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CONE PENETRATION TESTING IN EXTREMELY SOFT SOILS – SOLVING THE PROBLEM OF POOR SLEEVE FRICTION MEASUREMENTS

Introduction

Insitu Geotech Services Pty Ltd (IGS) is an Australian in situ testing and sampling company that provides services to construction, infrastructure and mining. It is the largest company that specialises in this field in Australia, but still numbers only about 30-40 personnel. See www.insitu.com.au.

IGS has built its business around providing high quality test data to their clients and is thus very much results-focused; if something seems to be lacking or warrants improvement then they will focus on solving that issue or improving on it. The small company has driven several innovations, in particular in the past in regard to better quality sampling of soft soils.

The most recent innovation driven by IGS has been the conception/development of a CPT cone capable of detecting and measuring extremely low sleeve friction (f_s) values.

This cone was conceived and developed in conjunction with IGS's CPT equipment supplier-partner Geomil Equipment B.V. of The Netherlands (Geomil), and it involved shifting a design paradigm.

The concept, design, paradigm shift etc, and the successful outcome, are described in a paper to be published as part of the proceedings of the Conference CPT'22, to be held in June 2022 in Bologna Italy.

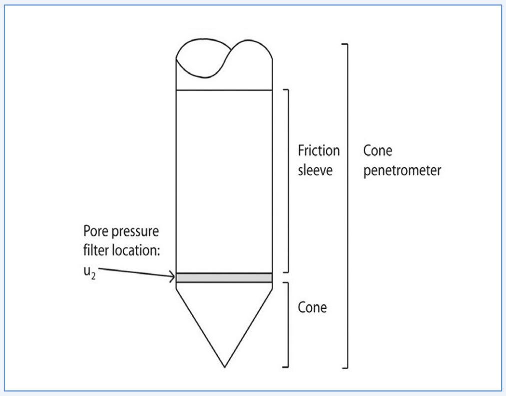

Figure 1 – Basic layout of the electrical cone.

Why is detection and measurement of f_s important?

CPT was invented in the first place, then evolved over several decades, to eventually be able to profile and characterise the strength and other properties of soils.

In the beginning, the 1930s and 1940s, the tool, known at that time as "Dutch Cone" was purely a mechanical device and could only measure cone resistance. In the 1950s a mechanical friction sleeve was added and in the 1960s to 1970s as technology advanced, the first electrical cones appeared plus, with time, cones that could measure pore pressure, known as piezocones.

Nowadays most CPT cones used have the components and proportions shown in figure 1 (taken from P.K. Robertson & K.L. Cabal (2015) 6th Edition Guide to Cone Penetration Testing for Geotechnical Engineering).

Size is usually described according to the cross-sectional area of the device, and most are either 10cm^2 or 15cm^2 (i.e. about 36mm or 44mm diameter).

Note that the conical point of the penetrometer, named in the figure as the "Cone" is often called the "Tip". This latter terminology will be used in this article.

A CPT test is performed by pushing the cone into the ground at a slow and steady speed of nominally 2cm/s, electrically measuring via load cells and a pressure transducer: (a) the tip load (expressed as pressure q_c); (b) the sleeve friction (expressed as a stress f_s); and (c) the pore pressure (usually designated u).

These three parameters are usually plotted graphically, including a plot of the ratio f_s/q_c– called Friction Ratio (R_f) – expressed as a %. Note that often q_c is subjected to a correction for pore pressure and then designated qt, then Rf is calculated using q_t. However for the purpose of this article that is not important.

What is important is that R_f, derived from the friction value f_s, is used in many different forms to determine soil type; these forms vary from "eye-balling" the R_f plot and using experience, to processing the data via various computer programs.

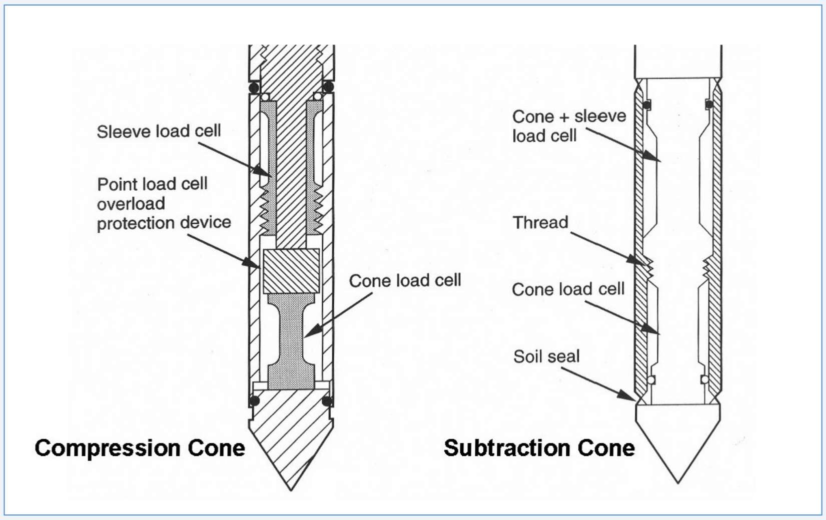

Figure 2 – Compression versus subtraction cone types.

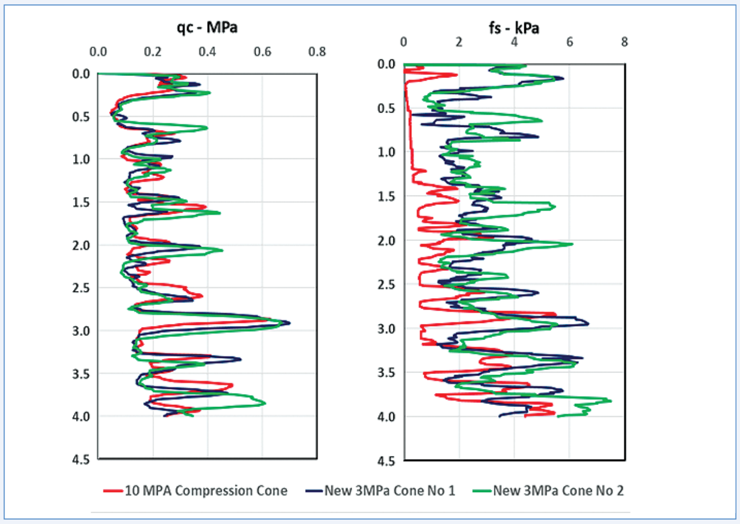

Figure 3 – Cone data comparison of 10MPa versus new 3MPa cone.

SUMMARY

This article is an extract from the CPT'22 paper referenced herein. Measurement of extremely low sleeve friction (f_s) values during CPT testing is an industry-wide problem, often treated as an "elephant in the room". The paper describes the development of an innovative new CPT cone that the author believes has largely solved this problem. The solution has involved shifting of the paradigm, that "if you want to most accurately measure sleeve friction, you must use a Compression Cone". This solution involved the use of a Subtraction Cone design. The solution also involved development of more-responsive-than-conventional load cells using a special alloy for the load cell base, rather than steel. So far the new CPT, calibrated and managed as described in this paper, is meeting or exceeding the authors' expectations.

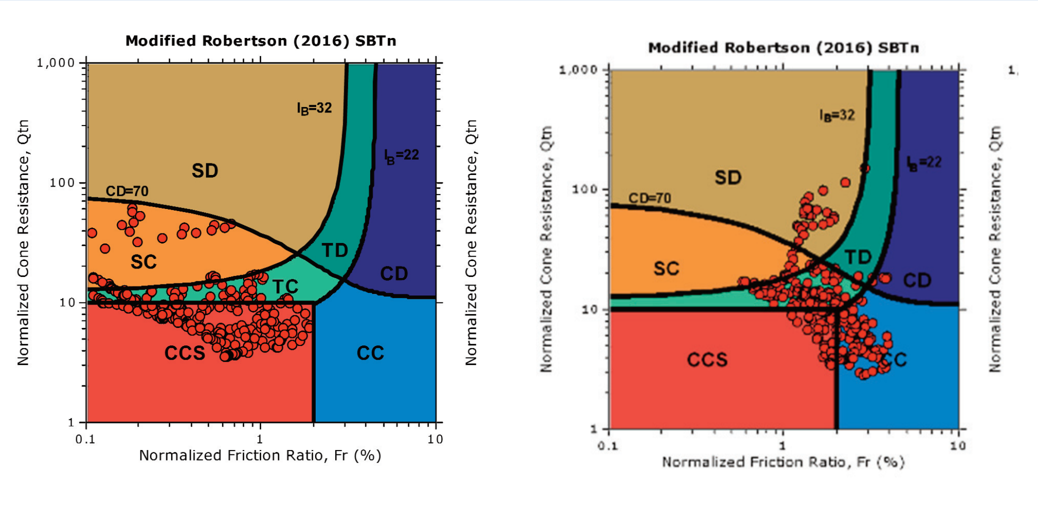

Figure 4 – SBT data comparison of 10MPa Compression Cone (left) vs New 3MPa Cone (right).

A sophisticated way of presenting "soil type", which among other parameters relies on R_f, is called Soil Behaviour Type SBT (refer to P.K. Robertson (2016) Cone penetration test (CPT)-based soil behaviour type (SBT) classification system – an update). CPT data can be conveniently processed to determine SBT using the popular computer software CPeT-IT, and by other methods. But the point is, if R_f is wrong, because f_s is wrong then any of these methods can be misleading.

If good quality CPT equipment is used for a test, and it is well calibrated, then in firm or stiffer soils, even moderately soft soils, soils with (say) q_c greater than about 200kPa, this has never been a problem. The design of modern CPT cones handles f_s measurement pretty well in firm or stiffer soils. But in very soft soils measurement of f_s has always been a problem. Determination of soil type of very soft materials has always suffered as a result of this. Experienced practitioners realised this but pretty much shrugged it off as an "elephant in the room" and some fell back on experience to overcome the shortfall.

It required an equipment re-design (in fact a paradigm shift) to overcome this weakness in CPT testing of very soft soils.

Why does this problem exist?

Almost all CPT testing in soft and very soft soils is done using what are termed Compression Cones, see figure 2 (which is taken from T. Lunne, P.K. Robertson & J.J.M. Powell (1997). Cone Penetration Testing in Geotechnical Practice, then slightly modified by this author).

The problem is related to the mechanical design of modern CPT compression cones, as follows:

- In a Compression Cone, the sleeve has to move slightly to permit it to apply load to the friction sleeve load cell.
- Dirt seals behind the friction sleeve resist this slight movement and use up some of the force applied by soil friction to the friction sleeve.
- Hence a noticeable error occurs if this applied force is very low (as it will be in extremely soft materials).

The paradigm shifting solution that evolved

The solution to the problem perceived by IGS and "made real" by Geomil was to develop a Subtraction Cone of very low capacity, with unusually high quality and sensitive load cells (using a special alloy base), and for IGS to calibrate these very rigorously and often. Details of all of this are provided in the CPT'22 Conference paper "An innovative new 3MPa CPT – to detect and measure very small f_s values" by McConnell (IGS) and Wassenaar (Geomil). Figure 3 shows the improved response to sleeve friction compared to what was previously possible.

Figure 4 compares results from a "conventional" but very high quality 10MPa Compression Cone, vs the newly developed "paradigm shifting" highly sensitive Subtraction Cone – designated in the figures as "new 3MPa Cone".

In regard to the all-important Soil Behaviour Type, data from the same tests shown in the preceding figure have been processed using the computer software CPeT-IT to determine and plot SBT.

The data from the new 3MPa cones interprets SBT that is significantly different to that from the conventional 10MPa Compression Cone.

Conclusion

Readers who have greater interest in this matter are referred to the full paper.

Closing discussion – why is this an important evolution in CPT?

Like all geotechnical tests, CPT was originally devised and evolved in a marketplace of testing of mainly natural soils which were to be tested for what might be called "normal engineering purposes": piles, footings, retaining walls, road or dam embankments, foundation preloads, etc.

In recent years mine tailings dams and ash ponds have become the focus of a whole "almost new" field of geotechnical engineering, and they typically involve very soft (maybe very very soft) ooze-like materials that need to be closed over by capping, raised by up-stream dam wall raisings etc. and assessed quantitatively for stability.

The accuracy and/or applicability of historical geotechnical investigation techniques has been found lacking in many instances, and new systems have been either sought or dreamed of. Non CPT examples include Vane Shear Tests that are now often run at different rotational speeds than according to standards, sampling systems that fail to take even-close-to-undisturbed samples being upgrade.

CPTs are now sometimes run at different penetration speeds (which in some ways makes them different tests).

And then the "elephant in the room" talked about in this article, that reduces the usefulness of CPT (or at least confidence in it) for site characterisation and determination of properties essential to assessment of the safety of tailings dams, and the design of closures and raisings.

Change and improvement are both inevitable – this article is about one such change/improvement. ●