under reaming
	Total	Effective			
0.3	9	8	2.89	3.99	38.06
0.4			4.02	6.18	53.73
0.6			6.51	11.81	81.41

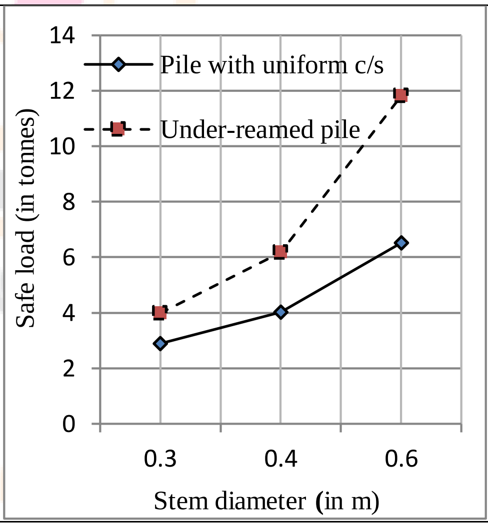


Table 4.7: Comparison of Percent Increase in Safe Load between uniform C/S pile and under-reamed pile

Stem diameter (in m)	Length of the pile in meter		Safe load for pile with uniform c/s (in tone)	Safe load for under-reamed pile (in tone)	Percent increase in Safe load with increase in stem diameter	
	Total	Effective			For piles with uniform c/s	For under-reamed piles
0.3	9	8	2.89	3.99	N/A	N/A
0.4			4.02	6.18	39.1	54.8
0.6			6.51	11.81	61.9	91.1

A quick comparison between the load carrying capacities of the two types of piles compared in this study, has revealed the following:

1) Pile with under-reaming at the base can bear more loads as compared to that with uniform c/s with other dimensions remaining constant for both (Table 4.6).

2) Also, with the increase in the stem diameter of the pile, the enhancement in load carrying capacity of under-reamed piles as compared to piles with uniform c/s also gets more appreciated.

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