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Methodology for Analysis of Socketed Piles in Weathered Rock in Mumbai Region

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ABSTRACT
This paper presents the analysis of static load tests that is carried out on axially loaded piles in Mumbai region of Maharashtra. The load settlement behavior for different diameter piles is plotted and ultimate pile capacity is estimated by using different empirical methods. The safe load is calculated by using the criteria given in IS-14593. The variation of ultimate load w.r.t. pile diameter for Mumbai region can be used to estimate the ultimate pile capacity of large diameter pile which cannot be tested up to failure. As a future scope, the study can be used to separate the end bearing capacity and shaft friction of the piles; also the relation between socket friction and pile diameter can be established.

Keywors
Pile Load Test, Load Settlement Curves, Emperical Methods, Ultimate load, Socketed Piles.

1. INTRODUCTION
The use of drilled piles socketed into rock as foundation structures is one of the best solutions when layers of loose soil overlie bedrock at shallow depths. In these cases, considerable bearing capacity can be ensured by the shaft friction in rock, even with small pile displacements (Carrubba, 1997).

The axial load carrying capacity of rock-socketed cast-in-place piles can be estimated by applying static analyses, information/data collected from pile load tests, numerical methods and empirical approaches. Load tests are conducted to determine the in situ bearing capacity and the load–deformation behavior of piles. Pile load testing provides the most reliable information for the design, because it is a large-scale, if not full-scale, model for the behavior of a designed pile in actual soil conditions.

It is believed and commonly accepted that pile load testing is the best way to determine the pile capacity and load-settlement behavior of piles. However, field load tests are unable to predict ultimate load due to limitation on application of heavy load and time for settlement particularly in case of bored piles in rock, tests have to be terminated well before the anticipated values. Therefore, there is a need for research to develop alternative methods to determine the pile capacity/settlement and load-settlement behavior of piles socketed in weak/weathered or hard rock.

The development of empirical design rules for pile shafts in rock commenced in the 1970's (Haberfield and Seidel, 1996). Emperical relations that exists gives load deformation behavior of piles or that specify the unit side shear and unit base resistance of rock sockets (Vijayvergiya, 1977; O' Neill and Hassan, 1994; Zhang and Einstein, 1998). Empirical relationships that express the unit pile resistance to the unconfined compression strength of intact rock, implicitly take into account the construction technique and are well suited for socketed piles (Carrubba, 1997).

2. PILE LOAD TEST
There are two types of tests for each type of loading (i.e. vertical, lateral and pull out) namely, initial and routine test. The various components of the test are Reaction load obtained from the Kentledge placed on a platform supported clear of the test pile. In case of load test below under-pinned structure, the existing structure if having, adequate weight and suitable, construction may serve as kentledge and Anchor piles with center-to-center distance with the test pile not less than 3 times the test pile shaft diameter subject to minimum of 2 m. Dial Gauges - Minimum 2 dial gauges for single pile and 4 dial gauges of 0·01 mm sensitivity for groups, each positioned at equal distance around the piles and normally held by datum bars resting on immovable supports

Maintained Load Method: This is applicable for both initial and routine test. In this method application of increment of test load and taking of measurement or displacement in each stage of loading is maintained till rate of displacement of the pile top is either 0·1 mm in first 30 minutes or 0·2 mm in first one hour or till 2 hrs. whichever occurs first.

3. LOAD SETTLEMENT CURVE
Figure 1 shows the typical load settlement curve which is plotted on the basis of the data obtained from the in situ test as per the above procedure.

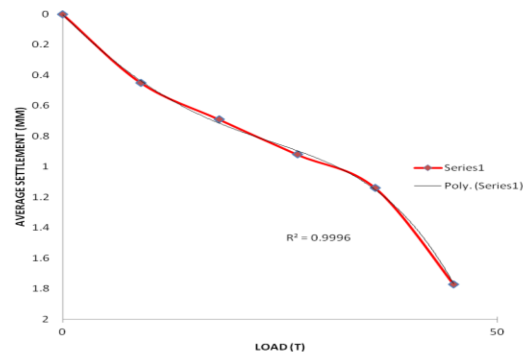

Fig. 1. Typical load settlement curve.

CRITERION FOR SAFE LOAD (IS 14593 - 1998)

Rock socketed piles are designed to carry compressive loads either in side shear or end bearing or combination of the both. This criterion is recommended for computing safe load capacity of the rock socketed pile. Safe load capacity is also evaluated from the field load settlement data. The load settlement curve is extrapolated for the regression value R^2 close to 1.

As per IS 14593 (1998), the safe load for a socketed pile is considered as the minimum of the following.

- Fifty percentage of the load at 12 mm settlement.
- One third of the ultimate failure load.

4. METHODS TO DETERMINE ULTIMATE LOADS

As per above criterion the safe load also depends on the 1/3 of the ultimate load. To evaluate the ultimate load various empirical methods have been proposed in the literature to determine the bearing capacity of piles using the results of pile load tests

4.1 De Beer Yield Load Method (1968)

De Beer made use of the logarithmic linearity by plotting the load-movement data in a double-logarithmic diagram. The intersection point of two straight lines on a log-log plot gives the magnitude of ultimate load. But the use of this method has a constraint due to the reason that, in most of the load tests, pile is not loaded up-to failure.

4.2 Van der Veen Method (1953)

Van der Veen plotted the settlement vs Ln (1-P/Pu) is drawn for various assumed values of ultimate load (P= corresponding load, Pu= assumed ultimate load and Ln represents natural logarithm). The ultimate capacity is defined as value of assumed ultimate load at which curve becomes closest to a straight line.

4.3 Chin's Method (1970)

Chin's proposed to divide each movement with its corresponding load and plot the resulting value against the movement. After some initial variation, the plotted values will fall on straight line .The inverse slope of this line is the Chin-Kondner Extrapolation of the ultimate load.

4.4 Shen's Method (1980)

Shen's plotted the Load-settlement curve with settlement vs log load coordinates and a curve with linear tail is obtained. Starting point of linear tail is defined as the ultimate load.

4.5 Decourt Extrapolation (1999)

Decourt divided each load with its corresponding movement and plotted the resulting value against the applied load. A curve that tends to a line that intersects with the abscissa. A linear regression over the apparent line (last five points in the example case) determines the line. The Decourt extrapolation load limit is the value of load at the intersection.

5. GEOLOGY OF MUMBAI REGION

Rocks in Mumbai region show various degrees of weathering and hence occur in the states ranging from fresh to highly weathered and disintegrated form, which is converted to a residual soil matrix, colloquially known as murrum. Datye (1990) briefly describes the sub-surface conditions of Mumbai region. Typical sub-surface stratigraphy in Mumbai consists of a heterogeneous fill followed by soft, compressible marine deposits in the creek areas. The change in sea bed level in the very recent geological past, marine clay and silty sand deposit sequence is found to abruptly change both in lateral extent and thickness. These layers are followed by a residual soil derived from the weathering of bedrock. The bedrock may be weak volcanic tuff, breccia or hard basalt. Compact or amygdaloidal basalt found in abundance in this region may be extrusive, hypabyssal or plutonic type. Such rocks are often fractured and jointed. Tuffaceous breccia is known to be relatively porous and in many cases yields a low core recovery.

6. SOIL PROFILE

Typical soil profile in Mumbai region is as follows:

Layer 1: This is a filled up layer of matrix (Murrum) soil varies with 0.5 to 2 m thick. It also consists of mixed soil including boulders and even waste material. SPT value shows the refusal.

Layer 2: In general this layer is formed due to deposition of marine clay. The consistency varies from very soft to stiff clay. In majority cases top 2 to 3 meters of this layer compose of organic soil. Liquid limit varies from 60% to 120%. STP value varies from 0 to 8. This deposit is classified as CI – CH

Layer 3: This is the weathered rock deposit. It is weathered from the parent rock such as basalt breccia etc. the disintegration is due to physical and chemical process. The weathered rock condition is divided in to three categories. First two categories are close to solid rock whereas third condition matches nearer to soil properties. SPT value varies from 60 to 120. The CR (core recovery) and RQD (Rock quality designation) varies from 10 to 80 and 0 to 50 respectively.

Layer4: It is the bottom most hard rock layer of amygdaloidal basalt breccia, tuff, etc. the unconfined compression strength varies from 200 kg /cm2 to 1000kg /cm2. The CR (core recovery) and RQD (Rock quality designation) varies from 50 to 100 and 30 to 80 respectively.

7. SAFE LOAD CAPACITY OF LOAD SETTLEMENT DATA FROM MILAN SUBWAY, SANATCRUZ

The observed load settlement data of foundation for the Milan subway located in Santacruz, Mumbai as shown in Fig. 2 (a).

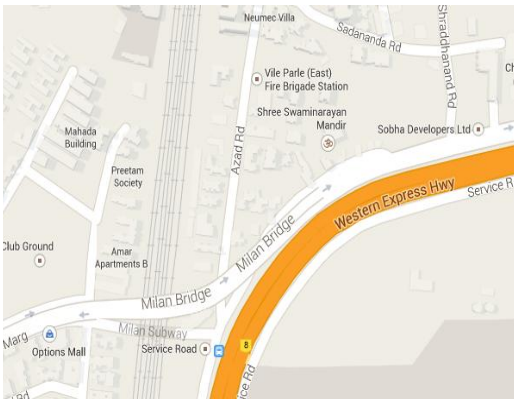

Fig. 2. a. Site location map for Milan Subway

The test pile of 1200 mm diameter is embedded for length 12.08m, including socketing depth of 6.08m. The observed and extrapolated load-settlement data is presented in Fig.2.(b).

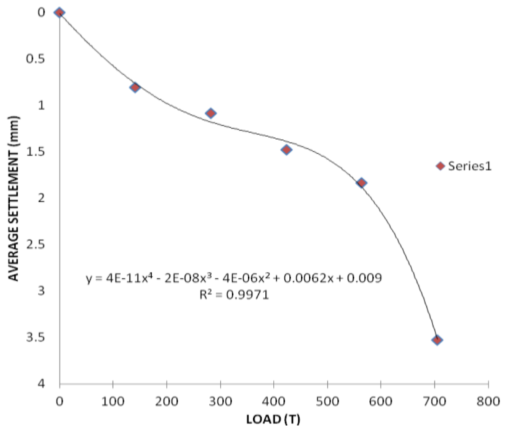

Fig. 2. b. Load settlement Data Milan Subway.

Ultimate load obtained by various empirical methods mentioned for above site are presented in fig. 3 to Fig.7.

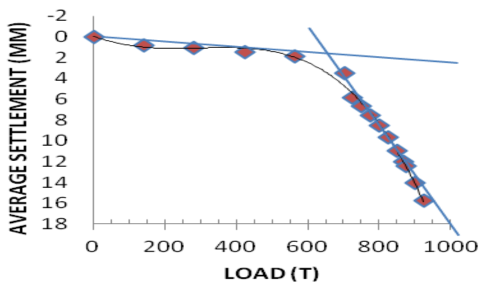

Fig. 3 De Beer yield load method (1968)

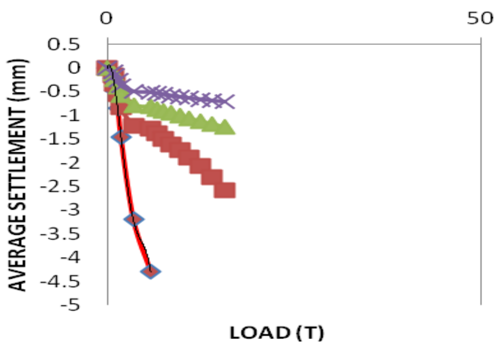

Fig. 4. Van Der Veen Method (1953)

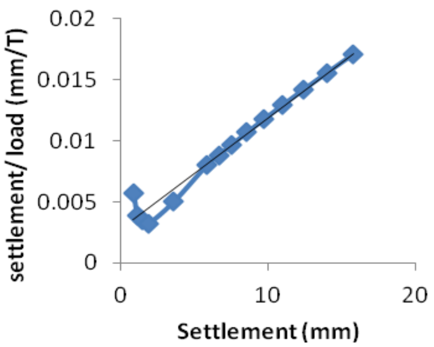

Fig. 5. Chin's Method (1970)

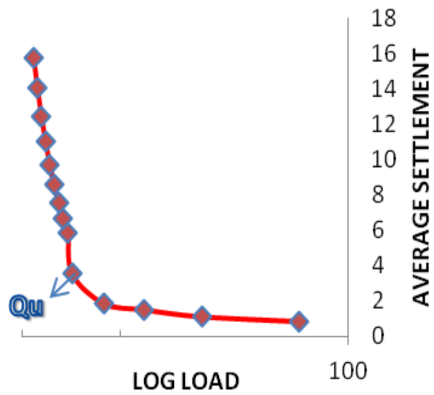

Fig. 6. Shen's Method (1980)

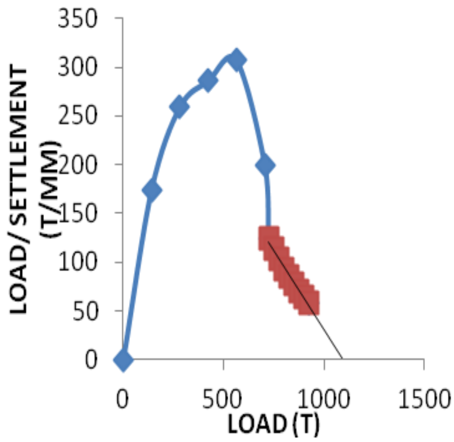

Fig. 7. Decourt Extrapolation (1999)

The ultimate loads obtained by the above empirical methods along with their respective safe loads as per IS 14593 – 1998 are presented in Table 1.

Table 1

Safe Load For Milan Subway Site At Santacruz

Empirical methods	Ultimate load (T)	50% of the load at 12 mm settlement (T)	1/3rd of the ultimate failure load (T)	Safe Load (T)
De Beer yield load method	735	434	245	245
Van der Veen Method	1800	434	600	600
Chin's Method	111.11	434	37.03	37.03
Shen's Method	705	434	235	235
Decourt Extrapolation	1100	434	366.66	366.66

8. RESULTS AND DISCUSSIONS

The Factor of safety is expressed as the ratio of the ultimate load and the Safe load. In this study the factor of safety is evaluated as dividing the ultimate load obtained from various empirical methods by safe laod from De Beers Yeild Load method calculated and presented in Table 2.

Table2: Factor of Safety

Empirical methods	Ultimate load (T)	Safe Load (T)	Factor of Safety
De Beer yield load method	735	245	3
Van der Veen Method	1800	600	7.34
Chin's Method	111.11	37.03	0.45
Shen's Method	705	235	2.87
Decourt Extrapolation	1100	366.66	4.49

9. CONCLUSION

Factor of safety (ratio of ultimate load to safe load given By IS 14593 -1998) are obtained using various empirical methods for the pile test at the Milan Subway site at Santacruz, Mumbai. It is concluded that, factor of safety as computed by Shen's Method is in the range of 2.5 to 3, whereas other methods such as Van der Veen Method and Decourt Extrapolation method are over estimating this range and Chin's Method underestimates the above range of factor of safety. Therefore Shen's Method appears to be more suitable than other method in respect to the study area.

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