Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)

Session Report: Rock and residual soil characterisation

E.A.G. Marques
Universidade Federal de Viçosa, Viçosa, Brazil

ABSTRACT: This report provides a short overview of the topics covered in eight papers submitted to the ISC´5 session on rock and residual soils characterisationon penetration testing.

1 INTRODUCTION

This report presents an evaluation and an overview of the eight manuscripts presented to the Rock and Soil Characterisation Technical Session. The themes were divided in only three papers focus on soils, while the other five presents results on characterisation of rocks. Papers were based on studies developed on five different countries (Australia, Brazil, Iran, Portugal, Singapore). Papers dealing with soils were mainly focused on in situ tests such as CPT, CPTu, SDMT, Seismic (Cross-hole tests), SPT, SPT-T and were applied to a wide range of soil types, including residual (from granite), stiff clays and lateritic soils developed under different climate conditions. The main purpose was, in general, to obtain geotechnical parameters, some of them for design.

For the manuscripts dealing with rock characterisation, two have used Schmidt hammer to characterise rock mechanical properties (one trying to determine strength loss with weathering and the other one its relationship with rock excavability). A third one deals with rock mass strength parameters obtained from rock mass classifications methods and a fourth presents results from plate loading tests used to determine deformability parameters of weak rock masses. The last paper focusing on rock presents the results of hydraulic fracturing test used for the determination of stress behaviour on two rock formations from Singapore.

2 SOIL CHARACTERISATION

The paper by *Shi et al.* entitled "Characterisation of a lateritic soil using laboratory and in-situ tests" deals with the characterisation of residual soils based on field (CPT) (Figure 1) and laboratory investigation of a laterite soil from the Millstream Dam site, southern West Australia (WA). Laboratory tests were performed on intact and reconstituted samples in order to evaluate the influence of soil structure on mechanical and general geotechnical characteristics: hydrometer and sieve particle size distribution, Atterberg limits, mean bulk density, specific gravity, degree of saturation, in situ water content and void ratio, X-ray diffraction, 1D compression (oedometer test) and triaxial tests. Some conclusions from the research were that

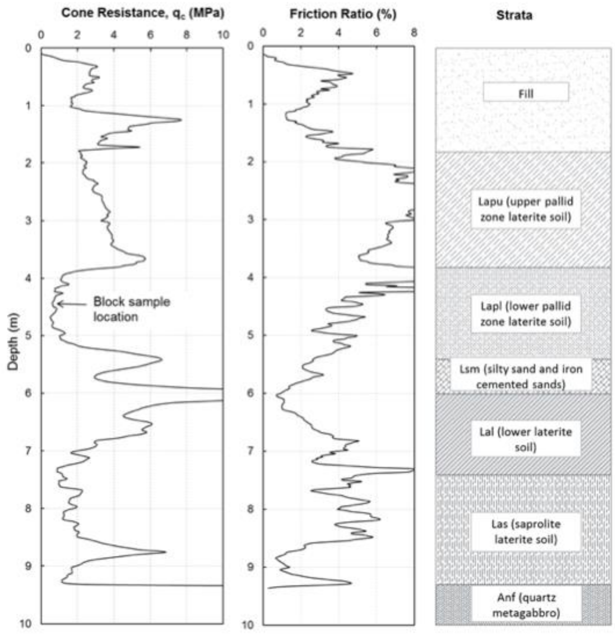

Figure 1 – The in situ CPT test results and soil profile.

Triaxial tests on high quality block samples from the lower pallid zone of a lateritic profile have shown a relatively low level of structure (consistent with a c' value of about 20 kPa) and a comparable friction angle to reconstituted material, as shown on Figure 2. The void ratio of the in-situ material is higher than equivalent reconstituted samples consolidated to the same effective stress level and that the CPT is show to provide reasonable means of assessing the in-situ undrained strength of the type of laterite encountered at the Millstream site.

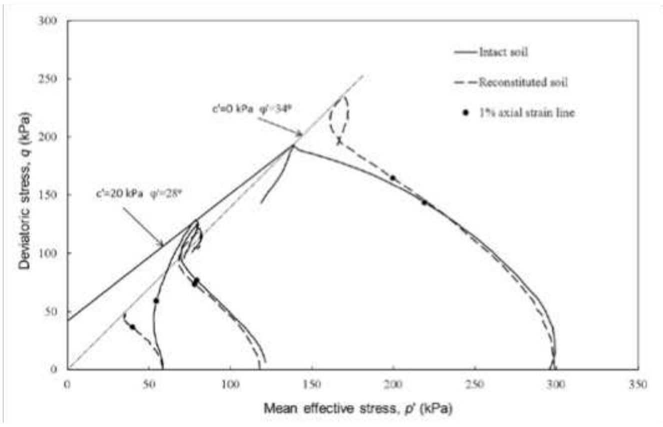

Figure 2 – Stress path in q-p' space during undrained triaxial compression both in intact and reconstituted (normally consolidated) samples from Shi et al.

Cruz et al. have presented an interesting manuscript, which is entitled "Piezocone tests in residual soils. A Portuguese experience in granitic soils". The authors state that Residual soils strength characterization it is not an easy task, due to its cohesive-frictional nature as well as disturbance effects related with both sampling and installation of in-situ devices. So, it is fundamental to be sure that any correlations with in-situ test parameters respond properly in these soils. The study presented aims to contribute to the evaluation of adequacy of CPTu current correlations to determine the geotechnical design parameters, in a similar way that was developed by one of the authors (Cruz, 2010) for DMT tests. The study was developed on Porto (North) and Guarda (Centre) regions of Portugal in granitic residual environments, where pairs of tests CPTu+DMT were available. One of the findings is that of strength behaviour, in the context of the range of NSPT deduced from CPTu (Robertson & Cabal, 2010) match perfectly with the results obtained in the field, indicating that the established correlation between the two tests is also valid in residual soils, at least in this specific environment." Part of the results show that CPT data revealed not strongly structured soils, lying near the lower bound line for cemented materials and converging to the previous findings (Figure 3). Also, the obtained results prove that CPTu tests correctly predict most part of the main geotechnical parameter ranges, with the exception of the deduction of cohesive strength (a correlation has to be settled) and the angle of shear strength that is over predicted when sedimentary approaches are followed. There is a specific research program is under development in IPG experimental site to try to solve this problem.

The paper named "Predicted and measured behaviour of a tall building in a lateritic clay" by Décourt et al. presents the results of a foundation design and the comparison between the predicted and the actual behaviour of this foundation. The study was performed in São Paulo city, Southeast Brazil. Foundation design was based on SPT-T results. Also Cross Hole and SDMT tests have also been carried out and the correlation between G0 and NSPT was used for identifying the lateritic soil type occurring within the area. .

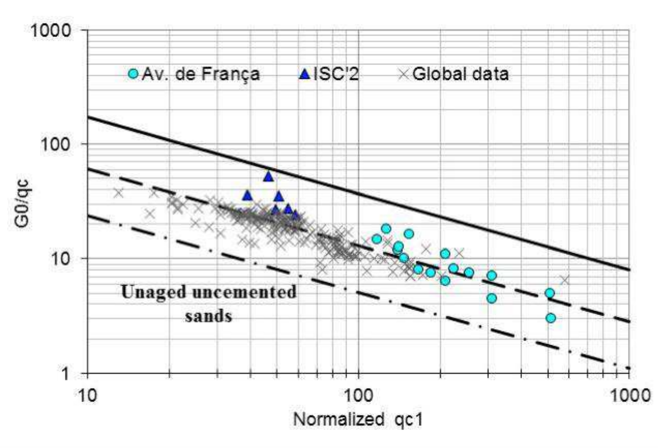

Figure 3 - Cemented/no cemented plot (adapted by the authors from Viana da Fonseca et al., 2007).

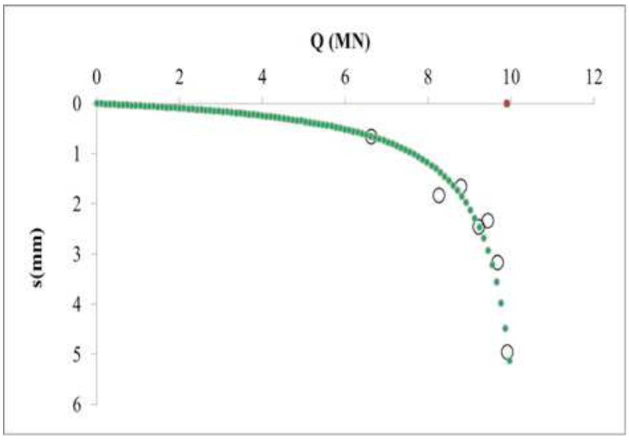

Figure 4 - Example of a corrected load-settlement curve for column P13-B/P15-B.

Later, with the building already under construction, other tests have been performed, exclusively for research purposes. Based on the results, predictions of capacity and deformations of the foundations have been made (as the example showed on Figure 3). Concluding, the authors have mentioned that the initial investigations (SPT-T, Cross-Hole and SDMT) allowed correct assessments of capacity and confirmed the lateritic characteristics of the upper clay layer. But these tests provided no information on the compressibility of this clay, which is fundamental for correct predictions of settlements and was latter obtained from a load test on a square block, which has confirmed the predicted capacity of shallow footings on this clay. Also of paramount importance, the test has shown that the average coefficient of intrinsic compressibility, C, were half of the estimated value used in design and was not constant, as it usually happens with most of the soils, but decreases as the applied stresses increase. So, the study shows the importance of recognizing lateritic clays, as it can present lower settlements.

3 ROCK CHARACTERISATION

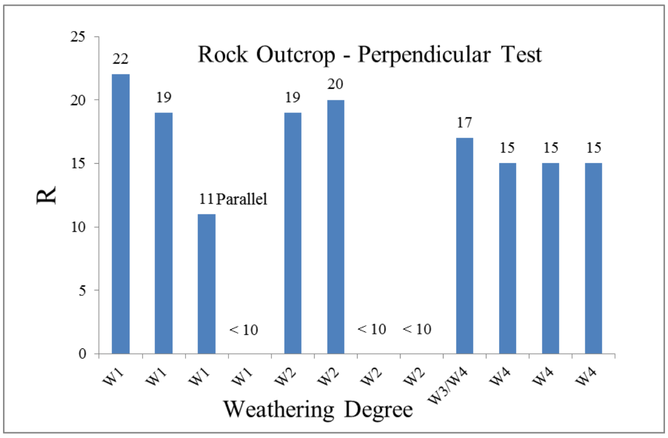

Figure 5 - Results from in situ Schmidt hammer rebound test for one phyllite from Iron Quadrangle.

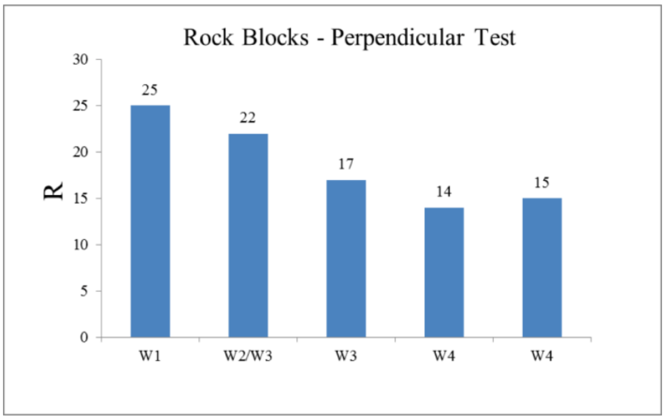

Figure 6 – Results from laboratory Schmidt hammer rebound for one phyllite from Iron Quadrangle.

Leão et al presented some initial results from a study on the "Morphology and geotechnical characterization of a phyllite weathering profile developed under tropical climate" developed in Iron Quadrangle Region, southeast Brazil. The study comprises a complete geotechnical characterization of rock material present in a phyllite weathering profile but the paper only presents the results from a detailed morphological description and Schmidt Hammer tests performed on those materials, both in situ and on lab. Five weathering materials - W1 to W5 (based on ISRM classification) were found. Contacts between different rock weathering materials are sharp and controlled by foliation. Characterization was performed throughout macroscopic analysis of mineralogy and mineralogical changes, evaluation of degree of coherence, fracture characteristics, RQD (from JV ratio) and Schmidt hammer in situ tests. JV, coherence and Schmidt rebound results, specially the last two, shows good correlation with weathering classes. Schmidt rebound has varied from 25 to 14 for W1 to W4 (Figures 5 and 6) and was also able to detect some strength anisotropy as for W1 materials results parallel to foliation the results were equal to 11 while in the direction perpendicular to this structure, the average values were equal to 21.5. The main conclusion is that the morphological description of weathering materials in the filed was in accordance to Schmidt hammer test results and from other authors (Marques & Williams, 2015) as differences on rebound could be observed for more sound materials in comparison to more weathered ones.

The paper Li et al. entitled "Impact of Rock Mass Strength Parameters on Lowwall Stability Assessment Outcomes in Open-cut Coal Mines" presents a rock mass strength estimation process (trough equations 1, by Hoek and Brown, 1997; equation 2, by Hoek, 1998; and Figure 7) applied to underground stope stability assessment and its application to an open cut coal mine over a two year period. The rock mass parameters were obtained from rock mass classifications – RMR, Q-system and GSI. The authors provide no information regarding the localization of the mine and according to them, they have started applying these rock mass strength estimation techniques to open cut coal mining in the last two years (2014?). The main conclusion of the study is that "understanding pit floor rock mass characterisation is the most critical and challenging step for rock mass strength estimation. Identification of floor shear and weak ground can be easily missed due to sparsely spaced exploration holes and limited floor trenches in coal mines." And, because of that "the default material strength values should not be blindly applied to any rock mass condition from aspects of either safety or cost reduction and productivity increase".

$$\sigma_{cm} = 0.5 \times \frac{RMR_{89} - 15}{85} \sigma_{ci} \quad (1)$$

$$\sigma_{cm} = 0.022 \sigma_{ci} e^{0.038GSI} \quad (2)$$

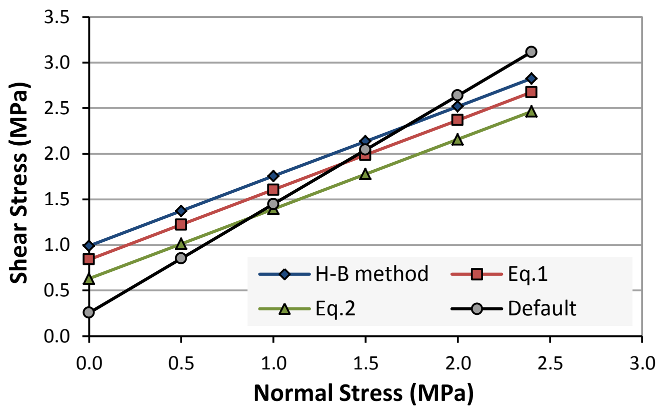

Figure 7 - Using the Mohr-Coulomb criterion to fit the Hoek-Brown criterion – the Hoek-Brown method.

The manuscript entitled "Investigation on the results of Plate Load tests using rigid plates in weak rock masses (case study)" was presented by Abrah et al. The paper presents and discusses the results of plate loading tests used to determine the deformability modulus of low quality rocks occurring under the left abutment of Karun 2 dam site. The tests results (Figure 8) were analysed through three methods: ASTM (2008), ISRM (1981) and UNAL (1997) and the last one has show significant differences with the first two, especially for higher anchor depths. The authors have performed tests for checking the results for the three methods but no explanation of the discrepancies between ASTM and ISRM methods to UNAL method was presented.

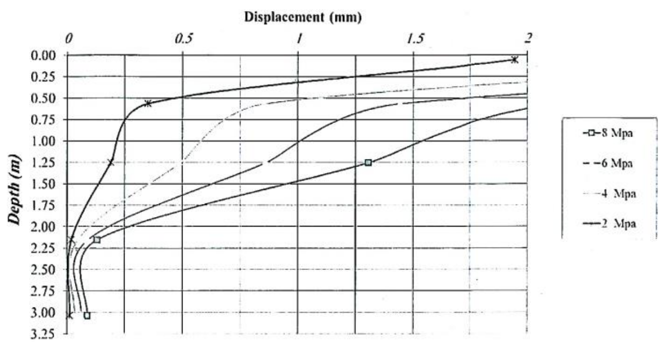

Figure 8 – Displacements measured for left plate.

The study by Elbaz et al. is entitled "Assessing rock strength and excavatability of diamondiferous kimberlite ore through in situ rock testing". The investigation have considered "the excavatability of diamondiferous kimberlite pipes of the Merlin field in the Northern Territory, Australia", through the use of in situ rock testing to "assess hardness and subsequently excavatability and have provided a relationship that can be used to relate field testing of rock hardness with rock strength. The results of the hardness (based on Schmidt hammer tests) to strength relationship (Figure 9) were used in established empirical equations to confirm excavatability of the kimberlite ore. The median of the twenty Q-values (Schmidt hammer rebound) for each core sample was taken prior to destructive UCS testing of the same samples in the laboratory. As a final conclusion, the authors states that the Schmidt Hammer rock strength (Q-value) showed a near direct relationship "to the UCS where UCS = 1.04 Q – 5.31. The results confirm the use of the Schmidt Hammer as a suitable device for in situ measuring of kimberlite and UCS estimation".

Finally, the last manuscript is the one from Kimura et al. entitled "In Situ Rock Stress Determined by Hydraulic Fracturing Test in Singapore" and presents the results of a series of hydraulic fracturing tests conducted in the Bukit Timah Granite and in the Jurong Formation, performed in vertical boreholes ranging in depth from 90 to 170 m mostly in Classes I and II of Rock Mass Rating (RMR).

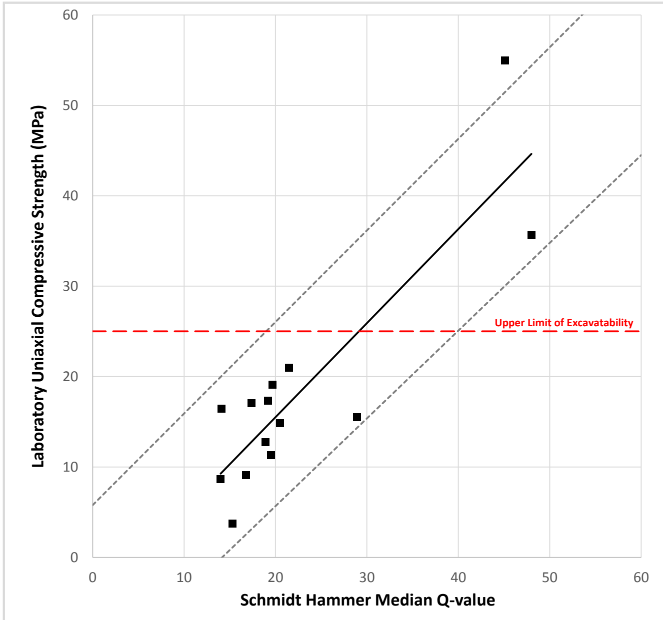

Figure 9 - Schmidt hammer test results relative to UCS (measured on lab).

The Bukit Timah Granite is located in the centre of Singapore Island and the outcrops are exposed on the ground surface on the hills and lies underneath recent deposits in valleys, while the Jurong Formation is distributed in the western part of the Island and is normally composed of series of sedimentary rocks such as sandstone, mudstone, shale, tuff, conglomerate, limestone etc. The hydraulic fracturing tests had been conducted in six different boreholes. The main conclusions were: the ratios of maximum horizontal stress to vertical stress are approximately 3 and 2 (Figure 8), in the Bukit Timah Granite and the Jurong Formation, respectively; the maximum and minimum horizontal stresses were higher than the vertical stress and indicates a thrust faulting stress regime that is characteristic of a compressional tectonic environment; and, finally, the orientations of the maximum horizontal stresses, generally N-S to NE-SW, are consistent with the general compressive stress in the region.

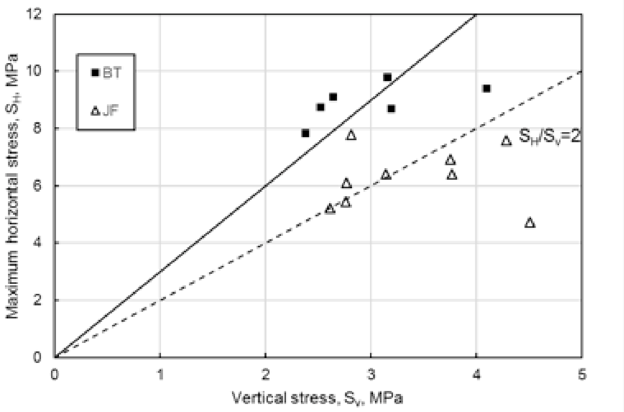

Figure 10 - Stress ratios of S_H (maximum horizontal stress)/S_V (vertical stress) in Bukit Timah Granite (BT) and Jurong Formation (JF).

4 CONCLUSIONS

Papers related to residual soil studies were, all, mainly focused on determining geotechnical parameters to provide data for engineering design. The most used test on the presented papers was CPT and event those that focused on other field tests, such as SPT, SPT, crosshole seismic and DMT, the main purpose was to correlate those results with CPT results. The only exception to this general trend was the paper by Décourt et al., which was mainly based on SPT-T results.

Based on this, the main contribution that can be withdraw from these contributions to the current state-of-the-art is the application of in situ tests to some unusual soil types and the proposition of new correlations for these materials to support design.

On the other hand, papers based on rock characterisation have presented a more wide variety of approaches, but again, the main purpose was to determine geotechnical parameters for engineering design and mainly by using already well established in situ and lab tests.

One final comment is related to the small amount of rock characterisation studies presented to the Symposium, which makes me suggest that authors should be encourage to present more studies on rock characterisation on future ISC symposia.

5 REFERENCES

ASTM D4394 – 08 2008. *Standard Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Rigid Plate Loading Method*. 10 p.

Begemann, H.K.S.P. 1965. The friction Jacket Cone as an aid in determining the soil profile. *6th International Conference of Soil Mechanics and Foundation Engineering, Proc., Montreal, Quebec, Canada*, v.1, 17-20.

Cruz, N. 2010. *Modelling geomechanics of residual Soils with DMT Tests*. Ph.D. thesis. Porto: Porto University.

Douglas, B.J. & Olsen, R.S. 1981. Soil classification using electric cone penetrometer. *Symposium of Cone Penetration Testing and Experience, Proc., ASCE. New York*, 209-227.

Eslami, A. & Fellenius, B. H. 1997. Pile capacity by direct CPT and CPTu methods applied to 102 case histories. *Canadian Geotechnical Journal*, 34 (6), 880 - 898.

Hoek, E. 1998. *Practical Rock Engineering. http://www.rocscience.com/roc/Hoek/Hoek.htm*

Hoek, E. and Brown, E. T. 1997. Practical estimates of rock mass strength. In Int. *Journal of Rock Mechanics & Mining Sciences,* 34 (8):1165–1186.

ISRM 1981. *The complete ISRM suggested methods for characterization, testing and monitoring*. 628 p.

Marques, E.A.G. and Williams, D.J. 2015. Weathering of Bunya phyllites in Southwest Brisbane – a geotechnical approach. In: *ANZ 2015 – 12th Australia New Zealand Conference on Geomechanics. Proc.,* New Zealand Geotechnical Society Inc., Wellington, p 1-8.

Robertson, P.K. 1990. Soil classification using the cone penetration test. *Canadian Geotechnical Journal*, 27: 151-158.

Robertson, P.K, Campanella, R.G., Gillespie. D. & Greig, J. 1986. Use of piezometer cone data". *In-Situ 86, Specialty Conference, Proc., ASCE, Blacksburg*, 1263-1280.

Robertson, P. K. & Cabal, K.L. 2010. *Guide to Cone Penetration Test*. Gregg Drilling and testing, Inc. 4th edition.

Schnaid, F., Lehane, B. M. & Fahey, M. 2004. In situ test characterization of unusual geomaterials. In: Viana da Fonseca e Mayne (eds.) *2º Geotechnical and Geophysical Site Characterization*. *Proceedings, Porto, Portugal.* 49-74. Rotterdam, Balkema.

Schmertmann J. H. 1969. *Dutch Friction Cone Penetration Exploration of Research Area at Field 5, Eglin Air Force Base, Florida, US Army Waterways Experimental Station*, *Vicksburg, Mississippi*, Contract Report S-69-4.

Unal, E. 1997. Determination of in situ deformation modulus: New approaches for Plate-loading Tests. *Int. J. Rock. Mech. Min. Sci*, 34: 897-915.