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Design of Marine Pile: A Case Study

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Abstract

Objective: This paper focuses on Marine piles which have significant importance in present day development near coastline. Different aspects of marine piles and their design challenges in consultancy offices in India will be studied.
Methods/Analysis: The study in this paper is mainly concentrated on geotechnical aspects. Reinforced concrete piles are selected due to their easy availability. Skin friction Capacity, End Bearing Capacity and Uplift Capacity of RCC are checked for finding lateral load carrying capacity and total settlement of a pile under a vertical working load.
Findings: load carrying capacity and total settlement of a pile under a vertical working load are found to be satisfactory for structural design. As per results, it is evident that the structure will be safe in critical cases like Compression, Tension, and Tension with Bending and Compression with bending.
Improvement: If the spring values are calculated for different layers of the soil, a model can be made in software package to check the feasibilities and note the deflections at different levels. Simultaneously, the study of Liquefaction of soil in marine pile foundations and their dynamic characteristics can be studied.
Keywords: *Marine Pile, SPT, RQD, Geotechnical Capacity, Lateral Load, Carrying Capacity, Subgrade Modulus, Interaction Curve.*

1. Introduction to Marine Pile

Theoretically a marine pile is a pile which supports the marine structures that is structures which are constructed in the one kilometer strip of coast line or sea shore. It is generally a long slender member which may be unsupported by a long distance from bottom of pile cap to the existing ground level depending upon its locations. Adjoining figure 1 shows typical example of marine piles.

Figure 1: Marine Piles

2. Design Perspectives

Any foundations whether it is shallow or deep, open or closed always have two kinds of design perspectives, one is Geotechnical and other is Structural. The study in this paper is mainly concentrated on geotechnical aspects, though a brief idea of structural design and its challenges will be sketched, following are some important steps of designs.

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3. Soil Data and Field Exploration

Davisson [1] reported that collection of soil data is most challenging in sea area due to its natural obstacles as well as unavailability of modern techniques. In almost every case with very limited exceptions piles in marine structures are cast- in-situ due to its unusual length. Also the time bound for tender and related issues restrict the proper investigation of soil parameters which are time consuming and complicated in nature. Tomlinson [3] Also there may be large variations in soil data within a frequent interval, produces uncertainty in design. Although detailed investigation of subsoil is in demand but due to lack of resources in India we have to depend on limited data and of course on safety factors.

Figure 2: Soil samples collected at field

Figure 2 shows typical samples collected at site. There are several boreholes at site to collect and analyze the data. At coastline or marine area subsurface profile generally consists of marine clay underlain by bedrock. Marine clay is generally encountered below sea bed in the boreholes. Based on SPT values the cohesiveness can be determined for this clayey part of the soil which also varies from soft to stiff (e.g. from 0.2m to 13m below sea bed). At least 2.5m more to the boreholes beneath clay is observed by rocks. Rocks can be of many kinds of nature whose RQD (rock quality designation) is observed and noted.

The next most important thing is to note the water table. Bowles [6] emphasized that the height of water table can be as high as 5m above sea bed. Seasonal and annual fluctuations are highly expected factors.

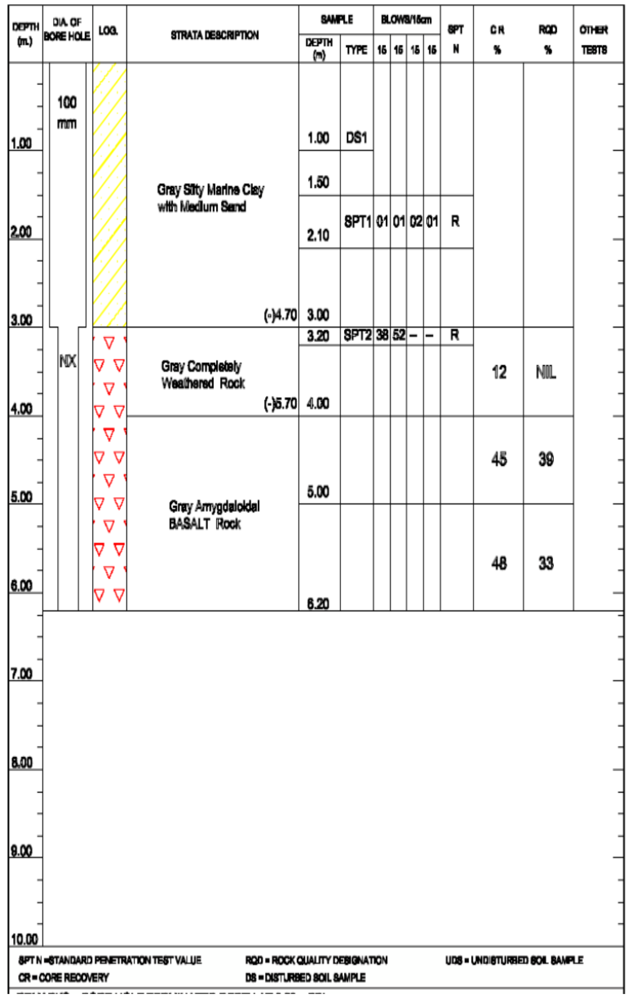

Figure 3: Typical SPT values

Typical Standard penetration test values are shown for example in figure 3 as above. The site investigation is normally carried out by a rotary machine. Casing is used to support sides of boreholes until a sufficient stiff stratum is observed. Then Standard penetration test is carried out. A 2" outside diameter split barrel sampler is driven into the soil by 63.5Kg weight falling through 75cm of height. After an initial settlement of 150mm, the number of blows counts to require an additional set of 300mm of the sampler is termed as "N" value. When SPT refusal is observed in hard strata, rock coring is done by diamond bit and double tube core barrel to get the rock sample. %R.Q.D. = 100 x sum of length of rock pieces in cms, each having lengths greater than 10cms/ Total length of core run.

4. Construction Materials

Das [8] classified marine piles as per materials in different categories like Timber, Steel and RCC etc. But we will particularly interest in reinforced concrete piles due to the easily available constituent materials and easy constructability. Following are some precautions in RCC pile.

Table 1: Some Parameters for Cement

Type of Cement	PPC
Minimum Grade of Reinforced Concrete	M35
Minimum Cement content	400kg/m^3
Maximum Water Cement Ratio	0.40
Minimum Grade of Steel	Fe 500 HYSD
Minimum cover to reinforcement	75mm

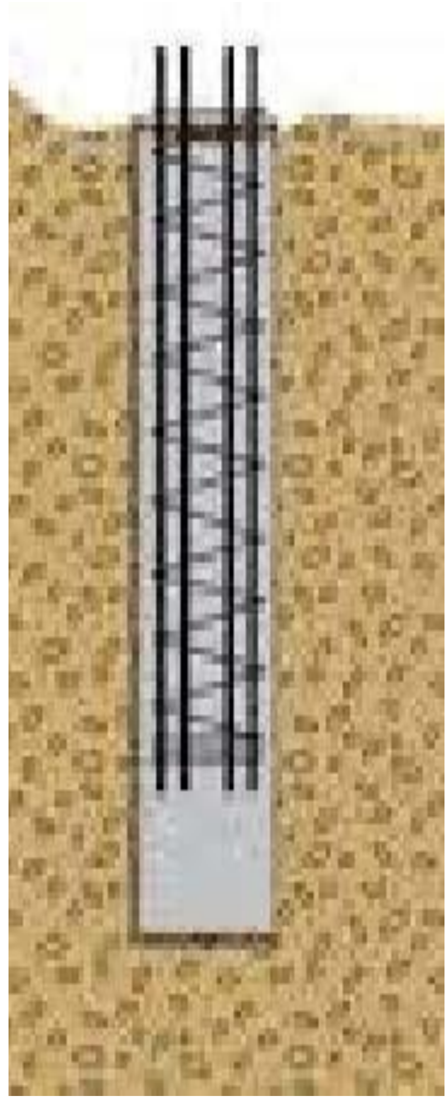

Figure 4: Typical RCC Pile

5. Sample Geotechnical Capacity Calculations

Say the pile diameter is 600mm socketed 2D in Bedrock.

Skin friction Capacity
Safe Skin Friction Capacity = Q_{sf}
$= Q_C\ \alpha\beta\ (\pi D L_s)$

Where,
Q_C = Uniaxial Compressive strength of Rock = 1960t/m^2 (say)
α= Rock reduction factor = 0.07 (say)
β= Rock correction factor = 0.2 minimum)
D = Diameter of Pile = 0.6m
Ls = Socket Length into the rock = 1.2m
Q_{sf} = 1960 x 0.06 x 0.2 x 3.14 x 0.6 x 1.2 = 53 Ton

(Note: Necessary data can be found in **IS14593** issued by BIS)

End Bearing Capacity
Safe bearing capacity = $Q_{eb} = Q_c\ N\phi\ N_j\ A_p$

Where,
$N\phi$ = Depth Factor = 0.8+0.2(I_s/ d) = 1.2 for 2D rock socket.
N_j = 0.1 to 0.4 (Assumed as 0.25)
A_p = Area of pile Toe = 0.28m^2
Q_{eb} = 1960 x 1.2 x 0.25 x 0.28 = 164 Ton

Hence Total Pile Capacity for Compression pile = 53 + 164 = 217 Ton.

Uplift Capacity

Safe uplift Capacity of Tension Pile = 0.7 x Safe Skin Friction Capacity = 0.7 x 53 = 37 Ton (**Say 35 Ton**)

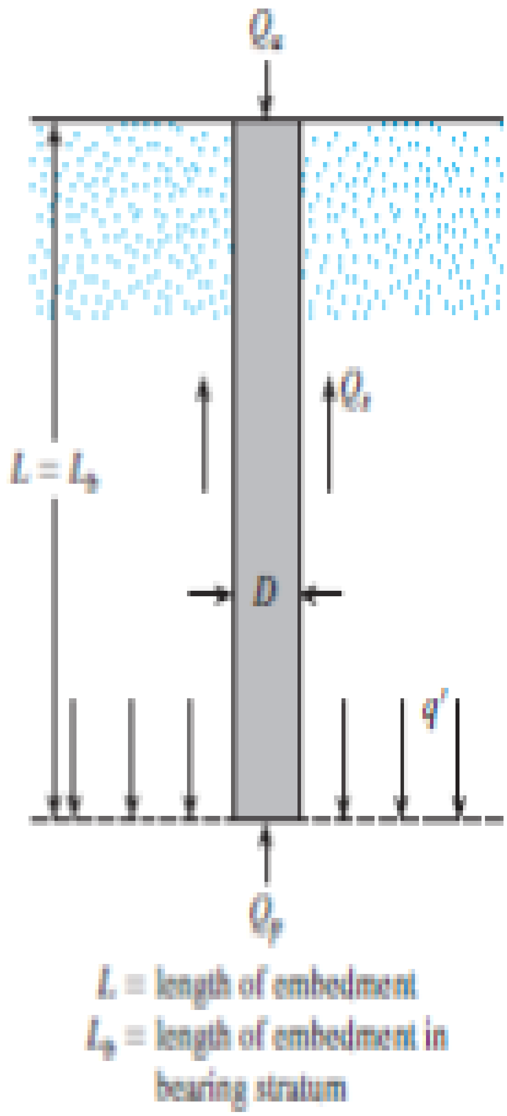

Figure 5: Load Carrying capacity of Pile. (Geotechnical Aspect)

Note: There may be loose soil which may exhibit negative skin friction. The case may be cleverly dealt by summing up different skin friction capacity values for different layers with appropriate sign. Self weight of pile and pile muff should also be taken into consideration to increase or decrease the uplift and end bearing capacity respectively.

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6. Lateral Load Carrying Capacity

The lateral load carrying capacity calculation is the trickiest part of pile design formulation. Due to the non-elastic nature of soil, this task is transformed to complex soil structure interaction problem. The pile itself can be classified as long or short according to its slenderness ratio. We will assume in general the marine pile is a long and slender member. According to Terzaghi et al. [4] pile may be characterized by its elastic stiffness **EI**, whereas the surrounding soil by its stress strain relationship, usually termed as modulus of horizontal subgrade reaction or as **p** vs. **y** curve.
The relative stiffness factor **R** for stiff and over consolidated clays is

$$R = \sqrt[4]{EI/k_h}$$

The same for sand is as follows

$$T = \sqrt[5]{EI/n_h}$$

Where, k_h and n_h are corresponding modulus of subgrade reactions. For a long pile D_f/T is greater or equal to 4 and D_f/R equal or greater than 3.5 (D_f = Embedded Length) some corrections can be persuaded in cases of fixed and free head piles as stipulated in IS:2911 [7] issued by Bureau of Indian Standard.

Soil Type	Value
Granular soils	n_h ranges from 0.5 to 50 kPa/mm, is generally in the range from 3 to 30 kPa/mm and is approximately proportional to the relative density.
Normally loaded organic silt	n_h ranges from 0.1 to 0.8 kPa/mm.
Peat	n_h is approximately 0.05 kPa/mm.
Cohesive soils	k_h is approximately 67 s_u.

Note: the effects of group action and repeated loading are not included in these estimates.

The above values of subgrade reactions are according to Davisson [1] in the year 1970.

Governing equation of elastic pile soil interaction is as follows

$$EI\frac{d^4y}{dx^4} + P_x\frac{d^2y}{dx^2} - p - W = 0$$

Where,

EI = Flexural Rigidity of the pile.
P_x = Axial Load.
p = Lateral soil reaction per unit length. W = Distributed Load along length.

Solving above equation is difficult. It can be treated by numerical techniques and will be another topic of interest. The solution has practical importance if the p-y curve shown in figure 6 nearby represents the soil behavior.

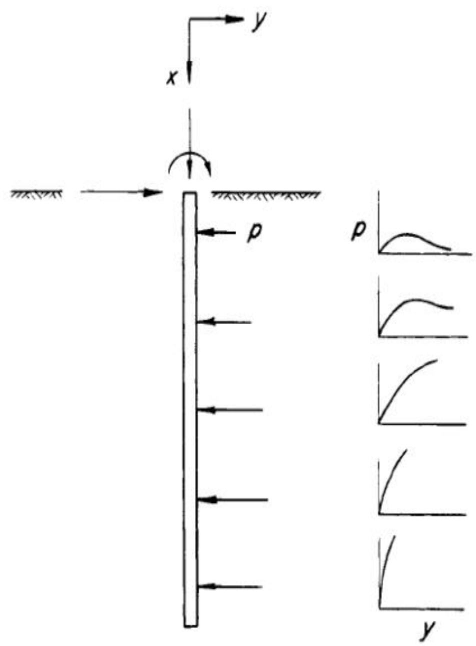

Figure 6: p vs. y Curve of a pile

Note: Lateral load carrying capacity may further be increased by considering passive resistance from pile muff only in case of compacted soil does exist at the level of Muff.

Where as a simple technique to handle the above things is depicted in IS code like IS: 2911 [7]. Accordingly it has provided some graphical presentation of cantilever length vs. so called modulus of subgrade reactions. The following figure **7** shows this plot.

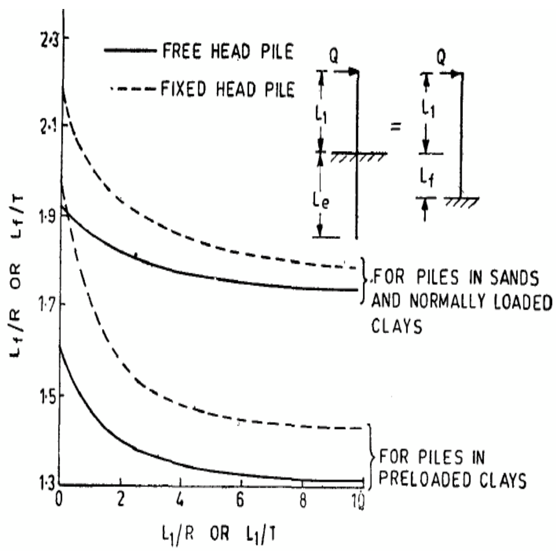

Figure 7: Determination of Depth of fixity (Appendix-C of IS2911)

(Above figure is valid until Le is greater or equal to 4R or 4T)

For T and R and their tabulated values, it is advised to consult the above section of IS code for a better understanding. Using the Cantilever deflection formula by knowing the equivalent cantilever length and restricting the allowable deflection of pile in lateral direction at dredge level by 5mm, one can easily estimate the rough lateral load carrying capacity.

A suitable safety factor say 3 may be adopted for marine case for several uncertainties in soil observations. This factor of safety may be increased or decreased by the Engineer-in-charge by help of engineering judgment.

7. Estimation of Settlement

The total settlement of a pile under a vertical working load Q_W is given by

$S_e = S_{e\,(1)} + S_{e\,(2)} + S_{e\,(3)}$

Where,

$S_{e\,(1)}$ = Elastic settlement of pile.
$S_{e\,(2)}$ = Settlement of pile by load at tip.
$S_{e\,(3)}$ = Settlement of pile caused by the Load transmitted along the pile shaft.

$S_{e\,(1)} = (Q_{wp} + \xi Q_{ws})\, L / A_p E_p$

Q_{wp} = Load carried at pile point
Q_{ws} = Load carried by skin friction
A_p = Area of cross section
L = Length of pile
E_p = Modulus of elasticity of pile material.
ξ varies from 0.5 to 0.67

According to Vesic [2] in 1977,
$S_{e\,(2)} = Q_{wp} C_p / D q_p$

q_p = Ultimate point resistance of the pile.
C = Empirical coefficient

Type of soil	Driven pile	Bored pile
Sand (dense to loose)	0.02–0.04	0.09–0.18
Clay (stiff to soft)	0.02–0.03	0.03–0.06
Silt (dense to loose)	0.03–0.05	0.09–0.12

Above Tabulated values are adapted from the book written by Vesic [2]

$S_{e\,(3)} = Q_{ws}\, C_s / L q_p$

$C_s = (0.93 + 0.16\,(L/D)^{0.5})C_p$

The above estimation is also by Vesic **[2]** in 1977.

8. Overview of Structural Design

Philosophically Marine piles are nothing but a long slender Column. Sinha [5] suggested that it should be designed and checked for several critical cases like Compression only, Tension Only, Tension with Bending and Compression with bending.

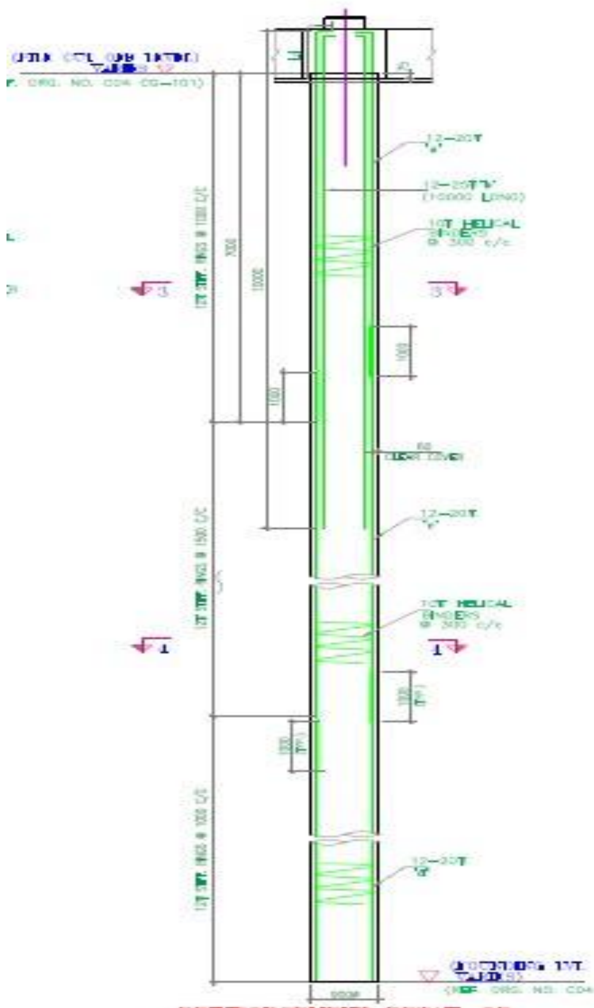

Figure 8: Typical 600ϕ pile detail

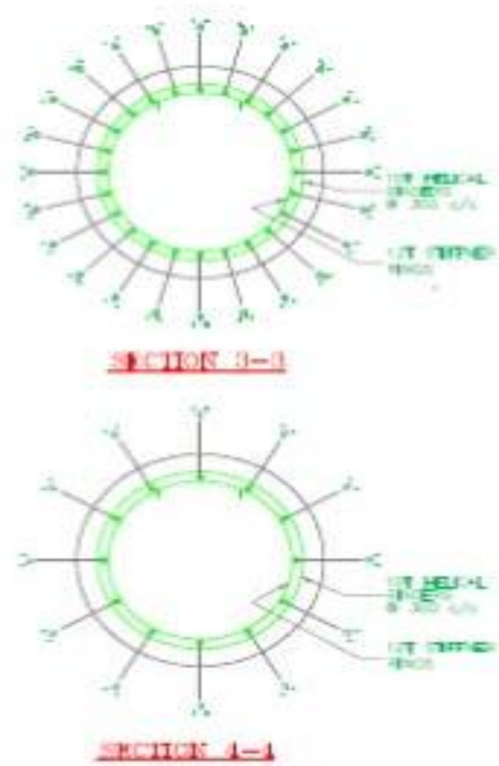

Figure 9: Cross Sections of 600ϕ Pile

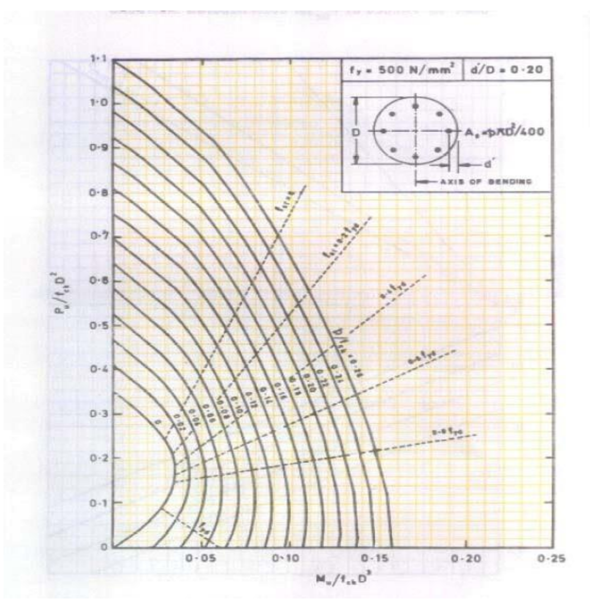

Figure 10: Typical Interaction Curve in SP16

9. Conclusion and Further Development

The design can further be refined or optimized by the help of computer aided design by some suitable model study. The main challenge in this regard is to represent the soil in the respective model study. Soil can be idealized by some spring whose values can be calculated or determined experimentally. Although we have a lot of study of these springs by several scientists like Winkler in the case of vertical ones. But for horizontal subgrade modulus only a limited empirical formulas are available. One such can be found from Bowles **[6]**. Once the spring values are calculated for different layers of the soil, a model can be made in software package like STAAD Pro V8i to check the feasibilities and note the deflections at different levels.

What we have omitted in this observation is the study of Liquefaction of soil in marine pile foundations and their dynamic characteristics.

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