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Pile Termination Criteria for Rock Socketed Piles in Chennai Metro Project

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Abstract. Pile termination decision at site is replete with dealing with uncertainties and challenges in identifying grade of rock in the case of rock socketed piles. This paper deals with application of pile termination criteria for some stretch inChennai Metro project. Methods of determining the criteria to decide on pile termination using rock classification, geological identification and pile termination ratio have been explored. A site friendly method for applying the pile termination at field has been executed and recommended as a guideline in this paper.

Keywords: Pile termination, metro project, site friendly method, guideline

1 Introduction

In all metro construction projects of India, large diameter bored piles are employed, with sizes varying from 1000mm-1500mm. These piles must be designed for heavy loads. Hence, socketing into the rock is essential and unavoidable. The termination of piles into the rock is not an easy exercise at the field due to degree of uncertainties involved in determination of grade of rock and suitable parameters at the field. This paper tries to develop a methodology for determining the pile termination criteria for socketed piles with due consideration to the safety of the structure.

2 Geotechnical parameters

Determination of parameters of soil and rock are still a tough engineering platform where the value of judgement is highly precious. It has also been observed quite widely in metro projects that grade of rock estimated during pre-construction stages is inconsistent with grade of rock evaluated during construction stage. Hence, a flexible and site friendly tool is required to deal with these uncertainties prevailing at estimation of geotechnical parameters.

3 Pile Termination Criteria

Hydraulic rotary rigs make penetration of piles faster in all types of rocks including hard rocks. At field, decision on pile termination is a challenging task as various inputs required for deciding the pile termination are qualitative and subjective in nature. There is a limiting value of resistance of chisel, based on pile termination decision cannot be arrived at. IS 2911 Part 1-Section 2 can be utilized for determining pile termination criteria at field based on some simple and easy tests at field. Pile termination criteria has been used as a quality control tool in IRC 78. There are various approaches to determine the pile termination. They are elaborated in the following sections.

3.1 **IS 2911 Part 1-Section 2 Method**

$$Q_a = c_{u1} N_c \frac{\pi B^2}{4F_s} + \alpha c_{u2} \frac{\pi B L}{F_s}$$

where
c_{u1} = shear strength of rock at pile base, in kN/m^2;
N_c = bearing capacity factor= 9;
F_s = Factor of safety=3;
α= 0.9;
c_{u2} = average shear strength of rock in the socketed length, in kN/m^2 ;
B = minimum width/diameter of pile shaft, in m; and
L = socket length of pile, in m.
This method is applicable when SPT value is >60.

Table 1. Shear strength of rock for various SPT values [1]

Value of N	Shear strength kN/m^2	Strength	Grade	Breakability	Penetration	Scratch
	400	Strong	A	Difficult to break against solid object with hammer		Cannot be scratched with knife
	200					Can just be scratched with knife
600	100	Moderately Strong	B	Broken against solid object with hammer		Can be just scratched by thumb nail
	80					
	60					
400	40		C	Broken in hand by hitting with hammer		Can be scratched by thumb nail
	20	Moderately weak	D	Broken by leaning on sample with hammer	No penetration with knife	

200		Weak				
	10	Hard or very	E	Broken by hand	2mm with knife	
	8					
100	6	weak	F	Easily broken by hand	5 mm with knife	
80						
60	4					

This method is quite empirical in nature. Estimation of shear strength plays a crucial role in determining pile capacity. Shear strength has been recommended in accordance with SPT values, which could not be conducted to good quality rock mass and would not be performed at field during piling. Ideally, best way to get shear strength of rock mass at site is by doing breakability and scratch tests.

3.2 **IRC 78 Method**

There are two approaches given in IRC 78. Method 1 is suggested when (CR+RQD)/2 <30 and Method 2 is recommended when (CR+RQD)/2 >30, where CR is Core Recovery in % and RQD is Rock Quality Designation in %.

<u>Method 1</u>

The ultimate load carrying capacity shall be estimated by using the following equation:

$$Q_u = R_e + R_{af} = K_{sp} q_c d_f A_b + A_s C_{us}$$

where

Q_u=Ultimate capacity of pile socketed into rock

R_e=Ultimate end bearing capacity of pile

R_f= Ultimate side socket shear resistance

K_{sp}= An empiricalco-efficient, to be referred from the Table 2.

Table 2. Values of empirical co-efficient,K_{sp} [1]

Sl.No:	(CR+RQD)/2 (%)	K_{sp}
1	30	0.3
2	100	1.2

q_c= Average unconfined compressive strength of rock core below base of pile for the depth twice the diameter/least lateral dimension of pile in MPa

d_f=Depth Factor= $1 + 0.4 \frac{Length\ of\ socket}{Diameter\ of\ socket}$

Maximum value of d_f should be 1.2.

A_b= Cross-sectional area of base of pile

A_s= Surface area of socket

c_{us}= Ultimate shear strength of rock along socket length=$0.225\sqrt{q_c}$

Maximum value of c_{us} shall be taken as 3.0 MPa for M 35 concrete. For other grades of concrete, this shall be modified by a factor $\sqrt{(fck/35)}$.

<u>Method 2</u>

This method is applicable when cores and/or core testing results are not available, or when geo-material is highly fragmented. The shear strength of geo-material is obtained from its correlation with extrapolated SPT values for 300 mm of penetration as presented in the Table below.

Table 3. Shear strength of rock for various SPT values [1]

Shear strength/Consistency	Mooderately weak	Weak	Very weak
N value	300-200	200-100	100-60
Shear strength/Cohesion in MPa	3.3-1.9	1.9-1.7	0.7-0.4

$$Q_u = R_e + R_{af} = c_{ub} N_c A_b + A_s C_{us}$$

c_{ub}= Average shear strength below base of pile, for the depth equal to twice the diameter/least lateral dimension of pile, based on average 'N' value of this region

N_c=9

In method 2, c_{us} is ultimate shear strength along socket length, to be obtained based on average 'N' value of socket portion. This also shall be restricted to shear capacity of concrete of the pile, to be taken as 3.0 MPa for M 35 concrete in confined condition, which for other strengths of concrete can be modified by a factor $\sqrt{(fck/35)}$.

Allowable capacity on the pile in both methods is given below:

$$Q_a = R_e/3 + R_{af}/6$$

3.3 IS 14593 Method

Depending upon the type of rock, any one of the following methods shall be used for computing compression capacity:

a. Based on uniaxial compressive strength of rock,

b. Based on limit pressure of rock,

c. Based on shear strength of rock, and

d. Structural strength of pile.

Based on uniaxial compressive strength of rock

Where the rock is sound, the strength of the foundation rock is generally much in excess of the design requirements, provided the walls of the discontinuity are closed and they are favourably oriented.

$$Q_s = q_c N_j N_d A_p + q_c \pi D l_s A_s \alpha\beta$$

$Q_s = Safe\ Load\ capacity\ of\ Pile$

$N_j = Empirical\ coefficient\ depending\ on\ the\ spacing\ of\ discontinuities$

$= \frac{3+S/B}{10\sqrt{(1+300\frac{\delta}{S})}}$

S=Spacing of discontinuities
B=Pile diameter
δ= thickness of discontinuities
N_d=Depth Factor=0.8+0.2 l_s/D , ≤2
l_s=socket length into rock
α=rock socket slide resistance reduction factor
β=rock socket correction factor

Based on limit pressure of rock,
This method is suited for weathered or closely jointed rocks and for soft rocks.

$$Q_u = [P_0 + K_b\left(P_1 - P_0\right)]A_p + \pi f_1 Dl_s$$

P_0=overburden pressure at the elevation of pile tip
K_b=bearing capacity coefficient depending on socket length
$P_{1=}$ limit pressure determined from pressure meter test in the zone extending two times the pile diameter above and below pile toe (top)
f_1= frictional resistance component.

Based on shear strength of rock

$$Q_a = c_{u1} N_c \frac{\pi B^2}{4F_s} + \alpha c_{u2} \frac{\pi BL}{F_s}$$

This equation is same as 3.1. In this code, Factor of safety recommended for getting allowable capacity is 6. This method is applicable for siltstone, mudstone and weathered sandstone. The partially mobilized frictional resistance offered by the soil may be neglected.

Structural capacity

The piles shall have necessary structural strength to transmit loads imposed on it, ultimately to the rock as per IS 2911 (Part l/Set 2**).**

3.4 Pile Penetration Rate Method

The concept of Pile Penetration Ratio (PPR) can be utilised in such case. The pile penetration ratio (PPR) reflects the energy in ton-meter required to advance the pile bore of one sq. meter cross-sectional area by 1 cm.
Energy E spent for N blows = 63.5 kg x 75 cm x N blows (in kg - cm units) =
E x 10^{-5} ton meter.
Area of samples is 0.758 x $(5.2)^2$ sq. cm = 21.24 sq.cm, penetrating 30 cm.
Hence PPR = 63.5 x 75 x N x 10^{-5} / (21.24x1 0^x30) =0.747 N
PPR for N = 50 = 37.35 tm/m^2/cm

and for N = 200 =149.4 tm/m^2/cm

From N values, Pile capacity can be back calculated using IS 2911 Part section 2 method/IRC Method 2.

4 Comparison

In this section, a typical case study from a stretch of Chennai Metro project is used for comparing the results obtained from various methods.

Strength/Consistency-Weak-Moderately Weak

Pile Diameter=1.2m
UCS of intact rock=50 MPa

Table 4. Comparison of Pile strength parameters by various methods

Strength/Consistency	Weak-Moderately Weak
Shear strength of rock below the base of the pile	1900 kN/m^2
Pile Diameter	1.2m
UCS of intact rock	50 MPa
Shear strength of rock below the base of the pile	2000 kN/m^2
Socket Length	3.6m
End Bearing Component as per IS 2911 Part 1 Section 2	678 Tonne
Socket Resistance as per IS 2911 Part 1 Section 2	814 Tonne
(CR+RQD)/2	50%
End Bearing Component as per IRC 78	565 Tonne
Socket Resistance as per IRC 78	275 Tonne
End Bearing Component as per IS 14593	380 Tonne
Socket Resistance as per IS 14593	633 Tonne

It is clear from the above Table that the pile capacity calculated from various methods is not matching with each other. Total pile capacity calculated using IRC method is on the lower side and shall be conservatively considered for design.
But during pile drilling, getting the values like RQD, CR, UCS is practically difficult considering huge numbers of piles involved for a metro project.

It is very difficult to penetrate through rock stratum and even penetration through 10 cm may take around 3 days sometimes. In such cases, a method of pile termination criteria based on penetration rate is recommended for speedy and safe execution of piles in such a large scale.

The input parameters as required for estimating the pile capacity are very difficult to be attained. The conservative estimation always causes delay in construction and the implication of these delays is very severe especially in metro projects. If we advise large termination lengths to socketed piles conservatively, penetration requirement will also be high. Hence, an optimisation of pile termination lengths is an important aspect in pile foundation design. In conventional methods using Indian standards and IRC codes, parameters like cohesion of rock mass, uniaxial compressive strength of intact rock play a key role. It is not logical to apply limited values of Uniaxial compressive strength of intact rock everywhere in all piles considering the extent of pile foundations available in a metro project.
Shear strength of rock mass is an input for 2 methods-IS 2911 Part 1/Section 2 method and IRC 78 Method 2. The value of shear strength assigned as per these standards is only based on empirical approaches.

Hence, a methodology based on Pile Penetration Ratio (PPR) is more economical, safe and time saving.
The correlation between PPR rate and N value can be easily derived using the formula given in IRC 78 as given below.

Table 5. Correlation between PPR and N value

N	Pile Penetration rate (PPR)	Cohesion in kPa
60	44.82	400
100	74.7	700
200	149.4	1900
300	224.1	3300
400	298.8	5000

Allowable capacity of pile has been calculated using the formula given in Appendix 5 of IRC 78-Method 2.

We need a reliable correlation between PPR and pile capacity so that we can guide the contractor during construction based on PPR values to determine the pile termination. Pile capacity required for the structure is around 6000 kN.

$$Q_a = c_{ub} N_c A_b / 3 + A_s c_{us} / 6$$

Formula reduces to

$$\frac{Q_a - c_{ub} N_c A_b / 3}{c_{us} / 6} = A_s$$

$$\frac{Q_a - c_{ub} N_c A_b / 3}{c_{us} / 6} = \pi D L_s$$

For the hinged piles resting on rock, proper seating has to be ensured. The minimum socket length should be 300 mm in hard rock, and 0.5 times the diameter of the pile The allowable end bearing component after dividing by factor of safety shall be restricted to 5 MPa. For calculation of socket friction capacity, the top rock 300 mm depth of rock shall be neglected. The friction capacity shall be further limited to depth of six times diameter of pile. Additionally, 50% of end bearing capacity has been considered for design due to chances of further reduction of end bearing capacity during construction.

Accordingly, socket length for various PPR values is derived as given below.

N	Pile Penetration rate (PPR)	Socket Length in m	Remarks
60	44.82	31.4	Frictional capacity limited to six times diameter of pile and hence socket length not feasible
100	74.7	16.9	
200	149.4	4.7	
300	224.1	1.8	
400	298.8	0.30	

If PPR is <149.4, socketed piles would not be effective and very less socket length is achieved if PPR >298.8. This would give proper awareness to site personnel regarding the penetration length and construction shall be conveniently adjusted accordingly.

5 Conclusion

Pile capacity calculated from various methods given in Indian standards is not matching with each other since the input parameters used in these methods are different. All these parameters are not easily available at field during pile drilling. A site friendly method is a method which will aid in determining pile termination criteria based on pile penetration ratio. This method has been used in Chennai Metro and was successfully executed in hundreds of piles.

References

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