DESIGN OF BORED CAST-IN SITU PILE SYSTEM IN A HIGHLY VARYING GROUND PROFILE

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ABSTRACT:
Bored cast-in-situ piles are generally considered appropriate for stratified stiff soil. However, in a highly varying ground profile, termination of the piles and their load transfer needs to be specifically addressed. The case study presented in this paper relates to a power plant project site where the ground profile indicates expansive black cotton soil underlain by highly weathered fractured basaltic rock and sandstone rock formations in some locations. These formations were generally reported around depths of 14-20m below Natural Ground Level. But in some of the locations these formations were not seen even at depths of 30m below Natural Ground Level. This paper discusses design procedures to be adopted for bored cast-in-situ piles to address varying sub-soil/rock profile encountered at different locations in the plant. Further, for the pile design, pile termination criteria were also specified based on strength parameters of the rock.

INTRODUCTION
The pile foundations are generally provided to transmit heavy loads from super structure to the competent stratum through weak strata or along weak strata. A stratum is deemed to be competent if it can take the transferred forces from the pile without failure with a desired safety factor and without undergoing deformations beyond permissible limits. Bored cast-in-situ piles are considered to be appropriate in stiff/dense soil conditions as pile drivability problems may not be a concern while adopting such type of piles.

In a sub-soil strata overlying comparatively hard bearing strata, the ultimate or net vertical capacity of the pile is estimated from the frictional resistance between soil medium and pile and the tip resistance at the bottom of pile. When a pile is embedded in a rock stratum, the downward force along the axis is transferred to the rock stratum by end-bearing at the pile tip and the shaft friction between pile and the competent stratum within the portion of the pile above the tip. The embedded length in the competent strata, particularly rock, which is designed to transfer either part or full axial force by shaft resistance, is commonly known as the socket length.

The extent of socketing depends on the quality of the rock encountered. In designing the rock socketed piles, the socket length need to be arrived based on the parameters of rock which is considered to be the competent strata. Hence termination criteria need to be specified to make certain that the pile is socketed in the weathered rock/rock strata for which it is designed for.

OVERVIEW OF THE ENCOUNTERED GROUND PROFILE
The site under consideration is for a proposed thermal power plant, in Coastal Gujarat where predominantly expansive stiff clay/bentonitic clay exists. Highly weathered to moderately weathered basaltic and sandstone formations were also observed at varying depths in some areas which is also a part of the proposed plant site. The Groundwater was observed at depths of around 2.5-10m below Natural ground level in the post monsoon periods of year, whereas in the other seasons the ground water table was not encountered, hence the encountered water table may be deemed as Perched water table.

Typical borelogs are presented in Fig 1 and Fig 2 which reflects the presence of entire sub soil in some areas and encountering of weathered rock in adjacent areas respectively. Borelog in Fig 1 shows the presence of expansive silty clay in stiff to very stiff conditions up to the termination depth of 30m which is representative of certain areas of the proposed site. Whereas borelog in Fig 2 represents other areas and indicates encountering of completely weathered sandstone at around 10-16m depth which is followed by high to moderate weathered basalt up to the borehole termination depth. In some of the borelog high to moderate weathered basalt which could be considered as competent stratum for pile socketing was found to be varying from 6m to 15m depths. From these sub soil/rock formation it was understood that the ground profile was highly varying and ascertaining the depth of weathered rock in each area would be very difficult.

DESIGN SYSTEM WITH BORED CAST-IN-SITU PILES
To address the highly varying ground profile, it was decided to adopt bored cast-in-piles with varying pile lengths which were predominantly friction piles and rock socketed piles. It was decided to keep the pile capacities (Vertical, Lateral & Uplift) constant for all pile lengths in order to avoid possible confusions at site regarding pile reinforcements. Basically the maximum and minimum pile lengths had to be predetermined for the same pile capacity considerations. The pile cut off level was generally
**Fig 1** Typical borelog reflecting the presence of entire soil upto the termination depth

**Fig 2** Typical borelog showing the encountering of High to moderate weathered rock
Design of bored cast-in situ pile system in a highly varying ground profile

The minimum length of the pile was decided as 6m below pile cut off level based on the considerations from lateral, vertical capacities and anticipated moments in the pile. Hence three types of piles were envisaged to address highly varying ground conditions at site. These piles were designed for different lengths according to the depth of encountering weathered rock strata at site. They were Type-1 piles- for piles encountering weathered rock from 6-15m below pile cut off level, Type-2 piles- for piles encountering weathered rock from 15-25m below pile cut off level, Type-3 piles- for piles which do not encounter weathered rock even drilling pile lengths beyond 25m. The Type 3 piles were designed as piles supported entirely in soil stratum and designed as predominantly friction piles. The high to moderate weathered basaltic rock was considered to be competitive stratum for socketing and hence the socketing length was designed based on resting in this stratum. The socketing length was arrived as 3 times the pile diameter for resting in high to moderate weathered basaltic rock for both Type 1 & Type 2 piles. Further the termination criteria were specified to ensure that the piles were socketed in the same stratum for which it is designed.

SPECIFIED TERMINATION CRITERIA

The fixing of termination criteria is very critical and it is solely on this basis that the pile can be ensured to rest in the competent strata for which it is designed for at site. The termination criteria that are commonly adopted are based on (i) SPT criteria (ii) Chisel energy criteria and (iii) Pile Penetration Ratio. The piling contractor at site had apprehensions of adopting the latter two methods as the same may lead to side collapse of the pile bore and would required use of sophisticated rigs having torque measurement. The limited / reverse SPT criterion was considered as an appropriate tool to ensure the termination of the piles in the designed competent strata. Conducting the limited SPT in a pile bore is simple and inexpensive. Judicious execution of the limited SPT in one select pile in a pile group would facilitate comparison of actual rock strength characteristics considered by the Designer while designing the socket length and pile founding level [4].

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In weathered rock the SPT was carried out for maximum 100 blows in 5 stages, recording the penetration for each 20 blows. Then the total penetration for maximum 100 blows was obtained by summing up penetration for individual 20 blows.

The penetration thus obtained had to correspond to less than 10cm to satisfy the above indicated criteria of N ≥300. If penetration value of <10cm is obtained say for maximum 100 blows then on extrapolation to 300 blows if the penetration is less than 30 cm the value will yield to N ≥300. In such a case the SPT was terminated. If the N ≥300 is not obtained for a particular stratum then SPT tool was detached and further drilling was carried out and then the SPT tool was again installed to ascertain the strength of the

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strata. Similar procedure was adopted to ascertain the desired values of N to terminate the piles. In the initial stages this procedure was considered as time consuming but after execution of few piles the execution team were able to map the approximate depth and nature of weathered rock where the reverse SPT criteria may pass. Once the strata was deemed to be competent which was considered in the design, the SPT tool was disconnected and for further drilling was initiated for pile socketing.

The drilling in the high to moderate weathered basaltic rock strata was carried out by hydraulic rig equipped with core catchers for the cutting and removal of boulder rock. Drilling in moderately weathered basaltic rock strata was carried upto the specified socketing length of 3 times the pile diameter as considered in the design.

![Removal of boulder rock and rock pieces using core catcher arrangement in hydraulic rig.](image)

For the pile bores which did not encounter weathered rock, the drilling was carried out upto 25m and the reinforcement cage was inserted followed by pile concreting. The installed piles were subjected to static and dynamic tests and the results of such tests were found to be satisfactory.

**CONCLUSIONS**

In varied ground conditions a very thorough geotechnical investigations are required to map and study the nature of profile ground conditions. In a high variation rock/weathered rock profile the maximum and minimum depth of encountering of rock/weathered rock need to be ascertained.

Adoption of bored cast-in situ piles are highly advantageous for piling in highly varied ground conditions. Pile lengths yielding to same capacities can be provided to address varied levels of weathered rock encountered. However the minimum length is to be specified considering the load capacities and moment considerations.

The limited/reverse SPT carried out in the pile bore as the bore progresses serves as a tool for quality control to check whether design criteria considered are actually fulfilled at site.

**REFERENCES**

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