Second International Conference on Geotechnique, Construction Materials and Environment,
Kuala Lumpur, Malaysia, Nov. 14-16, 2012, ISBN: 978-4-9905958-1-4 C3051

Bored Pile Socket in Erratic Phyllite of Tuang Formation

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ABSTRACT

This paper highlights a case study where about 950 nos. of cast in-situ bored piles were used as a deep foundation system to support a large manufacturing plant in suburban Kuching, Sarawak, Malaysia. Localised moderately-strong metamorphic metagreywacke and extrusive igneous andesite are found occurring together with the more dominant but erratic, metamorphic phyllite due to regional metamorphism. Such combination of geology requires stringent quality control during construction to ensure sufficient bored pile socketing lengths into the mostly erratic phyllite. For this very reason, 33 nos. of Pile Dynamic Analyzer (PDA) and 4 nos. of Maintained Load tests were carried out to determine the ultimate static capacities of the installed bored piles. The PDA and Maintained Load test results show that all the tested piles meet the pre-determined design working loads.

Keywords: phyllite, socket, Tuang formation, point load test

1 INTRODUCTION

The project location has been found to be influenced by contrasting geology that consists of the Padawan (mainly sedimentary), Tuang (mainly metamorphic) and Quaternary formations. Localised moderately-strong metamorphic metagreywacke and extrusive igneous andesite are found occurring together with the more dominant but erratic metamorphic phyllite due to regional metamorphism. The Tuang formation has been noted to be most prominent during construction, evidenced by the abundant encounters with the friable and erratic phyllite. The construction of the large manufacturing plant required thorough understanding of the underlying geology. A cast in-situ deep foundation system was recommended for the plant due to heavy imposed loads and limited tolerance to differential settlement. For the foundation system to be effective, sufficient socketing length is required into the erratic phyllite. This paper is an extension of Ong & Choo (2011) [1].

2 SITE GEOLOGY

The proposed deep foundation system was socketed in geology comprising mostly of moderately weathered phyllite, and flanked at the site boundaries with intrusions of moderately to completely weathered shale and strong moderately weathered andesite. These geological conditions are synonymous with the Tuang Formation, and to a lesser extent the Padawan and Quaternary formations. The manifestation of the metamorphic phyllite rock in the Tuang Formation is characterised by semi-schistose features, further evidenced by the parallel arrangements of distinct cleavages and grains, occasionally interbedded with discrete bands of quartz and calcite.

Recovered cores of phyllite mostly revealed RQD values of 0%, up to a maximum of 75%. Fig. 1 shows phyllite cores with Total Core Recovery (TCR) of 100% but having Rock Quality Designation (RQD) of 0%. This observation is consistent with indications reported in Tan (1993) [2]. If RQD is used as a measure of rock strength for design purpose, then literally phyllite has zero strength! However, as a homogenous rock mass underground, it is impossible that phyllite has no strength!

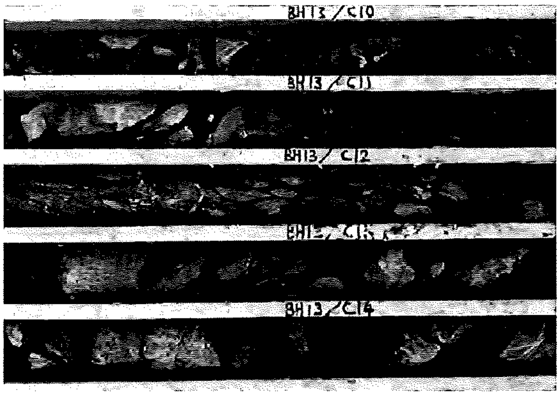

Fig. 1. Discontinuous and highly fractured cores of phyllite

3 BEHAVIOUR OF ERRATIC PHYLLITE

An overview of RQD and the Unconfined Compressive Strength (UCS) tests on the phyllite rock cores is presented in Fig. 2. Due to the relatively low RQD values, it was only possible to conduct UCS tests on 14 of the 194 core runs extracted (12.4%). A conservative approach for the design of deep foundations in rock considers that the pile capacity is attributed only to the rock strength. Hence, it is critical to determine the socketing length required for piled foundation systems. The requirements of the manufacturing plant also warranted the use of a piled foundation system to mitigate serviceability issues, such as differential settlement and pile movements. Given such conditions, the erratic phyllite behaviour provides serious challenges to designers.

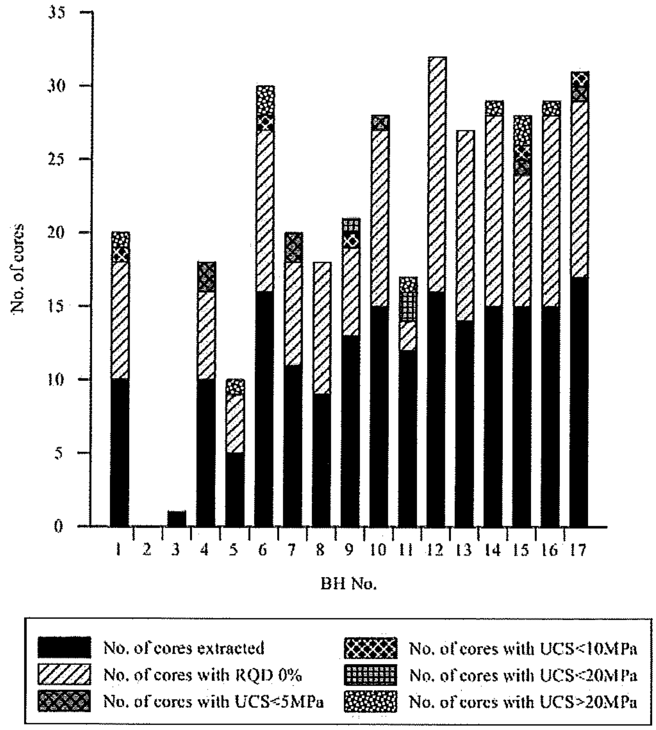

Fig. 2. Overview of RQD and UCS tests on phyllite cores (per 1m run)

3.1 Point load test on site

The outcome of the soil investigation works signalled expected difficulties in verification of socketing material during the construction of the deep foundation system. The occurrence of phyllite as well as its RQD values has been observed to be very low, most likely due to its friableness. As such, point load testing was suggested to be used as a complementary index test to help correlate the UCS values tested on the limited and unpredictable solid cores of phyllite.

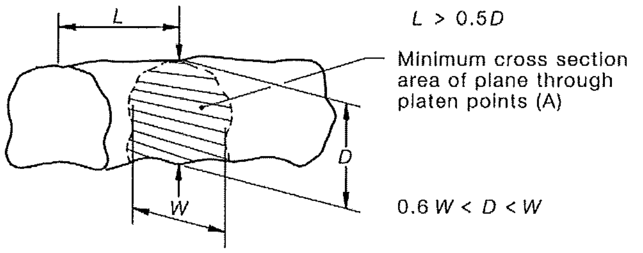

Fig. 3. Shape proportion for point load testing on irregular lumps (AS 4133.4.1-2007).

The point load testing apparatus was deemed suitable for field use due to its simple operation. The procedures outlined in AS 4133.4.1-2007 [3] were preferred for carrying out point load testing due to the allowances for tests to be carried out on irregular lumps. Requirements for sample size restricted testing to be performed on lumps with aspect ratios illustrated in Fig. 3. Irregularly-shaped test samples for verification purposes were collected from spoils during boring. Fig. 4 shows rock samples collected from various coring depths, which were subsequently collected for point load testings on site.

Fig. 4. Excavation spoils collected from various boring depths.

3.2 Review of test results

Table 1 shows the summary of results for 3 types of tests carried out as an attempt to characterise phyllite, namely (i) Point Load Index test on lump samples, (ii) Point Load Index test on rock core (axial direction) and (iii) Unconfined Compression Strength (UCS) test. It can be seen that the average Point Load Index, I_{s50} value for lump samples within depths of 10.0m-11.9m, 12.0m-13.9m, 14.0m-15.9m and 16.0-17.9m are 3.094MPa, 3.749MPa, 3.866MPa and 3.654MPa, respectively. No lump samples were available for depths exceeding 18m as the preliminary design did not warrant any bored pile socket length greater than 18m. Despite the consistency of the average values over the various depths as reported, the standard deviations are rather poor i.e. at 2.033MPa, 2.838MPa, 2.696MPa and 2.510MPa, respectively. In other words, if assumed on a normal distribution probability density function, the probability of getting the average I_{s50} value of 3.753MPa over the 374 samples is only about 15.1%.

Table 1 further shows the difficulty of obtaining intact core samples (minimum 14.1mm in length) for Point Load test (axial direction) between depths 10m and 14m due to the friableness of the phyllite at the upper depths. Between depths of 14.0m-15.9m, 16.0-17.9m and 20.0m-21.9m, the average I_{s50} values for intact cores tested on axial direction are 0.745MPa, 1.235MPa and 1.256MPa, respectively. The standard deviations recorded are 0.120MPa, 0.12MPa and 0.730MPa, respectively. If interpreted on a normal distribution probability density function, the probability of getting the average I_{s50} value of 1.138MPa over the limited number of 9 samples is about 43%.

Since UCS test requires intact rock core of at least 94mm in length, relatively competent phyllite is only available from 16m depth as shown in Table 1. At depths of 16m-17.9m, 18m-19.9m 20-21.9m, 22m-23.9m and 26m-27.9m the average UCS values obtained are 9.53MPa, 4.45MPa, 5.2MPa, 9.33MPa and 12.06MPa, respectively. The standard deviations recorded are 2.051MPa, 3.286MPa, 4.030MPa, 5.629MPa and 17.519MPa, respectively. If interpreted on a normal distribution probability density function, the probability of getting the average UCS value of 8.259MPa over the 14 samples is only about 4%.

Therefore, surprisingly as a summary on testing in this study, it seems that the most reliable way of statistically measuring the phyllite rock strength is via the Point Load (axial core) as compared to Point Load lump and UCS testing methods.

suggested by Williams et al. (1980) [4] and recommended for use by Ting and Fuad (2003) [5] for metamorphosed sedimentary rocks comprising a sequence of slate and phyllite intercalated rhythmically with greywacke sandstone found at the Batang Rajang Bridge site in Sarawak. In the absence of a more systematic design procedure for phyllite, Ting & Fuad (2003) [5] suggestion is hence adopted for use in this study as it is perhaps the closest empirical representation to phyllite for this case study.

During the design stage when only UCS and I_{s50} (axial core) values were available, based on judgment and literature review of Basu & Kamran (2010) [6] and Ting & Fuad (2003) [5], a preliminary design USC value of 7.4MPa is assumed and this value must be verified through pile load tests performed on sacrificial piles on site. A factor of safety of 2.0 has been used in the design of the bored piles.

Table 1. Summary of test results based on UCS and Point Load test on phyllite

	Information available only during design stage						**Information available only during construction stage**		
	PLT (axial core)			**UCS**			**PLT (lump sample)**		
Depths where phyllite are tested	**No. of samples**	**Ave. I_{s50} (axial core) (MPa)**	**Std dev (axial core) (MPa)**	**No. of samples**	**Ave. UCS (MPa)**	**Std dev on UCS (MPa)**	**No. of samples Lump for I_{s50}**	**Ave. I_{s50} (lump sample) (MPa)**	**Std dev (lump sample) (MPa)**
Depth 10m-11.9m	0	N/A	N/A	0	N/A	N/A	23	3.094	2.033
Depth 12m-13.9m	0	N/A	N/A	0	N/A	N/A	77	3.749	2.838
Depth 14m-15.9m	2	0.745	0.120	0	N/A	N/A	166	3.866	2.696
Depth 16m-17.9m	2	1.235	0.120	2	9.53	2.051	81	3.654	2.510
Depth 18m-19.9m	0	N/A	N/A	2	4.45	3.286	0	N/A	N/A
Depth 20m-21.9m	5	1.256	0.730	3	5.20	4.030	0	N/A	N/A
Depth 22m-23.9m	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
Depth 24m-25.9m	0	N/A	N/A	2	9.33	5.629	0	N/A	N/A
Depth 26m-28.0m	0	N/A	N/A	5	12.06	17.519	0	N/A	N/A
Over entire depths 10m-28m	**9**	**1.138**	**0.476**	**14**	**8.259**	**9.975**	**347**	**3.753**	**2.637**

4 BORED PILE DESIGN

It is common practice to determine the unit shaft and unit base resistances based on UCS or q_u values of intact rock core samples, for example, Williams et al. (1980) [3] states that:

$$f_s = 0.05q_u \ (MN/m^2) \tag{1}$$

$$f_b = 0.5q_u (MN/m^2) \tag{2}$$

Typical limiting resistance values (ultimate), but may vary subject to load test results. The analyses carried out in the subsequent sections are based on the empirical equations

5 PILE LOAD TEST

In order to improve the confidence level of the designer in view of the difficulty of determining a feasible rock strength value for phyllite during the preliminary design stage, pile load tests during the construction stage become very important. The field testing result would then provide data for back-analysis purpose and to subsequently firm up the design value for phyllite. As a procedure to ensure that the bored pile can perform satisfactorily at its allowable load limit and to verify the preliminary design UCS value of 7.4MPa, 33 sets of Pile Dynamic Analyzer (PDA) tests as well as 4 sets of Constant Rate Penetration (CRP) and Maintained Load Test (MLT) tests were performed on site.

Table 2. shows the results of the 33 Nos. of PDA tests performed on site. Based on the field test results, the average factors of safety provided for the 600mm diameter bored pile Types 1 and 2, as well as 750mm, 1000mm and 1200mm diameter bored piles are 2.23, 2.17, 2.06, 2.37 and 2.26, respectively. These values are in general comparable to the factor of safety of 2 used in the preliminary design stage.

Table 2. Summary of pile PDA test results

Bored pile diameter	**Rock socket length in phyllite**	**Test pile ID**	**Measured PDA ult. static resistance**	**Design working load (WL)**	**FOS**
(mm)	**(m)**	**(-)**	**(kN)**	**(kN)**	**(-)**
600 (Type 1) WL=1540kN	2.0	23	3,258	1,540	2.12
		39	3,541	1,540	2.30
		91	3,310	1,540	2.15
		106	4,197	1,540	2.73
		496	3,411	1,540	2.21
		505	3,277	1,540	2.13
		511	3,359	1,540	2.18
		515	3,502	1,540	2.27
		621	3,257	1,540	2.11
		779	3,380	1,540	2.19
600 (Type 2) WL=2500kN	2.1	620	5,398	2,500	2.16
		622	5,607	2,500	2.24
		624	5,183	2,500	2.07
		626	5,738	2,500	2.30
		629	5,349	2,500	2.14
		633	5,475	2,500	2.19
		704	5,390	2,500	2.16
		705	5,283	2,500	2.11
		735	5,135	2,500	2.05
		798	5,223	2,500	2.09
		TP1	5,875	2,500	2.35
750 WL=3250kN	2.2	5	6,676	3,250	2.05
		11	6,891	3,250	2.12
		13	6,588	3,250	2.03
		780	6,657	3,250	2.05
1000 WL=4500kN	2.3	56	9,257	4,500	2.06
		508	10,553	4,500	2.35
		508	10,553	4,500	2.35
		520	11,976	4,500	2.66
		778	10,988	4,500	2.44
		56	9,257	4,500	2.06
1200 WL=5800kN	2.5	436	13,605	5,800	2.35
		470	12,554	5,800	2.16

From the Maintained Load Test results as shown in Table 3, the magnitudes of the settlements that govern the serviceability limit state design are all less than the limit of 12.5mm, 38.0mm and 6.5mm at Working Load, twice Working Load and residual conditions, respectively. This means the design UCS ultimate value of 7.4MPa for phyllite is thus broadly verified in terms of strength and serviceability. Once sufficient confidence had been achieved on site after performing the CRP and MLT tests, mass installation of bored piles commenced.

Table 3. Summary of measured pile head settlement

Pile head sett	**Criteria - Not exceeding (mm)**	**Bored pile diameter (mm)**			
		600 Type 2	**750**	**1000**	**1200**
1xWL	12.5	5.32	4.06	5.59	4.45
2xWL	38.0	12.85	9.39	10.67	7.37
Residual	6.5	1.35	1.33	0.14	1.00

WL=working load

6 IMPORTANT OBSERVATION OF STRENGTH OF PHYLLITE

An important observation made is that despite the very low RQD obtained for the phyllite rock cores between 10m-18m depths (actual range of pile socketing depths as installed on site) and hence very limited UCS test was possible, however, from the back-analysis of the load test results the interpreted UCS ultimate value of 7.4MPa for phyllite seems to be very encouraging. It is therefore believed that phyllite, despite being friable, actually does have a reasonable good in-situ strength as a mass, which is often neglected because most, if not all the time, rock coring was carried out and hence RQD is usually used to interpret the rock strength.

It is believed that the main reason for obtaining a relatively high UCS of 7.4MPa for phyllite is due to the relatively large overburden pressure of 10m-18m overlying the rock layer. This provides a reliable confining stress to the phyllite layer. The metamorphic phyllite may be well-known to have small-scale slip-faults, intense shearing and faulting, but if it is kept largely under a confining pressure (compression in nature) with minimal disturbances, the in-situ strength will mostly be preserved. For this very reason, if external mechanical stresses are introduced to a mass of phyllite during rock coring, phyllite will tend to be disintegrated and when the core is retrieved the logging of phyllite as 'friable' in borehole logsheets is inevitable, hence the injustice of a misconception that by default phyllite should have a low strength value.

From this study, the following relationships on phyllite can be developed based on the successful pile socketing depths of between 10m and 18m on site (considering average values with respect to their respective standard deviations):

Unconfined Compressive Strength Test in cored samples

$$UCS = 7.48 - 11.58 \text{ MPa} \quad (3)$$

Point Load Test in axial direction on cored samples

$$UCS = k_A * I_{s50}$$

(4)

where $k_A = 5.5 - 12.0$ and I_{s50} is the point load index in MPa

Point Load Test using lump samples

$$UCS = k_L * I_{s50}$$

(5)

where $k_L = 0.9 - 6.6$ and I_{s50} is the point load index in MPa

Coincidentally, the preliminary design UCS value of 7.4MPa seems to coincide with the lower bound value of the UCS test within the depths of 10m-18m, noting that the I_{s50} lump results during design stage was still unknown. The coefficients k_A and k_L are applicable to Point Load test on samples in axial direction and Point Load test on lump samples, respectively.

Nonetheless, to increase the confidence level of utilising a relatively higher UCS design value for phyllite, more data is to be collected and interpreted in the future. In-situ testing, for example, pressuremeter test is definitely a recommended method to obtain a more reliable UCS value for use in design. The main advantage in using the pressuremeter test is that no extraction of phyllite sample is required and as such the in-situ strength of the rock mass is preserved and hence can be reliably tested.

7 CONCLUSIONS

This paper has documented the difficulties in quantifying rock strengths and designing for geological conditions with high degrees of fracturing, i.e. RQD of 0%, typical of the metamorphic phyllite of the Tuang Formation. Recovery of cores for testing is only sporadic at best, requiring the sinking of more boreholes for the extraction of intact rock cores.

Efforts to correlate UCS with the point load index require further studies, in particular the lower bound results which would govern the conservative design of piles socketed in rock.

Further research could realise the great potential in applying the in-situ pressuremeter test to obtain values of phyllite rock strength for the design of bored piles. The main advantage in proposing the pressuremeter test is that no extraction of sample is required and as such the in-situ strength of the strong mass is preserved and hence reliably tested.

It is important for engineers to be able to interpret the magnitude of phyllite rock strength as this would ultimately impact the design and costs of bored piles to be installed.

8 ACKNOWLEDGMENT

The authors would like to acknowledge Jurutera Jasa (Sarawak) Sdn. Bhd. for their kind co-operation in making this paper a reality.

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