An Experimental Study on the Socketed Pile in Soft Rock

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Abstract-Pile foundation systems are used in India in many projects such as metro and railways, flyovers, and multi-story buildings. The pile transfers superstructure load to the substructure, i.e. to rock layers by means of skin resistance and end-bearing resistance. In this study, an attempt is made to observe the performance of socketed piles in soft rock. A series of socketed small-scale model pile load laboratory studies have been conducted using the loading frame. Load tests were performed on a model steel pile to calculate its axial load-bearing capability at various socket depths. An unconfined compression test was performed on pseudo-rock variations to find out the properties of the soft rock used. The results showed the ability of the drilled pile to enhance the strength of the pseudo rock. An attempt was also made to calculate the optimum depth for the socketed pile in soft rock.

Keywords-pile foundation; socketed depth; settlement; axial load; model pile

I. INTRODUCTION

Utilization of socketed piles is one economical method which has been used to transfer heavy loads to the rock strata. Rock socketed piles are drilled into the rock and then filled with steel and concrete. These piles are designed to carry heavy loads by base resistance and side skin resistance. Broad diameter cast in situ piles are used to hold massive loads of super-structures. Almost in every construction project, 1000mm to 1200mm diameter piles are used. As these piles are built for heavy loads, they are basically to be lowered to the rock surface and need to be inserted into the rock [1]. The socket in the rock layer is absolutely necessary when the piles rest just on a rock at shallow depths. Boring in rock would have almost no challenge, except for occasional water pipes and boulders [2-5]. Rock sockets will pose several functional issues, usually ranging from rock classification to socket depth and actual terminating standards. Authors in [6] carried out a field pile load test by using Osterberg-cell which measures the skin friction of the pile. Authors in [7] carried out experimental investigations on the shaft friction of rock socketed piles using direct shear tests. Authors in [8] conducted numerical and experimental tests on model piles with good agreement between them. The method of [9] was applied to the field load-displacement curve to obtain the ultimate pile load. Authors in [10] presented a scale of strength and the corresponding N values for weak rock and soils. Authors in [11] introduced the chiseling energy criteria applicable for rocks of the Mumbai region. Authors in [12] suggested that almost every load, including its subsequent settlement and the corresponding magnitude, was also drawn towards the applied load. Authors in [13] investigated the case of piles in elasto-plastic rocks using finite element analysis.

Author in [14] strongly advocated the use of axisymmetric values of loads to define failure. Authors in [15] reviewed some of the methods of socket design. In their review, they recommended a range of bond values for piles socketed in shale rock. The author in [16] applied neural network modeling to compute the maximum load for a driven pile in cohesionless soil. Authors in [17] developed analytical solutions for the calculation of load-displacement response for axially loaded piles in rock. Authors in [18] proposed a simple geomechanical model for calculating the settlements of foundations in soft rock masses which showed good agreement with the field data. Authors in [19] carried out experimental studies for bond strength in rock socketed piers and stated that sidewall shear resistance essentially behaved in a non-brittle manner, i.e. it did not decrease even after the pile-rock bond was broken. Authors in [20] presented charts for rock socket design based on finite element analysis of an elastic pile resting on the elastic socket. Roughness classification and specification are shown in Table I. Authors in [21] proposed a design process for socketed pile in a soft rock complying with the defined settlement requirements and providing an appropriate factor of safety. Authors in [22] proposed a design method, which used parameters based on a wide range of theoretical, laboratory, and field investigations.

II. PILE SOCKETING

If the diameter of the pile is 1.2m, the rock socket is to be completed by breaking the hard rock for a length of 1.2m. For chiseling in hard rock, whose crushing strength is $1000 kg/cm^2$, more time is required. Each of these components may cause serious damage to a rock mass. The load is carried by the pile

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on the rock by point bearing. This makes necessary to socket the pile through the rock by breaking across the weak rock and by cutting down the hard rock for an appropriate depth generally to get the flat surface of the rock. This appropriate depth can vary between 200 and 400mm [23]. Also, if the soft or medium rocks precede the hard rock, each length of the socket can be considered from the level where soft rock has an N value higher than 50. There are variations in the form of the rock almost every time. It can be weathered rock, soft rock, or hard rock. Firstly, rock layer classification must be conducted. For this reason, we refer to field test reports such as RQD and SPT [24, 25]. For larger constructions like flyover and high-rise buildings, soil study must be conducted beneath every pier position. Hence, the above-mentioned studies are crucial to be performed for every pier site. [26-28].

TABLE I. ROUGHNESS CLASSIFICATION OF ROCK SOCKETS [18]

Roughness classification	Specification
R1	Soft socket, grooves less than 1mm deep
R2	Depth of grooves 1 to 4mm, spacing 50mm to 200mm, width > 2mm
R3	Depth of grooves 4 to 10mm, spacing 50mm to 200mm , width > 5mm
R4	Depth of grooves > 10mm, spacing 50mm to 200mm , width > 10mm

III. TECHNIQUES FOR ASSESSING SOCKETED PILE LENGTH IN ROCK

There are two different techniques used for the calculation of the socketed depth of piles in rock.

A. On the basis of Uniaxial Compression Strength Method

Rock socketed pile is primarily executed to make use of the complete structural strength of the pile. Sockets are built to hold the axial load through the side friction and the base resistance. It is important to gather all the information described above. In this regard, the elemental composition of the rock at the foundation stage should also be collected for the detection of chemical components influencing the capacity of the pile. The safe load-carrying capabilities of the socketed pile can be determined by the uniaxial compression strength of the rock.

B. Determination by the Energy Criteria Method

The configuration of the rock socket depth of the pile in the rock can be determined based on energy criteria. Rock socketing standards have a great deal of significance in weathered/soft rock. Core recovery ratio/rock content classification is the optimal measure to assess the rock type. It's hard to have the cores in the weathered/soft rock. The approach proposed in [10] is commonly used to determine the depth of the socket of the piles in soft-rock to obtain the ability of the pile and its structural strength. N values are used to describe the rock type and its shear strength. In fact, another technique uses a chisel to decide the form of the rock and the depth of the socket. The key points to be considered in the chisel energy system are the weight of the chisel, the number of blows, and the penetration into the rock for a predetermined number of blows. While this method appears to be more realistic and rational, it has many disadvantages, such as the strength of the chisel, the chisel dropping into the bentonite mixture, the mass of the chisel, and its type. Chisel energy is measured based on the findings of the load test carried out in those regions.

C. Steps to Follow During Rock Socketing

Other than drilling the rock up to the necessary depth in the rock socket, certain more important functional considerations need to be noticed. The heavy chiseling of high torque drilling can create vibrations during the rock socket operation. Such vibrations can allow the soil strata to destabilize the rock base and the pile would lose the resistance component of these levels. Therefore, better care must be taken to minimize disturbances. Rock socketing requires a longer time and often disturbs the layers by laying the rock strata. This disruption would allow the fine particles to break down and settle down at the bottom. In order to clear these small pieces and other boulders, the borehole must be thoroughly washed with a clean bentonite solution prior to the concreting process.

IV. EXPERIMENTAL PROCEDURE

Rock socketed pile load testing is an experiment to be performed in the lab with the intention of providing more data on the load transfer behavior in socketed piles with varying L/D ratios. The typical sub-surface profile of soft-rock socketed pile is shown in Figure 1. After the application of P downward axial load on the top of the pile, equal and opposite reaction is developed at the pile in the upward direction. Q base is the base resistance. The length of the weathered stratum and the length of the soft-rock stratum represent the skin friction in different layers.

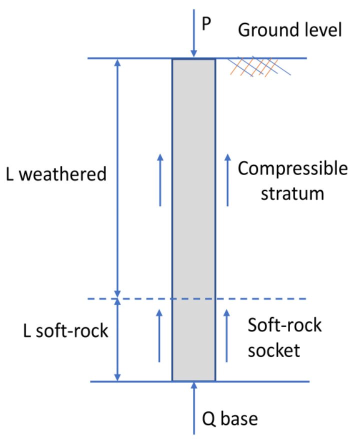

Fig. 1. Typical sub-surface profile of the rock socketed pile.

A. Model Pile Material and Tank

A stainless steel hollow pipe was used, having two different diameters of 60mm and 80mm and a length 600mm. The steel tank is made up of mild steel material whose dimensions are 1000×1000×1000mm and 6mm thickness. The front side of the tank is made up of a Perspex sheet to observe failure patterns during testing. The tank can be moved in the x and y directions under the load frame in order to apply centric and eccentric loading.

B. Devloping of Pseudo-rock Socket

For pseudo-rock formation cement, sand, bentonite, and water were used. Model rock specimens were developed, although their strengths varied widely. Table II provides the description of the ingredient proportions for pseudo-rock. The percentage of sand and water were kept constant and the percentage of cement and bentonite increased and decreased simultaneously. Unconfined compressive strengths, as shown in Figure 2, were determined by the Compression Testing Machine (CTM) after 28 days of curing.

Fig. 2. Testing of mortar cube and cylinder in the CTM.

TABLE II. MORTAR CUBE TEST RESULTS FOR DIFFERENT BENTONITE PERCENTAGES

Mix	Cement (%)	Bentonite (%)	Sand (%)	Water (%)	Avg. UCS (MPa)
M1	17.97	4.5	67.41	10.11	19.3
M2	15.73	6.74	67.41	10.11	16.7
M3	13.48	8.98	67.41	10.11	9.5
M4	11.23	11.23	67.41	10.11	4.7
M5	8.9	13.48	67.41	10.11	3.4
M6	6.74	15.73	67.41	10.11	1.9
M7	4.5	17.97	67.41	10.11	1.2

V. EXPERIMENTAL SET-UP

A hydraulic jack attached to the frame's bottom allowed the gradual application of axial load to the pile head throughout the experiment. A load cell was attached between the hydraulic jack and the loading frame. Therefore, two Linear Variable Differential Transformers (LVDTs) were installed on the wing plates, fastened to the opposing sides of the pile cap to measure the movement of the pile head. The whole assembly, including the hydraulic jack, has a capacity of 30kN. An initial load of 0.2kN was applied before initiating any load increments. Loads were applied in increments of 0.25kN up to 1kN, thereafter at 1kN increments until failure or 30kN whichever was earlier. A digital displacement monitor linked to the LVDTs recorded movement readings when each load was applied. We kept increasing the load until the rate of change in the pile movement was minimal. The schematic view of the experimental setup and the actual pile load test setup are presented in Figure 3 and 4 respectively. L/D ratios 1 to 7 were used for the testing program, where D is the diameter of the pile and L is the socketed length of the pile. Details of the testing program for 60mm diameter pile and 80mm diameter pile are given in Tables III and IV respectively. Different unconfined strengths of soft rock were used.

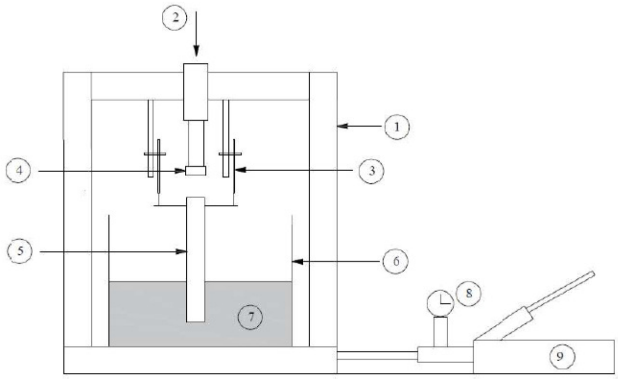

Fig. 3. Schematic view of the experimental setup (1= loading frame, 2= hydraulic jack, 3= LVDT, 4= load cell, 5= model pile, 6 = metal tank, 7 = pseudo rock, 8 = pressure indicator, 9 = hydraulic pump).

Fig. 4. Actual pile load test set-up with LVDT and load cell.

VI. RESULTS AND DISCUSSION

The behavior of load-settlement curves is discussed in this section. Based on the experimental results, the load-settlement response and the load transfer mechanism along the depth of the pile are discussed. All the piles were gradually loaded until failure to obtain their axial load-carrying capacities. Two different diameter piles were used in the testing program. The load vs displacement curves for the 60mm diameter piles are shown in Figure 5. A number of experimental model studies were carried out to determine the impact of the socket depth on the behavior of the in situ cast piles. Seven sets of experiments with different socket lengths of 1D, 2D, 3D, 4D, 5D, 6D, and 7D, where D is the diameter of the pile in pseudo rock were used in the testing program. With the help of the load settlement curve, the ultimate pile capacity was calculated.

TABLE III. DETAILS OF MODEL SOCKETED PILE LOAD TESTS ON SOFT ROCK FOR 60mm DIAMETER PILE

Test no.	Pile no	L/D	Socket length (mm)	Avg. UCS (MPa)
1	P1	1	60	9.45
2	P2	2	120	9.43
3	P3	3	180	9.36
4	P4	4	240	9.40
5	P5	5	300	9.21
6	P6	6	360	9.64
7	P7	7	420	9.33

TABLE IV. DETAILS OF MODEL SOCKETED PILE LOAD TESTS ON SOFT ROCK FOR 80mm DIAMETER PILE

Test no.	Pile no.	L/D	Socket length (mm)	Avg. UCS (MPa)
1	P1	1	80	9.30
2	P2	2	160	9.45
3	P3	3	240	9.46
4	P4	4	320	9.40
5	P5	5	400	9.31
6	P6	6	480	9.54
7	P7	7	560	9.43

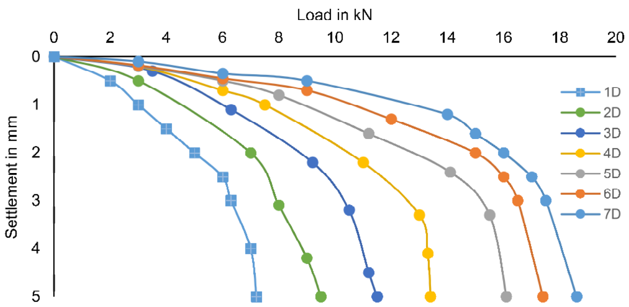

Fig. 5. Comparison of load vs. settlement curves for 1D -7D socketed piles for 60mm pile diameter.

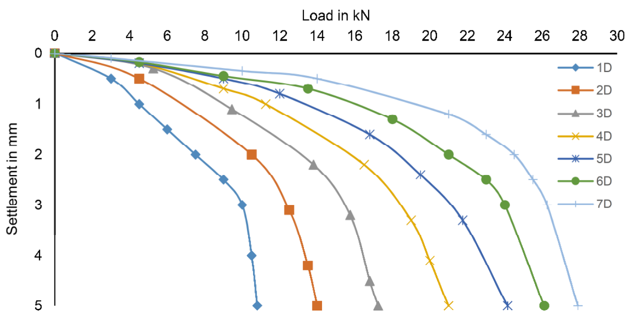

Fig. 6. Comparison of load vs. settlement curves for 1D -7D socketed piles for 80mm pile diameter.

The load was applied incrementally up to 30kN and the corresponding vertical displacements were recorded. For 1D, 2D, 3D, 4D, 5D, 6D, and 7D socketed depths, the observed axial pile capacities by the double tangent method were 6.2kN, 9.1kN, 11.2kN, 12.8kN, 15.3kN, 16kN, and 16.6kN respectively. The load vs displacement curves for 80mm diameter piles are shown in Figure 6. The loads were applied and the corresponding vertical displacements were recorded. For 1D, 2D, 3D, 4D, 5D, 6D, and 7D socketed depths, the axial pile capacities were 10.8kN, 14.1kN, 17.25kN, 21.1kN, 24.15kN, 26.1kN, and 27.9kN respectively.

The compression measurements on the model piles demonstrate that the pile resistance increases as the depth of the socket increases, which is essentially due to the friction between the pile and the socketed rock. Up to a length of 4D to 5D of socket depth, the capacity of the pile was observed to increase considerably, but after 5D socket length, the improvement in the pile capacity was marginal. This marginal increase in strength was caused by the decrease in strength of the material and low pile stiffness. So, it can be concluded that 5D of the length of socket is the optimum depth of the socketed pile in soft-rock. This is consistent with the observations of [7, 11].

VII. CONCLUSIONS

In the present study, an effort has been made to analyze the minimum depth of the socketed pile in soft rocks. The behavior of piles in the soft rock was studied through an elaborate laboratory program, with varying socket lengths. A large number of pseudo rock samples using cement and bentonite were made by changing the proportions of cement and bentonite (7 mixes, termed as M1-M7, having UCS values of up to 19.3MPa were prepared and tested). The present study demonstrated that the behavior of socketed piles can be successfully modeled in a soft rock. The results of the present model study and the reported data in the literature are in accordance. The conclusions of the experimental program are:

- UCS strengths were found to decrease as the proportion of bentonite increased in the pseudo-rock.
- Pile capacity increases dramatically for socket length up to 5D, but this is minimal above a length of 5D.
- As the diameter of the pile increases, the ultimate load capability of the pile also increases.
- The experimental results indicate that when the diameter of the pile increases by 35%, the loading capacity at the top of the pile increases by around 50%.

It should be noted that the conclusions shown above are based on laboratory testing with a 1-g model. Because the behavior of piles in rock is stress-dependent, which is not properly simulated in 1-g model testing, full-scale/centrifuge test data under axial loading are necessary to verify the above-mentioned conclusions. Therefore, these results may be very useful as both a firsthand description and as a resource for numerical verification.

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