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PERFORMANCE-BASED OPTIMIZATION OF PILE SOCKET DESIGN IN SRI LANKAN METAMORPHIC BEDROCK

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ABSTRACT: Pile socketing into bedrock is a common foundation technique in Sri Lanka. However, current design practices remain excessively conservative, leading to unnecessary construction costs. Despite the prevalence of competent metamorphic rocks, local designers continue to apply methods developed for sedimentary formations, significantly underestimating the available skin friction capacity. Field load tests have demonstrated that actual mobilized skin friction values frequently exceed design predictions by up to three times, as per local design guidelines. This conservatism stems from the use of high safety factors (often 3.0 or more) and outdated assumptions regarding rock-concrete interface behaviour. This study investigates the optimization of pile socket design by critically evaluating current practices and proposing data-driven improvements. Through an extensive review of case studies and pile load test results across Sri Lanka, the research highlights discrepancies between theoretical predictions and actual field performance. The analysis focuses on key parameters influencing socket capacity, including rock quality, socket roughness, and construction techniques specific to metamorphic formations. The findings reveal that existing design approaches fail to account for the superior mechanical properties of Sri Lanka's crystalline bedrock, resulting in over-designed and costly foundations. This study develops refined design recommendations that reduce reliance on excessive safety margins while ensuring structural reliability. The proposed optimization framework has the potential to achieve significant cost savings of 50% in foundation construction without compromising safety. This research provides a foundation for updating national design standards and promotes more efficient use of Sri Lanka's favourable geotechnical conditions. The outcomes will benefit practicing engineers, contractors, and clients by enabling more economical, yet safe pile designs. Future studies should expand the database of load test results to further validate and refine the proposed methodology.

Keywords: pile socket design, skin friction, metamorphic rocks, foundation optimization, load test analysis

1 INTRODUCTION

A load applied to a pile is transferred to the ground through both friction and end bearing. This whole process depends on the pile settlement and the resistance of the subsurface layers against settlement (Thilakasiri, 2009). Upon applying a load, resistance is generated on the surrounding surface of a pile. After fully mobilizing skin resistance, the remaining component is borne by the base resistance (Murthy, 2002). Despite the presence of favourable bedrock conditions, most local designers employ conventional conservative design practices such as those specified by ICTAD (1997), the Hong Kong Guidelines (Geotechnical Engineering Office, 2006), and the Williams and Pells method (Williams and Pells, 1981) which are suitable for sedimentary rock conditions in calculating the skin friction capacity of rock-sockets. Furthermore, designers incorporate the effect of the Bentonite filter cake into the design of skin friction capacity by dividing the obtained value by a safety factor of 4 (Wyllie, 1991) which results in very low design capacities for skin friction.

However, some case studies have found that the mobilized skin friction capacity of the socketed regions of local piles is more than twice the design values obtained from the ICTAD guidelines (Institute for Construction Training and Development, Sri Lanka) (Thilakasiri et al., 2015). Therefore, it suggests that these design methods are overly conservative and ultimately impose significant costs on pile construction by unnecessarily increasing the socketing length to account for the underestimation of the skin friction capacity of metamorphic rocks. Therefore, focusing exclusively on the characteristic of metamorphic bedrock in Sri Lanka and South Asia, this study provides a pioneering analysis of mobilized skin friction, a vital parameter for safe and economical pile design that has previously relied on conservative models.

2 METHODOLOGY

The results of the Maintained Load Test (MLT) along with borehole log data obtained from a database maintained by researchers of a parallel study (Samarawickrama et al., 2023; Ruwanpathirana, 2023) were used to obtain designed and mobilized skin friction capacities. Table 1 depicts the details of 15 piles used in the analysis.

Table 1. Pile details

Pile ID	Project Name & Pile No	Pile Dia. (mm)	Pile Length (m)	Socket Length (m)
1	Proposed Port Access Elevated Highway (PAEH)-TP-70A	1200	45.00	16.90
2	Proposed Port Access Elevated Highway (PAEH)-TP-39	1200	10.00	3.50
3	Central Expressway Project (CEP-2)-VD-05-P13-R2	1500	13.33	3.33
4	Central Expressway Project (CEP-2)-VD-06-P7-R2	1200	15.60	3.70
5	Central Expressway Project (CEP-2)-VD-06-P5-L2	1800	7.40	3.40
6	Maga Head Office -T2-TP1	1500	28.28	5.38
7	Prime Residency Ward Place-P-03	1500	39.60	6.60
8	Southern Expressway Project-P4L1	1800	54.39	1.89
9	Southern Expressway Project-P33R1	1800	38.22	9.88
10	Southern Expressway Project-P23L1	1500	14.00	3.00
11	Southern Expressway Project-P17L3	1500	13.00	4.50
12	Colombo Port City Project-P310-SPS01	900	15.20	3.70
13	Kelani Bridge Project-PRC2P17	1500	25.70	3.80
14	Central Expressway Project-(CEP-01)-TP-01	1500	23.90	6.90
15	Apartment complex for Prime Land residencies, Kelaniya	1000	29.40	5.40

Only 4 Instrumented Maintained Load Tests (IMLTs) were used in this analysis as the industry generally avoids performing IMLTs due to the high costs involved (Samarawickrama et al., 2023). These IMLTs found the skin friction mobilized in the socketed regions directly and accurately compared with the MLTs (Samarawickrama et al., 2023). The results of the MLTs were used to estimate the total skin friction of the pile by using the Chin (1978) method (Thilakasiri, 2009).The friction mobilized by the rock socket ($f_{s,\text{rock}}$) was obtained by deducting the friction taken by soil layers using the Bowels (1996) method.

Next, as recommended by Williams and Pells (1981), the theoretical skin friction capacity was calculated using borehole data. Equation (1) gives the total theoretical skin friction at the socketed region.

$$f_{us} = \frac{\sum(h_n f_{usn})}{\sum h_n} \tag{1}$$

where f_{us} is the total ultimate skin friction capacity, h_n is the rock layer thickness, and f_{usn} is the skin friction capacity of the respective layer. However, Wyllie (1991) has recommended a 75% reduction of ultimate skin friction capacity with the presence of Bentonite as the drilling fluid. Hence the theoretical skin friction capacity obtained by Williams and Pells (1981) method was divided by factor of safety 4 to obtain the recommended theoretical skin fiction. Finally, the theoretical estimation obtained from the recommendations of Wyllie (1991) was compared with the mobilized skin friction found by the Chin method to identify the possible optimizations for rock socket design.

3 RESULTS

As specified in the Chin (1978) method, the graph of settlement upon load (S/P) against settlement (S) was drawn and is shown in Figure 1. The gradient m_1 gives the total skin friction capacity mobilized by the pile.

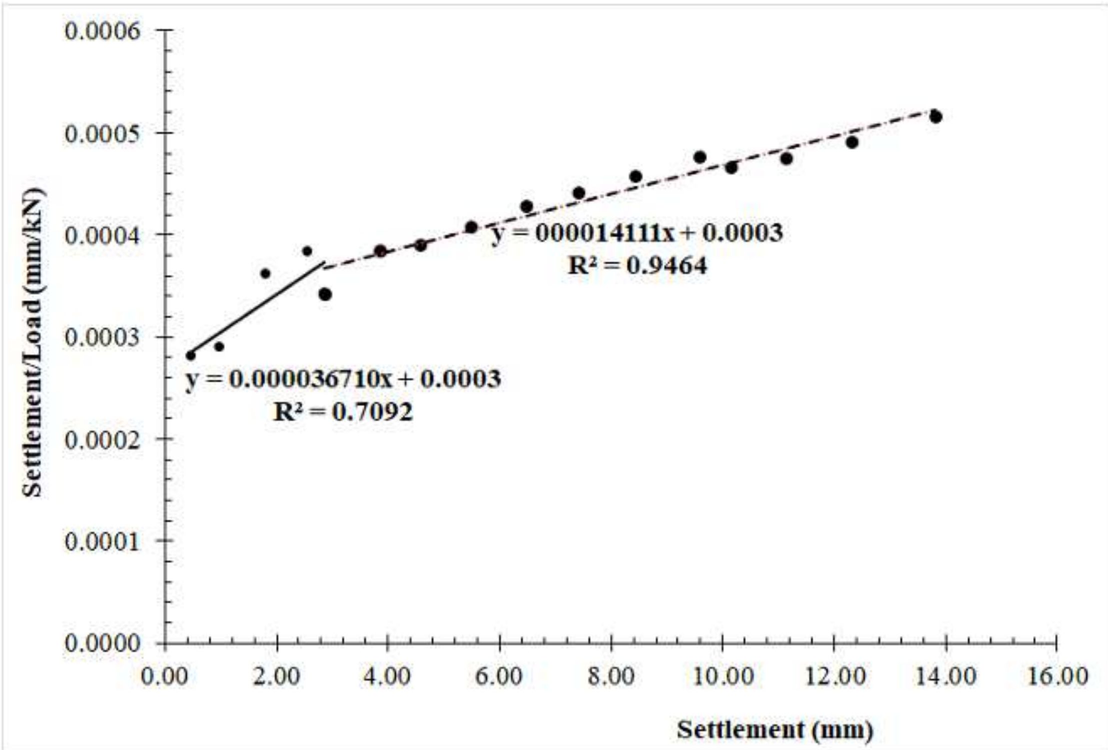

Figure 1. Settlement/load against settlement of pile ID 14

According to the linear regression model shown by the gradient m_1 for Pile ID 14, $\frac{S/P}{S}$ = 0.000036710 and the overall friction $1/m_1$ = 27240.77 kN. The friction mobilized by the rock socket is 0.803 MPa. The mobilized skin friction estimated for the socketed region by the Chin (1978) method and the theoretical estimation of f_{us} for all 15 piles are summarized in Table 2.

Table 2. Summary of Mobilized vs. Theoretical Skin Friction Capacities for 15 Test Piles

Pile ID	f_{su} (MPa), (Williams and Pells method, 1981)	Allowable f_{su} (MPa) with Bentonite Effect (Wyllie, 1991)	Mobilized skin friction (MPa), (Chin (1978) Method)	% of the mobilized to the theoretical estimation
1	0.777	0.194	0.728	375%
2	3.583	0.896	2.650	296%
3	1.282	0.321	1.393	435%
4	1.365	0.341	1.159	340%
5	1.575	0.394	0.708	180%
6	1.767	0.442	2.046	463%
7	0.796	0.199	1.295	651%
8	0.975	0.244	0.006	2%
9	0.537	0.134	0.678	505%
10	1.069	0.267	0.694	260%
11	1.369	0.342	1.253	366%
12	1.985	0.496	1.490	300%
13	1.109	0.277	0.728	263%
14	1.406	0.352	0.803	228%
15	1.306	0.327	0.837	256%

4 DISCUSSION

Local guidelines recommend an ultimate skin friction value of 0.2 MPa for completely weathered rock sockets, with a design value of 0.1 MPa. For all other bedrock types, designers estimate theoretical skin friction using the Williams and Pells (1981) method, applying a safety factor of 4 as recommended by Wyllie (1991) (Institute for Construction Training and Development, Sri Lanka, 1997). These values underestimate the actual skin friction and hence skin friction is neglected in most designs. The values obtained using the Chin (1978) method were compared with the theoretical mobilized skin friction obtained considering the effect of Bentonite (Wyllie, 1991). Accordingly, the mobilized skin friction values recorded a variation of 200% to 700% of the theoretical estimation, except the case of pile ID 8. In Pile ID 8, 0.006 MPa skin friction is mobilized in the socketed region since the entire skin friction was borne by the soil layers and has not yet been transferred to the rock layers.

5 CONCLUSION

When designing piles, if Bentonite is used as the drilling fluid, the theoretical skin friction capacity is divided by 4 (Wyllie,1991) to obtain the design load. However, these values are very conservative and therefore result in high pile construction costs. As shown by the calculations above, it is evident that the percentage of mobilized skin friction relative to the theoretical estimation exceeds 200% in almost all cases considered here. Hence, considering safer design principles, the pile socket design can be optimized by at least 200% leading to a reduction in rock socketing by at least 50%, especially in the metamorphic bedrock found in the South Asia region.

6 REFERENCES

Chin, F. K. (1978). *Introduction to rock mechanics* (Vol. 9). The Fifth Southeast Asian Conference on Soil Engineering.

Geotechnical Engineering Office. (2006). *Foundation design and construction* (Geo Publication No. 01). Civil Engineering and Development, The Government of the Hong Kong Special Administrative Region.

Institute for Construction Training and Development, Sri Lanka. (1997). *Guidelines for interpretation of site investigation data for estimating the carrying capacity of single piles for design of bored and cast in-situ reinforced concrete piles* (ICTAD/DEV/15).

Murthy, V. N. S. (2002). *Geotechnical engineering: Principles and practices of soil mechanics and foundation engineering*. CRC Press.

Ruwanpathirana, R. S. (2023). *Predicting the end bearing capacity of rock-socketed bored and cast in-situ piles in Sri Lankan metamorphic rock using rock mass properties* [Master's thesis, University of Moratuwa].

Samarawickrama, M. N. C., Puswewala, U. G. A., Thilakasiri, H. S., & Udamulla, K. M. L. A. (2023a). Review on the estimation of static deformability modulus of rocks and their adoptability in different rock masses. *Engineer: Journal of the Institution of Engineers, Sri Lanka, 56*(3), 99–120.

Thilakasiri, H. S. (2009). *Construction & testing of piles* (1st ed.). Sarasavi Publishers.

Thilakasiri, H. S., Abeyasinghe, R. M., & Peiris, T. A. (2015). Optimization of the designing of bored and cast in-situ piles in Sri Lanka. In *Proceedings of the International Conference on Geotechnical Engineering* (pp. 253–256). Sri Lanka Geotechnical Society.

Williams, A. F., & Pells, P. J. N. (1981). Side resistance of rock sockets in sandstone, mudstone, and shale. *Canadian Geotechnical Journal, 18*(4), 502–513. https://doi.org/10.1139/t81-064

Wyllie, D. C. (1991). *Foundations on rock* (1st ed.). E & FN Spon.