Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)
© 2022 Australian Geomechanics Society, Sydney, Australia, ISBN 978-0-9946261-4-1

Lessons learnt from seabed cone penetration testing in Sydney Harbour

Leçons tirées des essais de pénétration des cônes de fond marin dans le port de Sydney

Graham Scholey
Golder, Sydney, Australia, gscholey@golder.com.au

Fiona MacGregor
Douglas Partners, Sydney, Australia

ABSTRACT: The cone penetration test is routinely used throughout the world with the objective of rapidly profiling the ground. Even the most experienced geotechnical engineer could be excused from assuming that the test will always return accurate, reliable and repeatable results. ISO 22476-1 is the commonly applied standard used to nominate the accuracy and repeatability requirements of cone testing equipment. Without a high degree of rigour to the requirements of ISO 22476-1 there is a risk that the results obtained could be inaccurate, impacting on the interpretation of design strength profiles. In this paper we address the lessons learnt from testing soft sediments in Sydney Harbour, focusing on the calibrations performed to demonstrate compliance with ISO 22476-1. We present the techniques and processes that were developed with our specialist testing partner to calibrate cones at very low load ranges. Results of some of the testing in Sydney Harbour will be presented to illustrate the importance of rigorous calibration and testing processes, along with the potential sources of error.

RÉSUMÉ Le test de pénétration de cône est généralement utilisé de par le monde dans le but de déterminer rapidement les caractéristiques d'un terrain. Même les ingénieurs géotechniques les plus expérimentés peuvent être excusés de présumer que les tests renvoient des résultats justes, fiables et qui peuvent être répétés. L'ISO 22476-1 est le standard communément appliqué pour témoigner de l'exactitude et de la répétition des exigences du pénétration de cône. Sans un haut niveau de rigueur dans les exigences de la norme ISO 22476-1, il y a un risque que les résultats obtenus soient erronés et qu'ils aient un impact sur l'interprétation des profils de résistance de conception. Dans ce document technique, nous évoquons les leçons apprises du test des sédiments mous dans le port de Sydney en se concentrant sur les étalonnages réalisés pour démontrer leur conformité avec l'ISO 22476-1. Nous présentons les techniques et processus qui ont été développés par nos partenaires spécialisés dans les tests pour calibrer les cônes à leurs plus faibles charges. Les résultats de certains tests dans le port de Sydney seront présentés pour démontrer l'importance d'un rigoureux étalonnage et processus de tests, ainsi que les sources potentielles d'erreurs.

KEYWORDS: cone penetration test, calibration, soft soils, reliability, accuracy.

1 INTRODUCTION

Cone penetration testing (CPT) is commonly seen by geotechnical engineers as a method of rapidly capturing reliable and repeatable data about the soil profile. The data are captured continuously throughout the test depth and can be used to estimate the soil classification and a variety of engineering parameters for use in design. The reliability of the data obtained is subject to limitations of the electronic data capture systems, in which errors can be introduced through a range of factors, such as hysteresis and non-linearity.

Peuchen and Terwindt (2014) provided a comprehensive discussion that addresses in more detail the potential sources of errors in CPT. They make the wonderful observation that the "supreme" in situ testing tool provides zero measurement uncertainty, returns unambiguous soil behaviour identification, has a closed form theoretical interpretation model linked to fundamental soil mechanics, penetrates at high speed in a wide range of ground conditions, with extremes of temperature, is low cost and can be operated on any terrain (above and below water) and has a unique method of standardization. They conclude that no such tool exists but that the CPT comes closest to meeting these aspirational objectives.

The impact of the potential errors in CPT is most significant for the design of engineering structures in "soft" soils. For the purpose of this paper "soft" soils are broadly considered to be soils with a shear strength less than 50 kPa. This paper explores the reliability of cone penetration testing, specifically focusing on the calibration procedures that are required so that the data obtained can be relied on for engineering design.

The outcomes presented in this paper are valid for engineering applications in soft soils, for example tailings dams, offshore seabed structures and submerged tunnels. In these applications design refinement can be sensitive to the interpreted soil strength and uncertainty about the reliability of the CPT results could influence the degree of design conservatism.

It is beyond the scope of this paper to discuss the reliability of the interpretation of CPT data, for example, in estimating shear strength and other design parameters, and predicting soil classification.

2 BACKGROUND

The last 10 years have seen an explosion in the rate of urban infrastructure renewal in the city of Sydney. Opportunities have abounded for geotechnical engineers, challenged by the constrained urban environment as projects are increasingly forced underground and onto land that might otherwise have been considered unsuitable for development.

The construction of new road and rail tunnels under Sydney Harbour has required investigation of the geological conditions under the seabed. The presence of submerged palaeochannels within the harbour area has been well known for many years. Holocene-aged sediments filled these channels as water levels in the region rose after the last ice-age, flooding the steep-sided valleys in the underlying sandstone. In the areas of the

proposed crossings of Sydney Harbour the soft sediments that infill these channels are up to about 30 m thick. The implications to the recently constructed Sydney Metro tunnel were captured in the television documentary, "Sydney's Supertunnels".

3 TESTING METHODS

The CPTs which are the subject of this paper were pushed using a seabed reaction frame during investigations carried out in Sydney Harbour between 2017 and 2019. Whilst a seabed reaction frame is commonly used for in situ testing in offshore deep water applications, for example for seabed pipelines and platforms, this is thought to be the first use of a seabed frame for CPTs in Sydney Harbour.

Previous CPTs undertaken in Sydney Harbour in 2015 from a jack-up barge were limited by the rigidity of the casing system extending from the barge deck to the mudline. The casing was subject to bending in relatively deep water and restricted the ability to push the cone to high resistances. For subsequent investigations the seabed reaction frame was selected because the project brief required that the CPTs were taken down to the top of weathered rock and it was anticipated that it would be possible to push to the higher cone resistances required using the seabed reaction frame. It was also expected (and shown) that the testing could be completed more rapidly and hence at lower cost than testing from a jack-up barge.

The seabed reaction frame used was custom-built and operated by a Perth based specialist geotechnical testing contractor. The frame was transported nearly 4000 km by truck across Australia on several occasions for different projects and phases of work. The frame was used for over about one hundred tests in Sydney Harbour.

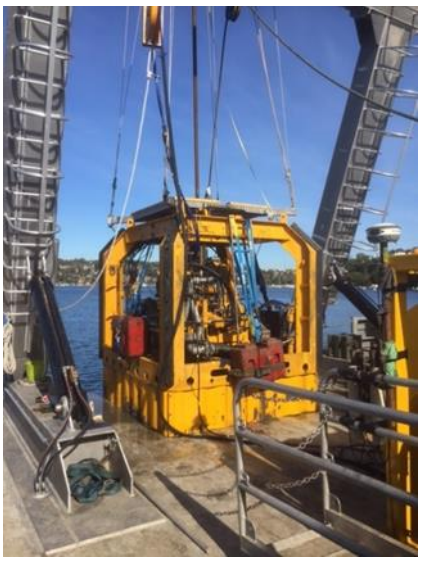


Figure 1. Seabed reaction frame lifted onto the deck of the workboat using an A-frame.

The seabed reaction frame is about 2.3 m by 2.3 m in plan and weighs approximately 5 tonnes. The frame was deployed to the seabed using an A-frame mounted on the deck of a dynamically positioned work boat. Reaction for the CPTs is provided by the weight of the frame and suction. The suction is created by a "skirt" around the perimeter of the base of the frame that penetrates into the seabed, similar to a suction pile. Vacuum pumps are used to assist the penetration of the skirt into the sediment.

The pushing force available from the seabed reaction frame was designed to be sufficient to push the cone to 100 MPa cone tip resistance. The maximum cone tip resistance recorded during the testing was 96 MPa. Tests were terminated when there was a sudden increase in resistance to avoid damaging the cone and rods, particularly when the sediment above was of very low strength. The cones used were standard sized cones with a cone diameter of 35.6 mm or 35.7 mm, a cone end area of 1,000 mm^2 and a sleeve area of 15,000 mm^2.

Different testing tools were deployed from the seabed reaction frame for a variety of test types - cone penetration tests (CPT), seismic cone penetration test (sCPT), ball penetrometer tests (BPT), dilatometer tests (DMT) and seismic dilatometer test (sDMT). Data were captured in real-time on the deck of the vessel via an umbilical cord.

4 REQUIRED ACCURACIES

The testing and reporting of the CPT results was undertaken in accordance with the requirements of the International Standard ISO 22476-1 – Geotechnical investigation and testing – Field testing – Part 1: Electrical cone and piezocone test for "Application Class 1" cones. This international standard requires the following allowable minimum accuracies for Application Class 1 tests in very soft and soft soil deposits:

- Cone resistance (q_c) – the larger of 35 kPa or 5% of the measured value
- Sleeve friction (f_s) – the larger of 5 kPa or 10% of the measured value
- Pore pressure (u) – the larger of 10 kPa or 2% of the measured value.

The specific project brief, however, required that the accuracy of the CPT equipment, after considering all possible sources of error, should be better than ± 2% of the average measured value of any of the soil layers (assumed to be 1 m thick). For example, in a layer with an average q_c value of 200 kPa the accuracy of the q_c results was required to be ± 4 kPa.

One of the test objectives was to delineate the interface between the sediments and underlying rock which required pushing cones to "refusal". For this reason, the initial phase of testing was carried out using cones with full ranges of cone resistance of 0 MPa to 100 MPa or 0 MPa to 50 MPa, even in very soft soils. Subsequently, when it became apparent that the strength of the soft seabed sediments was critical to the project design, a second phase of testing was undertaken in locations where significant thicknesses of soft soils had been identified using cones with a full scale range of only 0 MPa to 10 MPa and the testing was contained within the sediments.

5 CALIBRATION PROCEDURES

During cone penetration testing the loads on the transducer in the cone are transmitted in units of voltage. The voltages are converted to units of load using calibration factors that are derived during load testing in controlled laboratory conditions. The calibration factor is a number in units of MPa per volt or kPa per volt.

Most standard cones are calibrated by the suppliers and operators in a laboratory using a loading frame. Typically the calibrations will be undertaken by loading the cone in load increments of 1/10th of the full scale range of the cone. For example, if the full scale range is 100 MPa the cone will be loaded at 10 MPa increments and at each load increment the voltage output is recorded.

The calibration reports provided by international suppliers typically present only loading data, that is they do not present the measured voltages during unloading, so there is no opportunity to determine whether there is any hysteresis between the loading and unloading cycles. In addition, the net area ratio (a) is typically reported on calibration reports as a single number so the details of how this parameter was determined are not known.

This value is required to correct the q_c values to q_t values to allow for an unequal area effect in which the pore pressure acting on the shoulder area behind the cone reduces the measured q_c value.

For this project the cones used on the first stage of the testing were manufactured by the in situ testing contractor. The cones were calibrated by the contractor in their Perth laboratory over the full-scale output (FSO) of the cone (initially 50 MPa or 100 MPa) using a NATA calibrated reference load cells with matching load capacities. The cones were calibrated for each of the outputs – q_c, f_s and u using load cells and the 'a' value was calculated from calibrations undertaken using a pressure chamber.

The calibration process was repeated three times and the mean value of voltage at each load increment was recorded during loading and unloading cycles. The calibration factors were derived from the slope of the linear best fit line through the points on the load/ unload curve. The presentation of the loading and unloading data allowed an assessment of hysteresis to be undertaken.

The cones were calibrated prior to, during and after the investigations (except for those cones which were destroyed or lost during the testing).

6 INITIAL TESTING

For the first stage of the investigation in Sydney Harbour the testing was carried out using calibration factors that were derived during the pre-testing calibration for each of the cones.

Five cones were used during the seabed testing. All five cones were calibrated prior to the testing using applied pressure ranges of either 5 MPa to 50 MPa or 10 MPa to 100 MPa. Two of the cones were lost during testing and one cone was only used once.

Following completion of the testing the results and the calibrations were reviewed. Some of the tests penetrated significant thicknesses of soft sediments where the applied pressure on the tip was less than 1 MPa, significantly lower than the first load increment used for deriving the calibration factors over the full-scale output range of the cone. In other words, the load range during testing was significantly lower than the first point on the calibration curve.

Review of the original calibrations showed that the voltages in the cones at zero load were not recorded. Questions were asked about whether linearity in the cone response could be expected across the full scale range of the cone. The validity of the calibration factors used during the testing and the test results at very low loads was called into question.

As a result the two cones which had been used for most of the CPTs were calibrated again (post-testing) using a lower load range of 0 to 1 MPa. A calibrated 1 kN load cell was purchased by the in situ test contractor specifically for this project. The objective was to derive calibration factors over this relatively low range of applied pressures using smaller load increments than used to calibrate over the full-scale output range to account for potential non-linearity in the cone response. Applied pressure increments of 0.1 MPa were adopted. The derived calibration factors for q_c over the low load range were different to those derived from the FSO calibrations, as shown in Table 1.

This was the first experience that the in situ testing contractor had of calibrating cones at such low applied pressures. The smooth application of the load was challenging, particularly at the lowest load increment. Over time the calibration procedures were refined to "smooth" the initial load application.

7 ANALYSIS OF POTENTIAL ERRORS

Detailed analysis of the potential errors in the calibrations was undertaken for each of the cones used during the initial testing and then the potential errors in each completed CPT were also assessed to determine the reliability of the CPT data, particularly in the soft sediments.

Table 1. Measured calibration factors for q_c – Pre and Post Testing

Cone	*Pre-testing (MPa)*	*Post-Testing*	*Post Testing*
Testing Range	5-50MPa	5-50MPa	0-1MPa
EC17 (50MPa)	6.70	6.80	6.39
EC68 (100MPa)	11.31		11.43

7.1 *Potential Sources of Errors*

Whilst there might be a common perception in our industry that the cone penetration test is reliable and repeatable, particularly when compared to the standard penetration test, it is important to understand the factors that can limit the accuracy. Accurate and reliable test data requires close attention to the processes for calibrating and testing, particularly if there is a high expectation that the levels of accuracy nominated by ISO 22476-1 are to be achieved.

For any CPT there is potential for errors in the results to occur from a number of sources, as discussed in Lunne et al (1997) and illustrated in Figure 2, from Schaap and Zuidberg (1982). The main sources of potential errors are:

- During calibration:
  - accuracy of measurements;
  - repeatability of measurements;
  - hysteresis of loading and unloading;
  - zero offsets;
  - linearity of data (or ability to fit a single coefficient to the data); and
  - range of calibration pressures not suitable for the strength of soils being tested.
- During each CPT test:
  - zero drift errors – i.e. any difference between zero readings taken before and after each CPT test;
  - temperature effects;
  - poor saturation of the piezocone; and
  - wear on the CPT.
- Correction of test results prior to plotting:
  - inaccuracies in the measurement of the net area ratio (a); and
  - inaccuracies in the correction for zero drift error.

7.2 Errors during Calibration

For each of the cones used the calibrations were reviewed and the potential calibration errors assessed. The potential errors were then combined and a Nominal Maximum Error due to calibration was assigned to each cone using the estimated maximum error plus an allowance for possible zero offset errors in the cases where no zero load reading was recorded during calibration.

For all five cones the estimated Nominal Maximum Errors for sleeve friction were in the range of 5 kPa to 10 kPa, and for pore pressure in the range of 5 kPa to 15 kPa.

The cone resistance values are critical for estimation of shear strength of soft soils. The calculated Nominal Maximum Errors for q_c ranged from 20 kPa (for the cones recalibrated using the lower pressure range 0-1.0 MPa) to 350 kPa for a cone that was only calibrated in the range 10 MPa to 100 MPa.

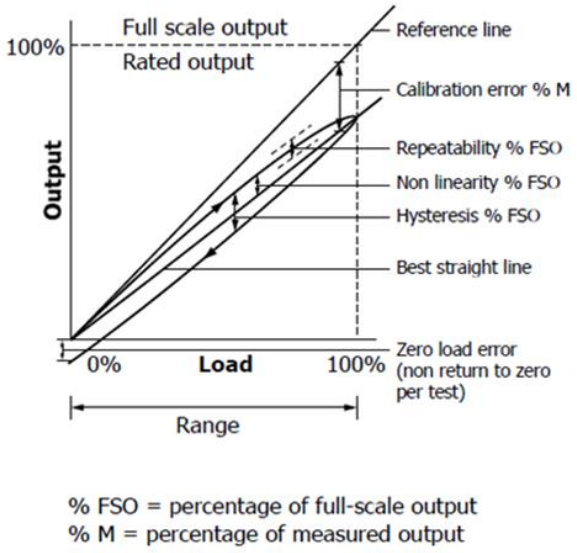


Figure 2. Definition of calibration characteristics (from Schaap and Zuidberg 1982, as presented in Lunne et al 1997)

7.3 *Errors during Testing*

The test procedure calls for zero load readings of q_c, f_s and u to be taken before and after each CPT test. The differences in these readings, the "zero drifts", were recorded with each set of data. The measured zero drifts for q_c in the different tests ranged from 0 kPa to 477 kPa. Zero drift can occur for a variety of reasons including temperature differences, extreme loading (hard refusal), and soil ingress into the filter.

The options available for allowing for zero drift in the readings are either:

- reporting the zero drift measurements with the results so that the users of the information can make their own allowances; or
- adjusting the data in each CPT by linearly spreading the drift over the measurements as the depth increases.

The second option was adopted for this project.

7.4 *Errors during Correction of Results*

The measured cone resistance values (q_c) are corrected to q_t values by allowing for an unequal area effect, the net area ratio (a), in which the pore pressure acting on the shoulder area behind the cone reduces the measured q_c value. For this project the unequal area effect was measured in a pressure chamber during calibration of the cones in Perth. The correction to the cone resistance values are calculated using the following equation:

$$q_t = q_c + (1 - a)u_2 \quad (1)$$

where u2 is the measured pore pressure.

As can be seen from the above equation, the magnitude of the correction depends on the 'a' value and the pore pressure at each measurement point.

The 'a' values interpreted from the initial calibration data were assessed over pressure ranges which had a lowest pressure of 300 kPa or 400 kPa. The hydrostatic pressures at the seabed level typically ranged from about 140 kPa to about 320 kPa, increasing to a maximum of about 470 kPa at the base of the tests. Pore pressures measured during testing ranged from negative values to more than 900 kPa in some tests, however, in the soft soil layers the pore pressures were typically less than 100 kPa. The pore pressures in the softer soils were typically at the lower end of the calibration pore pressure range and in some cases less than the lowest calibration point.

The calibration data showed good linearity, giving consistent 'a' ratios of 0.78 to 0.79, however in some cones there was significant hysteresis observed between the loading and unloading results. When considered individually the 'a' ratios from the loading and unloading data are very similar to the value computed from all the data.

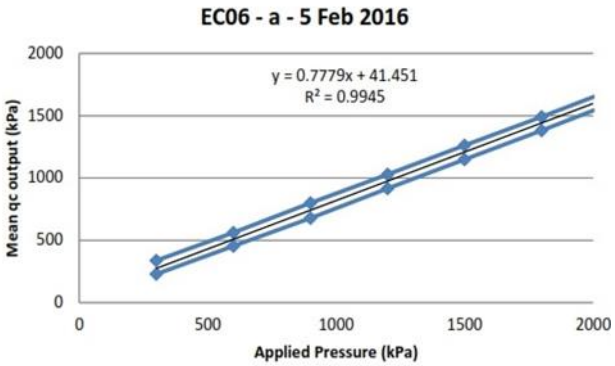


Figure 3. Example of hysteresis observed when measuring net area ratio

The available data suggested that the 'a' ratios were likely to be constant over the full pressure, however, there was no testing data to confirm this and the observed hysteresis raised concerns about the reliability of the cones during unloading.

7.5 *Reliability of Initial CPT Data*

To assess the potential errors in the q_t values due to varying net area ratio values the thicknesses of soil with q_c values less than 0.5 MPa were identified in each CPT and the maximum pore pressures measured in these 'soft' layers recorded. Using these maximum u2 values the potential errors in q_t in the soft layers were calculated using both 'a' ranging from 0.7 to 0.8 (most likely scenario) to 'a' ranging from 0.3 to 1.0 (worst possible scenario).

Having assessed the potential errors in q_t corrections, they were combined with the nominal maximum q_c calibration errors for each cone to produce a total combined error for each of the two possible 'a' scenarios within the 'soft layers.

Assuming that the zero-drift error is spread over the test results then the total combined error is a combination of the nominal maximum q_c calibration error and the potential error in 'a'.

The detailed analysis of potential sources of errors suggested that there could be errors in some of the CPT data in the soft soil layers which were higher than the required accuracy. In addition, the detailed calibration of the cones at lower loads was undertaken many months after the original testing was completed and there was additional uncertainty as to whether these calibrations could be applied to the original test data.

8 RETESTING

8.1 *Approach*

To provide more reliable CPT data in the soft soils, 12 additional CPTs were undertaken adjacent to selected previous CPT locations where significant thicknesses of soft soils had been identified and the detailed error analysis had indicated that the previous test results might not be reliable.

The testing was again undertaken using the seabed frame, but the cone used for the additional investigation was manufactured and supplied by Geomil.

8.2 *Calibration of cone*

The cone was originally calibrated by Geomil in the Netherlands. It was then separately calibrated before the testing by the specialist in situ testing contractor at their facility using NATA calibrated reference load cells and the data acquisition system used for the field testing, and then again after the testing was completed.

Table 2 summarises the calibration factors that were obtained from each of the three calibration rounds.

Table 2. Measured calibration factors - Retesting

	Range (MPa)	*Geomil*	*Probedrill Before Testing*	*Probedrill After Testing*
q_c	0-1	1.271	1.253	1.252
q_c	0-10	1.258	1.252	1.254
f_s	0-0.5	60.257	60.395	60.370
u	0-2	237.273		238.102
a		0.81		0.78

8.3 *Analysis of Potential Errors*

Detailed analysis of the potential errors due to the differences in the derived calibration factors was again undertaken. The error analysis showed that the maximum potential errors due to calibration factor variability were:

- Cone resistance (0-1 MPa) < 10 kPa
- Cone resistance (1-10 MPa) < 25 kPa
- Sleeve friction < 5 kPa
- Excess pore pressure < 5 kPa

The net area ratio (a) is often determined from the cone geometry which is an assumption that would lead to uncertainty about the reliability and accuracy of the results. For this project testing was carried out by calibration using a pressure chamber. Review of the calibration data for 'a' values carried out by the specialist in situ testing contractor showed that there was good linearity in the data, with no significant hysteresis observed.

8.4 *Zero Drift*

Prior to the start of each test, with the cone at the seabed, the "zero-value" of voltage for all parameters was recorded. On completion of the test, with the cone returned back to the seabed, the "drift" from the "zero" reading was also checked and recorded. For the 12 additional CPTs the zero-drift values are summarised below:

- Cone resistance – all less than 25 kPa
- Sleeve friction – all less than 0.5 kPa
- Excess pore pressure – all less than 7 kPa

8.5 *Comparison between the original tests and retests*

The detailed analysis of potential errors due to calibration, testing and plotting for the retesting indicated that the CPT data in the soft soils was within the accuracy required by the international standard, ISO22476-1 for Type 1 application class.

As all 12 additional CPTs were tested adjacent to previous CPTs there was an opportunity to compare the overall reliability of the CPT when testing through soft soils.

When comparing the corrected cone resistances (q_t) for the additional tests with the original tests, 8 of the CPTs had very similar results in the soft soil layers to the original CPTs (allowing for some minor variations in ground conditions). Three additional CPTs had corrected cone resistances typically about 50 to 100 kPa less than the original CPTs.

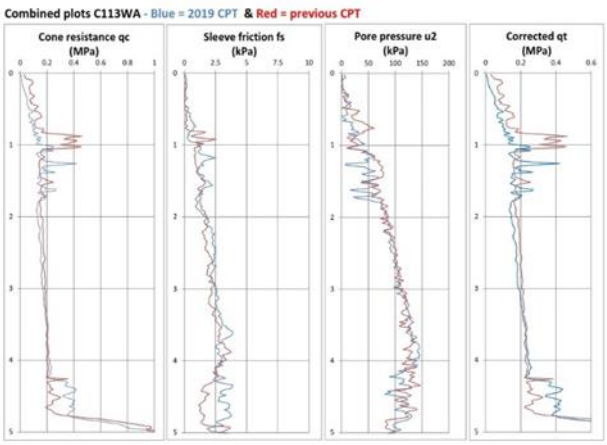


Figure 4. Comparison between original and retest CPT – good correlation

Only one test showed a significant difference in q_t values, with the additional test typically recording values about 250 kPa lower than the original test. As well as lower cone resistance values, there were also higher excess pore pressures measured in the lower strength soils in this CPT which has increased the difference in the corrected cone resistance.

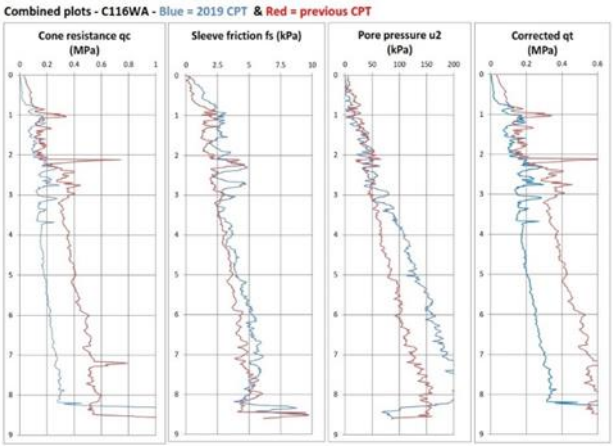


Figure 5. Comparison between original and retest CPT – poor correlation

The additional testing provided confidence that the CPT results provided for the project meet the accuracy requirements of the original brief.

9 CONCLUSIONS

Without a high degree of rigour to the requirements of ISO 22476-1 there is a risk that the CPT results obtained could be inaccurate, impacting on the interpretation of design strength profiles. In this paper we have addressed the lessons learnt from testing soft sediments in Sydney Harbour focusing on the calibrations performed to demonstrate compliance with ISO 22476-1.

Our experience with using the seabed frame compared to CPTs undertaken from a jack-up barge showed that the CPTs were able to penetrate to greater depths and it was possible to complete more CPTs per shift because setting up over test locations was more efficient.

International suppliers typically do not provide sufficient information on their calibrations to allow a detailed error analysis to be undertaken. Our specialist in situ testing partner provided detailed information about the calibrations which we were able to analyse to estimate potential errors. They also developed techniques and processes to calibrate cones at very low load ranges that are more onerous than typically employed.

During the second stage of testing the accuracy and repeatability errors during calibrations over the full-scale output range were shown to be less than 1% which complies with the requirements for Class 1 cones according to the definitions in ISO 22476-1.

The comparison between tests undertaken immediately adjacent to each other showed that in most cases, even with uncertainties about errors, the data obtained using the CPT was repeatable. The additional testing provided confidence to the client that the CPT results met the accuracy requirements of the project and were reliable.

In very low strength soils the test results are sensitive to the calibration factors used to calculate the cone parameters: cone tip resistance, q_c, sleeve friction, f_s and pore pressure, u; the method of calibration, the accuracy and repeatability of the cone and non-linearity, including hysteresis. In these soils the reliability of the tests requires:

- careful selection of cones, preferably with a full scale range matching that of the expected loading during testing,
- duplicate testing at the same location using cones with different full scale ranges where there is the conflicting requirement to push to refusal and obtain reliable results in soft soils, or use of alternative tools suited to soft soil conditions, such as the ball penetrometer or T-bar,
- a high level of sophisticated calibration by experienced operators at loads that match the expected test loads and capture load /unload and zero load points,
- presentation of calibration data at a higher level of detail than normally provided by commercial operators to allow an independent detailed assessment of the compliance of the cone with the designated ISO22476-1 application type, and
- experienced operators who understand and can respond to the test objectives.

10 ACKNOWLEDGEMENTS

The authors acknowledge Transport for New South Wales for providing their permission to publish this paper. We also acknowledge Brett Edwards and his colleagues at Probedrill for their diligence and commitment to the level of sophistication that was required for this project. Finally, thanks to Derek Pennington who initially highlighted the significance of potential errors to the reliability of the data.

11 REFERENCES

International Standards Organisation. (2012). Geotechnical investigation and testing – Field testing. Part 1: Electrical cone and piezocone penetration test. Ref. ISO 22476-1:2012 (E).

Lunne, T., Robertson, P.K. & Powell, J.J.M. (1997). Cone Penetration Testing in Geotechnical Practice. Spon Press

Peuchen, J. & Terwindt, J. (2014). Introduction to CPT accuracy. In *3rd International symposium on cone penetration testing CPT14 : May 12-14,* Las Vegas, Nevada.

Schaap, L.H.J. & Zuidberg, H.M. (1982). Mechanical and electrical aspects of the electric cone penetrometer tip. In *Proceedings of the 2nd European Symposium on Penetration Testing, ESOPT-II, Amsterdam,* 2, 841-51, Balkema Pub, Rotterdam