Case studies of CPTu exploration techniques in investigating challenging ground conditions in Malaysia

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ABSTRACT: This paper aims to present a few case studies of utilizing cone penetration testing (CPTu) to investigate the subsurface conditions of peaty soils, weathered tropical residual soils, backfill materials and very soft fine soils in Malaysia. Due to the unusual nature of these materials, the pore water response of the CPTu results exhibits very interesting behaviours, which are worthy of further research in depth. Very often, the existence of coarse soil particles/grains is suspected to produce instant high negative pore pressure at the cone tip and shoulder during the displacing action of the soil grains while penetrating the cone. For the very soft fine soils, it was found that dissipation tests in the intermittent sand layers or lenses reveal the pore water pressure profile to determine whether the sub-soil is under consolidation or normal consolidation. It is observed that the dissipation in these intermittent sand layers or lenses is practically short and hence produces useful results for ground improvement design. Finally, this paper will highlight the common problems of using CPTu in sub-surface exploration work based on the experience of Malaysia.

1 INTRODUCTION

Cone Penetration Test (CPTu) with piezometric measurement or piezocone is a common investigation tool for weak and compressible sub-soils in Malaysia, as common in-situ testing methods such as the Standard Penetration Test (SPT) would not yield useful and adequate information on ground characterization for engineering design. Tan et al. (2003) presented the engineering characterization of Klang clay using piezocone testing.

This paper presents some interesting piezocone results in weathered residual soils of meta-sedimentary formation, residual soil backfill materials and weak peaty sub-soils from two case histories in Malaysia.

2 CASE HISTORIES

There are two case studies, namely Site A and Site B, presented in this paper.

2.1 *Site A – Weathered meta-sedimentary formation and its residual soil backfill*

This case history involved the following piezocone probing:

- 3 piezocones (PZ1, PZ2 & PZ3) carried out on 30th August 2005.
- 1 additional piezocone (PZ1(a)) re-conducted on 8th November 2005 by same contractor.
- 3 additional piezocones (APZ1, APZ2 & APZ3) independently carried out by another contractor on 29th March 2006. These piezocones were supposed to verify the earlier piezocone results, which showed a negative piezometric response.

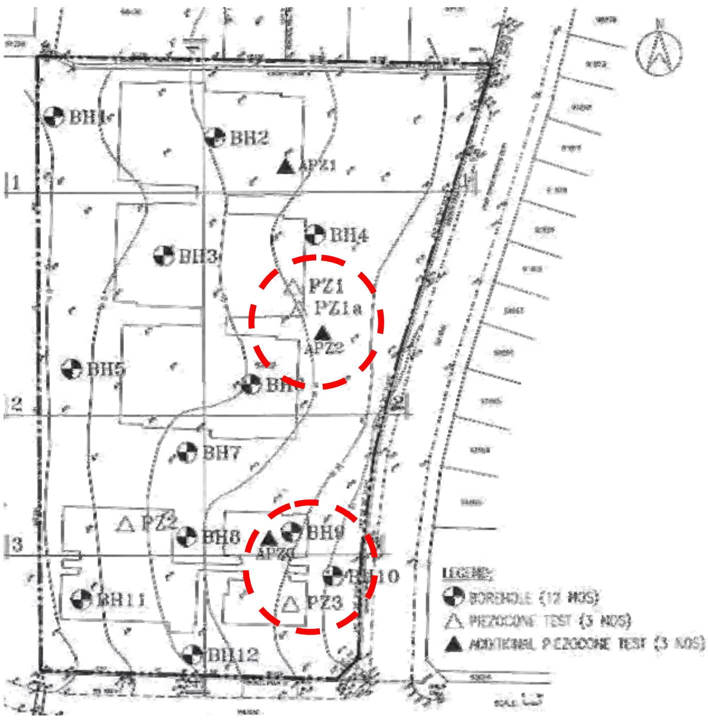

Figure 1. Layout of the Subsurface Investigation.

However, only piezocones PZ1, PZ1a & APZ2 and piezocones PZ3 & APZ3 are correspondingly clustered into two groups with reference boreholes, namely BH-4, BH-9 and BH-10 respectively for the discussion presented in this paper. It is generally noted that there is some interesting piezometric response during penetration into the saturated backfill made of residual soils. The layout of the piezocone clusters and reference boreholes is shown in Figure 1. The project site is believed to be a previous oil palm estate with original ground level ranging from RL 2m to RL 7m. The subsequent earthwork produced pre-development platform sloping from the lowest at RL 8m on the west towards the highest at RL 13m on the east. There is a layer of alluvial deposit 2m to 7m thick spreading over the residual soil derived from meta-sedimentary formation locally known as Kenny Hill formation. Residual soil backfill was used in the pre-development earthwork.

Figure 2 shows the two relevant sections (Sections 1-1 and 3-3) consisting of reference boreholes, namely BH-4, BH-9 and BH-10 for piezocone cluster PZ1, PZ1a and APZ2 and piezocone cluster PZ3 and APZ3 respectively. The groundwater level for borehole BH-4 was about 3m below ground level (bgl), whereas for boreholes BH-9 and BH-10, the groundwater level was about 4m bgl. 8m thick backfill was detected at borehole BH-4, whereas 9 to 10m thick backfill was found at boreholes BH-9 and BH-10. Generally, the soil consistency of the backfill is medium stiff to stiff (SPT-N values of 4 to 14). Below the backfill, 2m to 7m thick alluvial deposits with SPT-N values of 8 to 16 were found.

Figures 3 and 4 show the profiles of corrected tip resistance, friction ratio and piezometric response during cone penetration for the two piezocone testing clusters. It is evident that the repeated piezocone tests show reasonable consistency in both the tip resistance and piezometric response. There are more remarkable variations (maximum about 25%) in the friction ratio profile. The repeated piezocone test results have generally lower friction ratio.

It is interesting to notice that significant negative piezometric response was observed within the top 15m depth, which covers the residual soil backfill and in-situ weathered meta-sedimentary formation. It has remained unclear why such negative porewater pressure does not occur below 15m from the ground surface. Some of the negative piezometric values can be as high as -100kPa, which is close to cavitation pressure. It was initially suspected that such profile of negative piezometric response could be attributed to localized groundwater drawdown. Therefore, repeated piezocone tests were instructed to primarily verify the negative piezometric values seven months later after the previous piezocone testing. Full dissipation tests at various depths were specifically conducted during the re-testing to confirm proper functioning of the piezometric sensor. Generally, most dissipation tests had successfully achieved close to the condition of full dissipation within a relatively short duration, i.e. piezometric value restoring back to hydrostatic pressure, thus confirming no groundwater drawdown found at the project site as initially suspected.

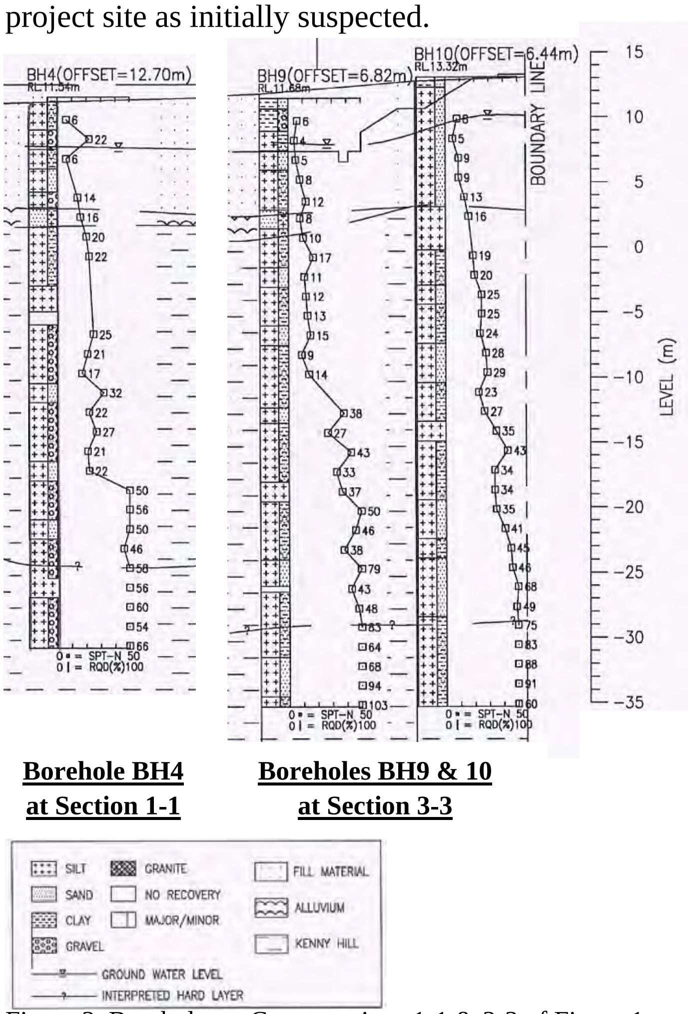

Figure 2. Boreholes at Cross-sections 1-1 & 3-3 of Figure 1.

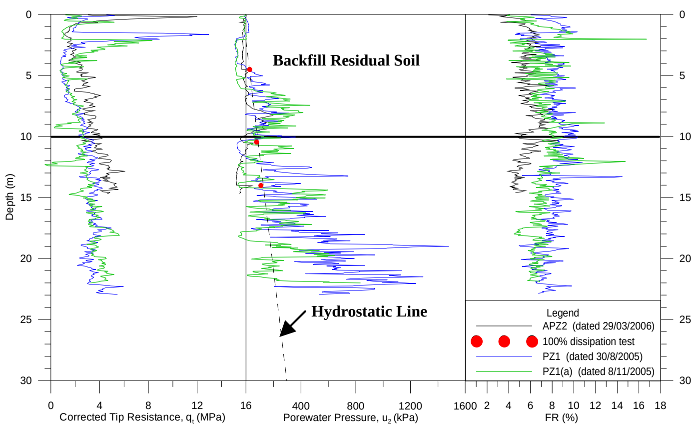

Figure 3. Comparison of Piezocones PZ1, PZ1a & APZ2.

From the observation on the profile of piezometric response during penetration and dissipation test results after penetration ceased, it is evident that soil dilation during shearing as a result of cone penetration could have occurred in order to generate very high temporary suction within the localised zone at close proximity to the piezocone tip. However, such high suction cannot be sustained over a long duration after the penetration ceased.

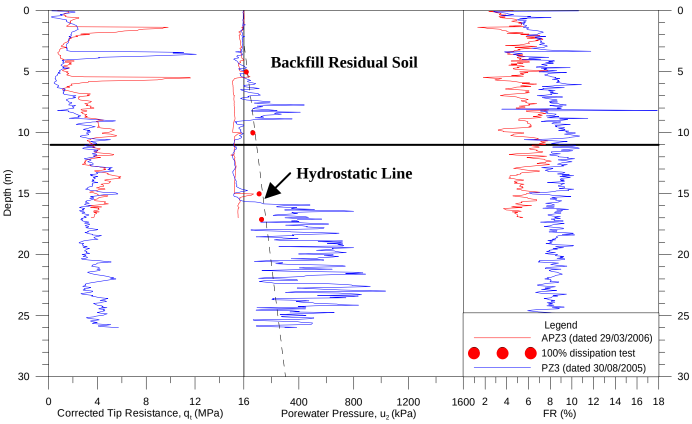

Figure 4. Comparison of Piezocones PZ3 & APZ3.

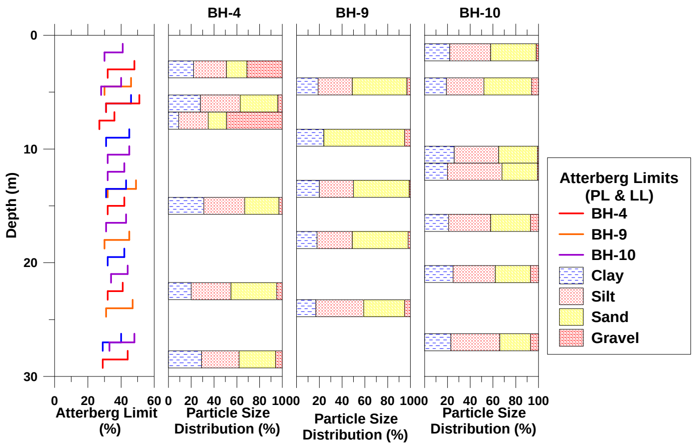

Figure 5. Atterberg Limits and Particle Size Distribution of Sub-soils.

Another interesting observation is the friction ratio as high as 8, leading to soil classification as clayey soils. Figure 5 shows the Atterberg limits and composition of the sub-soils within 30m below the ground surface, where the piezocones were conducted. The plastic limits range from 27 to 33 whereas the liquid limits range from 40 to 51. The fine components (clay and silt) constitute about 60% of the total composition of the sub-soils with silt as dominant fine component. Generally the sub-soils are mainly silt of intermediate plasticity based on British Soil Classification System (BS 5930, 1999). Calibration of the piezocone results with the conventional soil classification tests would be needed for proper soil classification of tropical residual soils.

2.2 *Site B – Thick peaty soils overlying limestone*

This site consists of thick organic peaty soil overlying the karstic Kuala Lumpur limestone formation. At certain locations, the organic peaty soils can be as thick as 65m. Interpretation of the boreholes information, it is believed that such thick intermixed organic peaty soils with silty sand and clay were deposited in sequences at the low lying area in front of the limestone cliff, which encroaching into about one-third of the project site. Figure 6 shows the undisturbed organic peaty sample on the weighing equipment. The measured sample bulk density is about $[(6.937\times10^{-3}\text{kN})/(\pi/4\times(72\text{mm})^2\times(144\text{mm}))=]$ 11.83kN/m^3, which is slightly heavier than water. The bulk density of the peaty soil samples can range from 9kN/m^3 to 12kN/m^3. Water content of the peaty soil samples can be as high as 485%. The organic peaty soils contain materials from decayed wood to highly humificated peat. Generally, decayed wood has lower density, higher water content and more fibrous than that of humificated peat. The organic content of the peaty soils ranges from 35% to 88%.

Figure 6. Weight and Close-up View of Peaty Soil Samples.

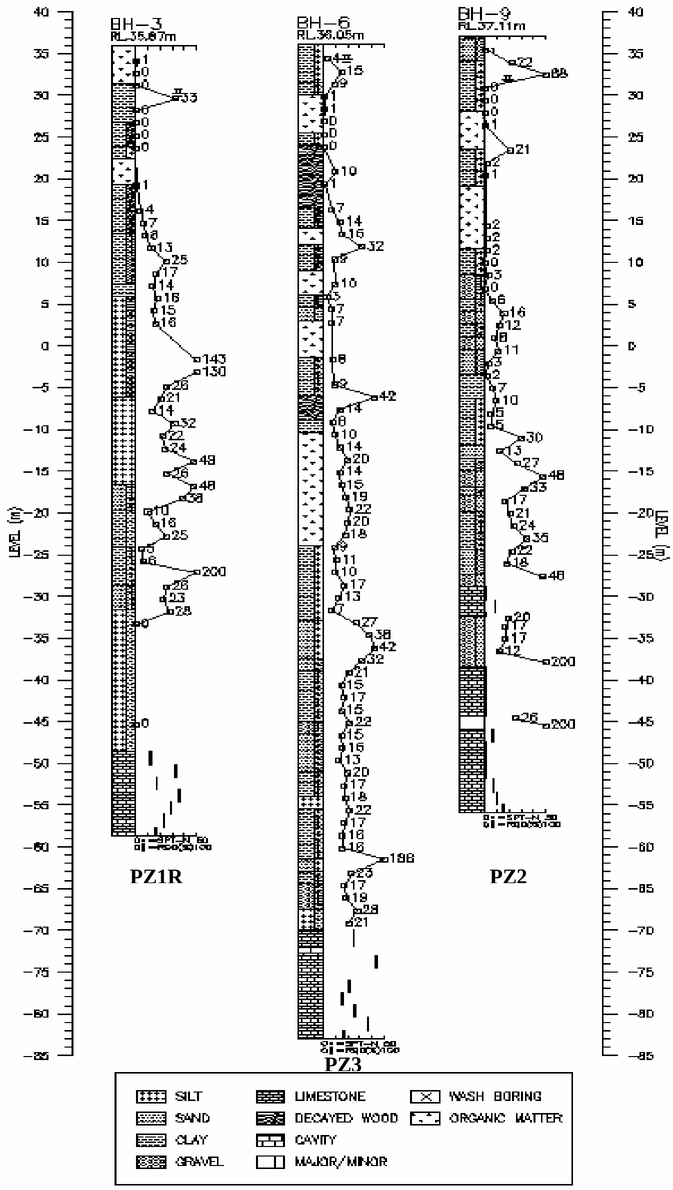

Figure 7. Reference boreholes for Piezocones PZ1R, PZ2 and PZ3.

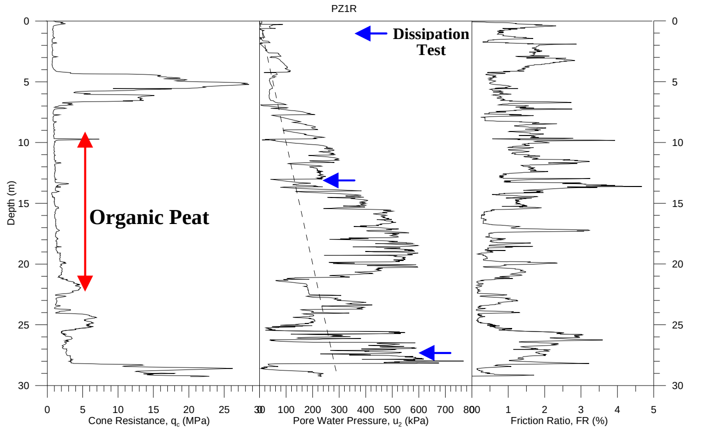

Figure 8. Testing Results of Piezocone PZ1R (Reference borehole BH-3).

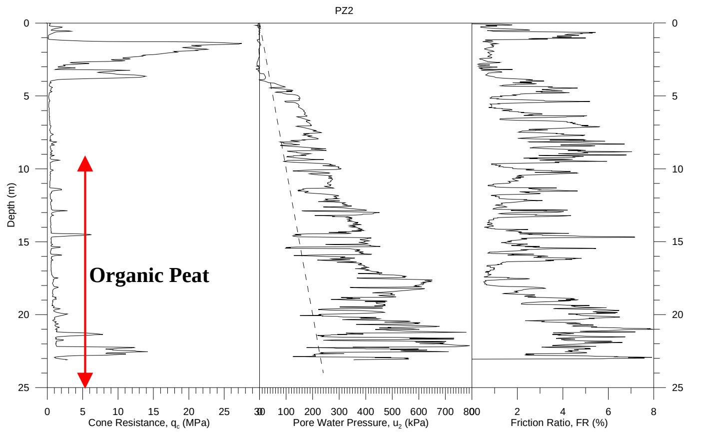

Figure 9. Testing Results of Piezocone PZ2 (Reference borehole BH-9).

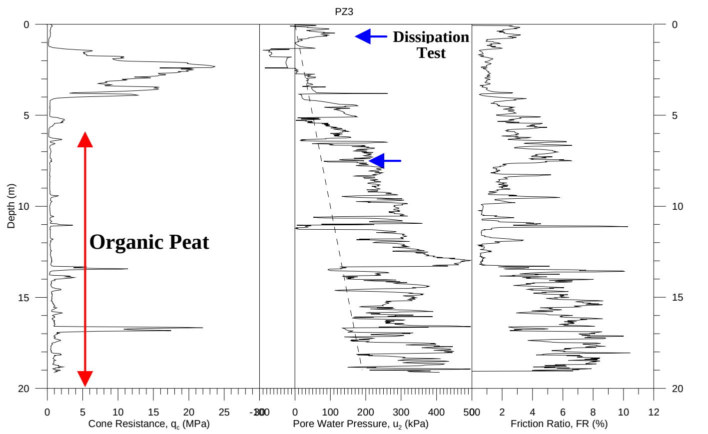

Figure 10. Testing Results of Piezocone PZ3 (Reference borehole BH-6).

Three piezocones with corresponding reference boreholes at the identified organic peaty soil areas are selected for presentation in this paper. The reference borehole loggings are shown in Figure 7 whereas the three piezocone results are separately presented in Figures 8, 9 and 10. The corresponding peaty soil strata identified from the reference boreholes are indicated in Figures 8, 9 and 10. Generally, the peaty soils are characterized with low cone resistance of less than 1MPa and high excess pore pressure. However, the friction ratio profile of the peaty soils is highly variable, ranging from 0.5% to 8%. This is probably a result of the inherent heterogeneity of the peaty soils, which contain intermixture of very fibrous decayed wood to highly humificated peat. Based on the soil classification chart (Robertson, 1990), these peaty soils are classified as clay.

The dissipation tests performed in the peaty soils took about 50 to 90 minutes to achieve full dissipation. Full dissipation of the dynamic excess pore pressure generated during penetration confirms that the ground is not under-consolidation. Therefore there should be no concern of settlement other than those areas with additional future surface imposed loading. It was decided to perform some dissipation tests at the more permeable strata, like sand lenses or layers, to speedily confirm the groundwater regime. It is generally assumed that the pore water regime in the sub-soils has reached hydrostatic equilibrium. The cone penetration in these more permeable strata may induce temporary excess pore pressure, but the high permeability of the material should allow quick dissipation of the excess pore pressure at a reasonable testing duration, and should re-establish hydrostatic equilibrium as before.

3 COMMON PROBLEMS OF PIEZOCONE APPLICATION IN MALAYSIA

3.1 *Equipment Aspect*

There are at least four types of piezocone equipment commonly found in Malaysia, namely the Hogentogler cone (www.vertek.ara.com), the GeoMil cone (previously named the Gouda cone, www.geomil.com), the AP Vandenberg cone (www.apvdberg.com) and the Memo cone (www.envi.se).

The Hogentogler system is widely available in Malaysia, while the GeoMil system has also started gaining popularity recently. The capacity of the cone is usually 10-Tons and 20-Tons. The 10-Ton cone is more popular as a result of its wide applicability to most top surfacial materials in Malaysia. Occasionally, a 5-Ton cone is used for testing in very weak compressible soil. There are a total of 37 sets of piezocone equipment available in Malaysia (courtesy of GDS Instrument Sdn Bhd).

What follows are the author's experience and some common problems in using piezocone equipment in Malaysia:

– Cable connection problems causing erratic electrical signal.
– Poor connection water seal leading to water or moisture ingression affecting the analog electrical signal.
– Overheating of data acquisition units, especially during dissipation tests with longer duration.

– Inability to hold the cone in stationary condition during dissipation tests or/and vibration at ground surface causing spiking dissipation curves, sometimes electrical noises can create similar nuisances.
– In order to save storage space, a large recording interval (every 25mm) is adopted in the data acquisition unit, which will lead to poor resolution of the penetration data profile. Some cone manufacturers have improved their system with a capability to take readings at 10mm intervals.
– Rapid and excessive wear and tear of the cone, sleeve and filter in Malaysian soils, probably due to existence of quartz in alluvial deposits.
– Less favourable on-site calibration procedures. Proper saturation of filter and piezometric sensor, and calibrating the piezometric sensor with standing water in a borehole are the good practices for accurate piezometric response. Sometimes a contractor alleges that such on-site calibrating procedures will lead to moisture ingression to the circuit board in the cone housing, thus affecting the electrical signal.

3.2 *Operation Aspects*

Frequently occurring operational issues are as follows:
– Once the depth of a designated dissipation test is reached, the testers must immediately turn on the switch to acquire the data for dissipation test if the testers use manual mode for the dissipation test. Otherwise some information will be missing such as the dynamic response of the pore pressure when the cone penetration is stopped.
– Contractor's unwillingness to penetrate cones with a rated thrust capacity due to fears of damaging the cone.
– Intrusion of soil particles within the gap of the piezometric sensor and the sleeve jacket, leading to constantly high friction ratios and low cone resistance.

3.3 *Data Processing and Interpretation Aspects*

In processing the piezocone data, basically involving cone resistance (q_c), sleeve resistance (f_s) and pore water pressure at the cone shoulder (u_2), there are different ways to compute the friction ratio (R_f) depending on the data processing software provided by the cone manufacturers (Coneplot software by Hogentogler and CPT Task software by Fugro/Geomil).

Hogentogler's Coneplot computes the friction ratio by dividing the sleeve friction (f_s) taken at 100mm behind the cone over the cone resistance (q_c) to get the friction ratio (R_f). Fugro/Geomil's CPT Task software uses running average of the cone resistance values (11 q_c values) over the sleeve length as the denominator of the friction ratio (R_f) whereas the corresponding sleeve resistance (f_s) taken at the location of the sixth q_c value as the numerator. As such Geomil's approach will generally show lesser "spikes" as a result of the continuous smoothening effect by the running average of q_c values. Generally, the resolution of the cone resistance profile is higher than that of sleeve resistance. Though there is no standard or guideline on the computation of R_f, the running average method seems to be a more logical approach as the measurement of sleeve resistance is also an average of the friction over the sleeve length of 135mm. Nevertheless, it is still important to have the R_f computation standardized for the consistency of the calibration or classification charts produced.

3.4 *Testing Guidelines and References*

The widely used technical reference for piezocone testing in Malaysia is Tom et al (1997). Similarly, the International Reference Test Procedure (IRTP) by ISSMGE TC6 (1999) is well accepted as a set of guidelines for piezocone testing.

4 CONCLUSION

From the two case studies on piezocone testing in meta-sedimentary residual soils and peaty soils, the following observations and remarks can be made:
– The piezocone can be used as an investigation tool in tropical residual soil derivatives of meta-sedimentary formations with SPT-N value as high as 25. However, high friction ratio is observed for both the reworked residual soils and the in-situ residual soils of meta-sedimentary formation. More research should be conducted to establish specific soil classification for residual soils and to understand the dynamic pore water response during cone penetration to yield useful results. As a good practice, it is suggested to conduct more full dissipation tests whenever practical.
– Temporary high pore water suction can be generated in weathered meta-sedimentary soils with fine content as high as 60% regardless of whether the soil is at its in-situ condition or subject to disturbance as a result of reworking of the material. Soil dilation during cone penetration could be the possible attribute to such high temporary pore suction.
– If full dissipation test can be carried out at the more permeable subsoil strata, like sand pockets, lenses or even layers, in the ground condition with predominantly fine soils, one can easily obtain useful information about the consolidation conditions of the ground before future imposed loading.
– Peaty soil was not correctly identified using the soil classification chart by Robertson (1990).

Common problems of piezocone testing encountered in Malaysia were presented and discussed.

The most urgent issue is to standardize or harmonize the approach of computing the friction ratio. This will affect the future calibration results of soil types and empirical design charts produced using different approaches, and subsequently causing confusion.

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