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A Comparative Study of Load Carrying Capacity of Conventional Cast in-Situ Solid Piles and Hollow Piles

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ABSTRACT: *In this paper, a comparative study for the techno-economic analysis has been made to compare the load transfer capacity of the different combinations of diameter and lengths of solid cast in-situ piles and corresponding hollow piles.The main objective of this study was to bring out increased load carrying capacity or its efficiency on technical grounds and the decrease in cost due to saving in volume of concrete on economic grounds using hollow piles in place of conventional solid piles.*
Keywords: *About five key words in alphabetical order, separated by comma*

I. INTRODUCTION

Although piles are often made of steel or concrete today and most of the equipment used to drive piles belongs in this century rather than in Roman times, piles continue to be used today as deep foundations to support many types of structures and in many types of ground conditions. When the soil at or near the ground surface is not capable of supporting a structure, deep foundations are required to transfer the loads to deeper strata. Deep foundations are, therefore, used when surface soil is unsuitable for shallow foundation, and a firm stratum is so deep that it cannot be reached economically by shallow foundations. The most common types of deep foundations are piles, piers and caissons. The mechanism of transfer of the load to the soil is essentially the same in all types of deep foundations.

A deep foundation is generally much more expensive than a shallow foundation. It should be adopted only when a shallow foundation is not feasible. In certain situations, a fully compensated floating raft may be more economical than a deep foundation. In some cases, the soil is improved by various methods to make it suitable for a shallow foundation.In this study, the main purpose was to carry out estimation of load carrying capacity of two piles, solid pile and hollow pile having the same dimensions and put to test under the same loading conditions. The results that came out were expected. Under the same applied loads the load carrying capacity of hollow pile was more in comparison to solid pile. Also, the estimation of volume of concrete used in casting both the piles was also calculated, the hollow pile as the name speaks it hollow in central part, so the amount of concrete is saved. Hence, overall the concrete used is less in hollow piles in comparison to solid piles.Fromforegoing analysis it is obvious that for a given soil, use of hollow piles over solid concrete piles, would result in much saving of concrete. Additional safe load would be available for the external imposed load, i.e. increased load carrying capacity and hollow piles be economical due to lesser concrete volume used.

II. METHODOLOGY

COLLECTION OF SUBSOIL DATA & STATIC METHOD

The load carrying capacity of the piles is determined using Static method or the dynamic method. The Bureau of Indian Standard for the determination of load carrying capacity of pile by Static method is provided in the IS:2911 (Part-III) 1985 for coarse grained as well as fine grained soils. The separate formulae are being expressed as follows.

For Cohesive soils,

$\mathbf{Q_u} = A_p \,.\, N_c \,.\, C_p + \alpha \,.\, \hat{C} \,.\, A_s$

where,

$\mathbf{Q_u}$ = Ultimate Bearing Capacity of Piles in kg.

$\mathbf{A_p}$ = Cross sectional area of pile toe in cm^2.

$\mathbf{N_c}$ = Bearing capacity factor usually taken as 9.

$\mathbf{C_p}$ = Average cohesion at the pile tip in kg/cm^2.

□= Reduction factor

□ = Average cohesion throughout length of pile in kg/cm^2

$\mathbf{A_s}$ = Surface area of pile shaft in cm^2.
For granular soils,
$\mathbf{Q_u} = A_p\,(1/2\ D\ .\ \gamma\ .\ N_\gamma + P_D\ .\ N_q) + \sum K.\ P_{Di}\ .\ \tan\delta\ .\ A_{si})$

where,
$\mathbf{Q_u}$ = Ultimate Bearing Capacity of Piles in kg.
$\mathbf{A_p}$ = Cross sectional area of pile toe in cm^2
D = Stem diameter in cm
□= effective unit weight of soil at pile toe in kgf/cm^3
$\mathbf{N_r}$& $\mathbf{N_q}$ = bearing capacity factors depending upon angle of internal friction ϕ at toe.
$\mathbf{P_D}$ = effective overburden pressure at pile toe in kgf/cm^2
□ = summation for n layers in which pile is installed.
K = Coefficient of earth pressure
$\mathbf{P_{Di}}$ = effective overburden pressure in kgf/cm^2, for the i^{th} layer where i varies from 1 to n.
□= angle of wall friction between pile and soil, in degrees (equal to ϕ) and
$\mathbf{A_{si}}$ = surface area of pile stem in cm^2 in i^{th} layer where i varies from 1 to n.

The variables in the above stated formulae necessitates index properties of the soil, such as sieve analysis, Atterberg's Limits, moisture content, bulk and dry density, shear parameters i.e. cohesion and angle of internal friction and the corresponding dependent values such as reduction factor, etc. for determination of load capacity of the piles. Keeping in mind the need for assessment of load capacity of presumed pile in non-cohesive soils and the cohesive soils, the data for index properties of the soil is to be collected for each of these soils. As such, the following data has been obtained from the Bridge Construction Unit, Mathura and Bridge Construction Unit, Aligarh under the UP State Bridge Corporation. These data refers to the sub soil investigation conducted for the Road-Over-Bridge (ROB) at the railway crossing in the city of Mathura and the Ramganga river near in the Aligarh district.

Table: Sieve Analysis & Atterberg's Limits Results for **Bore Hole-1**

Bore No. 1		Period: April' 2016				Water Table :				11.000			M
SN	Depth (mtr)	Percentage of Material Passing in mm/micron (µ)									Atterbergs' Limits		
		10.00	4.75	2.00	1.00	600	425	212	150	75	LL	PL	PI
1	1.00	100	100	95	88	68	45	23	14	5	Non Plastic		
2	2.50	100	100	95	88	68	45	24	12	5	Non Plastic		
3	4.00	100	100	94	86	66	46	24	13	5	Non Plastic		
4	5.50	100	100	94	85	66	46	23	13	5	Non Plastic		
5	7.00	100	100	94	85	66	47	25	13	5	Non Plastic		
6	8.50	100	100	93	85	67	45	25	12	5	Non Plastic		
7	10.00	100	100	93	84	67	48	23	11	5	Non Plastic		
8	11.50	100	100	92	84	68	48	24	10	5	Non Plastic		
9	13.00	100	100	91	86	68	47	24	13	5	Non Plastic		
10	14.50	100	100	90	87	70	46	23	12	5	Non Plastic		
11	16.00	100	100	94	87	70	45	23	13	5	Non Plastic		
12	17.50	100	100	94	88	67	45	25	11	5	Non Plastic		
13	19.00	100	100	95	84	68	46	26	13	5	Non Plastic		
14	20.50	100	100	95	85	68	47	20	13	5	Non Plastic		
15	22.00	100	100	93	83	66	44	20	12	5	Non Plastic		
16	23.50	100	100	93	83	65	48	21	12	5	Non Plastic		
17	25.00	100	100	93	82	65	48	23	13	5	Non Plastic		

Table: Grain Size Distribution Results for **Bore Hole-1**

SN	Depth	Water Table: 11.000 M					
		Grain Size Distribution				IS Group/Classification	
	(Meters)	Gravel	Sand	Silt	Clay	-	
1	1.00	0	95	5	0	SP	Poorly Graded Fine Sand
2	2.50	0	95	5	0	SP	Poorly Graded Fine Sand
3	4.00	0	95	5	0	SP	Poorly Graded Fine Sand
4	5.50	0	95	5	0	SP	Poorly Graded Fine Sand
5	7.00	0	95	5	0	SP	Poorly Graded Fine Sand
6	8.50	0	95	5	0	SP	Poorly Graded Fine Sand
7	10.00	0	95	5	0	SP	Poorly Graded Fine Sand
8	11.50	0	95	5	0	SP	Poorly Graded Fine Sand
9	13.00	0	95	5	0	SP	Poorly Graded Fine Sand
10	14.50	0	95	5	0	SP	Poorly Graded Fine Sand
11	16.00	0	95	5	0	SP	Poorly Graded Fine Sand
12	17.50	0	95	5	0	SP	Poorly Graded Fine Sand
13	19.00	0	95	5	0	SP	Poorly Graded Fine Sand
14	20.50	0	95	5	0	SP	Poorly Graded Fine Sand
15	22.00	0	95	5	0	SP	Poorly Graded Fine Sand
16	23.50	0	95	5	0	SP	Poorly Graded Fine Sand
17	25.00	0	95	5	0	SP	Poorly Graded Fine Sand

Table : Moist content, Bulk Density, Specific Gravity, Shear parameters, Void ratios, Compression Index Results for Bore Hole-1

SN	Depth (meter)	Moist Cont.	Bulk Density	Dry Density	Sp. Gr.	Shear values		void ratio	Comp Index
		%age	γ	γ_d	G	c	Φ	e	C_c
1	1.00	0.00	1.6823	1.6823	2.62	0.00	28	0.765	0.0000
2	2.50	1.25	1.7234	1.7021	2.62	0.00	29	0.740	0.0000
3	4.00	1.80	1.7481	1.7172	2.62	0.00	29	0.735	0.0000
4	5.50	3.45	1.7845	1.7250	2.62	0.00	28	0.725	0.0000
5	7.00	5.56	1.7750	1.6815	2.62	0.00	28	0.725	0.0000
6	8.50	9.35	1.7990	1.6452	2.62	0.00	29	0.720	0.0000
7	10.00	16.20	1.8025	1.5512	2.62	0.00	29	0.710	0.0000
8	11.50	17.75	1.9764	1.6785	2.62	0.00	30	0.705	0.0000
9	13.00	17.65	1.9661	1.6711	2.62	0.00	30	0.705	0.0000
10	14.50	17.50	1.9675	1.6745	2.62	0.00	30	0.675	0.0000
11	16.00	17.50	1.9670	1.6740	2.62	0.00	30	0.665	0.0000
12	17.50	17.45	1.9700	1.6773	2.62	0.00	30	0.620	0.0000
13	19.00	17.45	1.9720	1.6790	2.62	0.00	30	0.625	0.0000
14	20.50	17.40	1.9725	1.6802	2.62	0.00	30	0.625	0.0000
15	22.00	17.40	1.9725	1.6802	2.62	0.00	30	0.620	0.0000
16	23.50	17.40	1.9730	1.6806	2.62	0.00	30	0.610	0.0000
17	25.00	17.40	1.9730	1.6806	2.62	0.00	31	0.610	0.0000

Table : Sieve Analysis & Atterberg's Limits Results for Bore Hole-2

Bore No. 2		Period: April' 2016						Water Table :			11.000	M
SN	Depth (in mtr)	Percentage of Material Passing in mm/micron (μ)									Atterbergs' Limits		
		10.00	4.75	2.00	1.00	600	425	212	150	75	LL	PL	PI
1	1.00	100	100	100	100	100	100	95	92	86	33	16	17
2	2.50	100	100	100	100	100	100	95	92	87	33	16	17
3	4.00	100	100	100	100	100	100	95	92	87	33	16	17
4	5.50	100	100	100	100	100	100	96	93	86	33	16	17
5	7.00	100	100	100	100	100	100	96	93	86	34	17	17
6	8.50	100	100	100	100	100	100	96	93	86	32	15	17
7	10.00	100	100	100	100	100	100	96	93	86	32	15	17
8	11.50	100	100	100	100	100	100	95	92	85	32	17	15
9	13.00	100	100	100	100	100	100	95	92	85	32	17	15
10	14.50	100	100	100	100	100	100	96	91	85	33	17	16
11	16.00	100	100	100	100	100	100	96	91	85	33	17	16
12	17.50	100	100	100	100	100	100	96	91	86	33	17	16
13	19.00	100	100	100	100	100	100	96	92	86	32	17	15
14	20.50	100	100	100	100	100	100	96	92	85	32	17	15
15	22.00	100	100	100	100	100	100	95	92	86	32	17	15
16	23.50	100	100	100	100	100	100	95	92	86	32	17	15
17	25.00	100	100	100	100	100	100	95	92	86	32	17	15

Table : Grain Size Distribution Results for **Bore Hole-2**

SN	Depth (Meter)	Water Table: 11.000 M					
		Grain Size Distribution				IS Group/Classification	
		Gravel	Sand	Silt	Clay	-	
1	1.00	0	14	16	70	CL	Silty Clay of Low Plasticity
2	2.50	0	13	15	72	CL	Silty Clay of Low Plasticity
3	4.00	0	13	15	72	CL	Silty Clay of Low Plasticity
4	5.50	0	14	16	70	CL	Silty Clay of Low Plasticity
5	7.00	0	14	15	71	CL	Silty Clay of Low Plasticity
6	8.50	0	14	15	71	CL	Silty Clay of Low Plasticity
7	10.00	0	14	15	71	CL	Silty Clay of Low Plasticity
8	11.50	0	15	16	69	CL	Silty Clay of Low Plasticity
9	13.00	0	15	16	69	CL	Silty Clay of Low Plasticity
10	14.50	0	15	16	69	CL	Silty Clay of Low Plasticity
11	16.00	0	15	16	69	CL	Silty Clay of Low Plasticity
12	17.50	0	14	16	70	CL	Silty Clay of Low Plasticity
13	19.00	0	14	16	70	CL	Silty Clay of Low Plasticity
14	20.50	0	15	16	69	CL	Silty Clay of Low Plasticity
15	22.00	0	14	16	70	CL	Silty Clay of Low Plasticity
16	23.50	0	14	16	70	CL	Silty Clay of Low Plasticity
17	25.00	0	14	16	70	CL	Silty Clay of Low Plasticity

Table: Moist content, Bulk Density, Specific Gravity, Shear parameters, Void ratios, Compression Index Results for **Bore Hole-2**

SN	Depth	Moist Cont.	Bulk Den	Dry Den	Sp. Gr.	Shear values		void ratio	Comp Index
	Meters	%age	γ	γ_d	G	c	Φ	E	C_c
1	1.00	2.25	1.7820	1.7428	2.61	0.12	13	0.740	0.1410
2	2.50	5.50	1.7980	1.7043	2.61	0.13	13	0.745	0.1425
3	4.00	5.70	1.8235	1.7252	2.61	0.13	14	0.730	0.1380
4	5.50	5.85	1.8345	1.7331	2.61	0.13	13	0.710	0.1320
5	7.00	6.15	1.8550	1.7475	2.61	0.14	13	0.680	0.1230
6	8.50	8.25	1.8600	1.7182	2.61	0.14	14	0.675	0.1215
7	10.00	9.00	1.8650	1.7110	2.61	0.14	13	0.665	0.1185
8	11.50	14.20	1.8600	1.6287	2.61	0.15	13	0.640	0.1110
9	13.00	13.25	1.8750	1.6556	2.61	0.15	13	0.640	0.1110
10	14.50	13.30	1.8995	1.6765	2.61	0.15	12	0.635	0.1095
11	16.00	13.30	1.9250	1.6990	2.61	0.15	12	0.635	0.1095
12	17.50	13.40	1.9665	1.7341	2.61	0.16	14	0.625	0.1065
13	19.00	13.20	1.9715	1.7416	2.61	0.16	14	0.615	0.1035
14	20.50	13.28	1.9740	1.7426	2.61	0.16	14	0.625	0.1065
15	22.00	13.30	1.9760	1.7440	2.61	0.17	13	0.625	0.1065
16	23.50	13.50	1.9760	1.7410	2.61	0.17	14	0.625	0.1065
17	25.00	13.50	1.9770	1.7419	2.61	0.18	13	0.615	0.1035

Calculation for Load Capacity of Solid Piles and Hollow Piles

The Calculations for the evaluation of Load capacity of the circular cylindrical piles for each of the Solid as well as Hollow piles with similar shaft length and the outer diameters in case of Sandy soil i.e. coarse grained soil and the Clayey soil i.e. fine grained soil have been carried out. However in case of hollow piles, the inner diameter is dependent on the wall thickness of the hollow pile. The wall thickness has been considered as 200mm. Therefore, the inner diameter of the hollow piles would be 600mm and the same has been used for calculation of the frictional resistance from inside the pile and the soil concealed within the pile

III. RESULTS AND DISCUSSIONS

The sub soil data collected from two different sites, bearing the cohesionless soil and cohesive soil has been used for determination of index properties of the subsoil. The extent of the soil stratum at each of these sites is 25.00M from the natural ground level (NGL). The circular pile of diameter 1000mm having the effective shaft length of 20.00M with a cut-off of 1.00M from NGL has been presumed each for solid pile and hollow pile. The wall thickness of the hollow pile being 100mm i.e. the inner diameter of the hollow pile as 800mm. The water table is being 11.00M below NGL i.e. half of the effective length of the pile being above water table and the remaining below the water table. The load carrying capacity of the pile is evaluated for each of these solid and the hollow pile in each of the two cases of cohesionless and cohesive soil. The piles being friction-cum-bearing, thus, the total load would be the sum of the load carried by the friction through cylindrical pile surface and the load carried by the tip of the pile. Therefore, in case of the solid piles the total load would be the sum of load taken up by the friction and the pile tip. However, in case of hollow piles, the pile would have inner cylindrical surface in additional to outer cylindrical surface corresponding to the inner diameter. On the other hand, the load taken up by the tip would decrease to the extent of the decreased base area on account of the hollowness at the pile tip.

In case of Cohesionless soil;

For Solid circular friction-cum-bearing pile:

Total load shared by the outer cylindrical surface, = 897.47 Ton
Total load shared by the tip or base of pile, = 412.56 Ton
Total Load Capacity of the pile, = 1310.03 Ton

For Hollow circular friction-cum-bearing pile:

Total load shared by outer & Inner cylindrical surface, = 1448.63 Ton
Total load shared by the tip or base of pile, = 27.17 Ton
Total Load Capacity of the pile, = 1475.80 Ton

% age in increase in load capacity of hollow pile over solid piles= {(1475.80 – 1310.03)/1310.04} x 100
= 11.23 %
In case of Cohesive soil;

For Solid circular friction-cum-bearing pile:
Total load shared by the outer cylindrical surface, = 536.34 Ton
Total load shared by the tip or base of pile, = 11.30 Ton
Total Load Capacity of the pile, = 547.64 Ton

For Hollow circular friction-cum-bearing pile:
Total load shared by outer & Inner cylindrical surface, = 1287.93 Ton
Total load shared by the tip or base of pile, = 4.07 Ton
Total Load Capacity of the pile, = 1291.00 Ton
% age in increase in load capacity of hollow pile over solid piles
= {(1291.00 – 547.64)/1291.00} x 100
= 34.40 %
Similarly**;**
Volume of Solid Pile = (3.14/4) x D x L
= 0.785 x 1.00 x 23.00
= 18.06 m^3
Volume of Hollow Pile = (3.14/4) x (D_{outer} – D_{inner}) x L
= (0.785) x (1.00 – 0.60) x L
= 11.56 m^3
%age saving in volume of concrete ={(18.06 – 11.56)/11.56} x 100
= 56.25 %

IV. CONCLUSION

Thus, it could be concluded that the use of cast in-situ Hollow piles over conventional bore cast in-situ pile would result in;

- Nominal increase in pile Load Bearing Capacity in case of cohesionless soil.
- Considerable increase in Load Bearing Capacity in case of cohesive soil.
- Considerable saving in the volume of concrete.
- It is also observed that for the given pile, load bearing capacity is increases with increase in the length of pile.
- In case of hollow piles, the load bearing capacity increases on account of increased frictional surface area, being outer and inner surface area.
- In case of hollow piles, the load bearing capacity decreases on account of decreased End bearing area at the pile tip.

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