APPLICATION OF ADVANCED IN SITU TESTING EQUIPMENT AND METHODOLOGIES TO CHARACTERISE A LOW STRENGTH SOIL DEPOSIT IN SYDNEY HARBOUR

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ABSTRACT

In situ testing equipment and methodologies have evolved rapidly over the last 5 years. This paper looks at three devices that demonstrate this evolution: (1) a Special Purpose 3MPa CPTu Cone; (2) the automated Medusa flat plate dilatometer; and (3) the automated down-the-hole Vane Shear device. CPTu cones are now commercially available with special internal design and with capacities as low as 3MPa. These "special" cones, when carefully calibrated, are capable of reliably measuring CPTu parameters in soils right to the bottom end of the very soft range. The cones come with a temperature sensor to enable the management of potential inaccuracies associated with transient temperature effects during the penetration. The Medusa DMT, was developed by Marchetti to provide technicians and engineers with complete control and repeatability of the DMT diaphragm inflation and measurement process, eliminating many of the operator-dependant variables often encountered with the traditional gas-operated DMT. The Vane Shear Test is perhaps the most relied-upon geotechnical strength test; however traditionally it has had in-built potential errors, particularly in very soft soils, mainly due to ambiguity in friction corrections; it has been traditionally restricted to use in pure clay or clay-like soils. Equipment design has evolved (in some equipment) to eliminate the friction-correction problem. High quality calibration is required. These advanced in situ testing tools and improved methodologies were utilised in combination to characterise a low strength soil deposit in Sydney Harbour for a major infrastructure project. The results from the use of the advanced equipment and methods are discussed and reviewed in this paper.

1 INTRODUCTION

A piece of civil infrastructure was to be constructed in very soft sediments on/in the seabed of Sydney Harbour. The initial site investigation works, that were conducted between 2017 and 2019, were undertaken conventionally by normal CPTu equipment, under the assumption that "CPT tests will always return accurate, reliable and repeatable results". Unfortunately, a variety of accuracy and repeatability issues were experienced (see Scholey and McGregor, 22 and Scholey, 24).

Further investigation work was undertaken in 2022, using up-to-date, ie "evolved", in situ testing equipment and methods, to improve data quality for the project. Three different in situ tests were utilised: (1) the (then) new 3MPa Special Purpose CPTu; (2) the (then) new Medusa DMT; and (3) electronic down-the-hole Vane Shear.

Soil strength was thus able to be assessed using several different methods, all of the most up-to-date type.

This is discussed more in the following; we have assumed that the reader has a basic knowledge regarding CPTu, DMT and VST testing.

2 SPECIAL PURPOSE LOW CAPACITY 3MPA CONE

2.1 THE SPECIAL PURPOSE CPT CONE

This cone was introduced at the CPT22 Conference in Bologna by McConnell et al (2022) as "An innovative new 3MPa CPT – to detect and measure very small f_s values". Innovations included:

- Somewhat controversially the cone is of the subtraction type – refer Figure 1. This type was adopted as in a subtraction cone the force from a device's friction sleeve is transferred directly to the relevant load cell, without relative sleeve-to-load-cell movement, thus avoiding the problematic effect of friction in the sleeve's dirt seals.

- To increase sensitivity, the load cells were manufactured with a special alloy with a stiffness of approximately one third that of a traditional CPTu cone, tripling load cell sensitivity. This resulted in a cone with a tip capacity of 3,000kPa and a sleeve capacity of 200kPa. The resolution of both the tip and sleeve is 1/24,000th of the capacity.

The cone is currently the highest resolution commercially available CPT known to the authors, and certainly the only one that can properly measure the very small sleeve friction values of very soft materials.

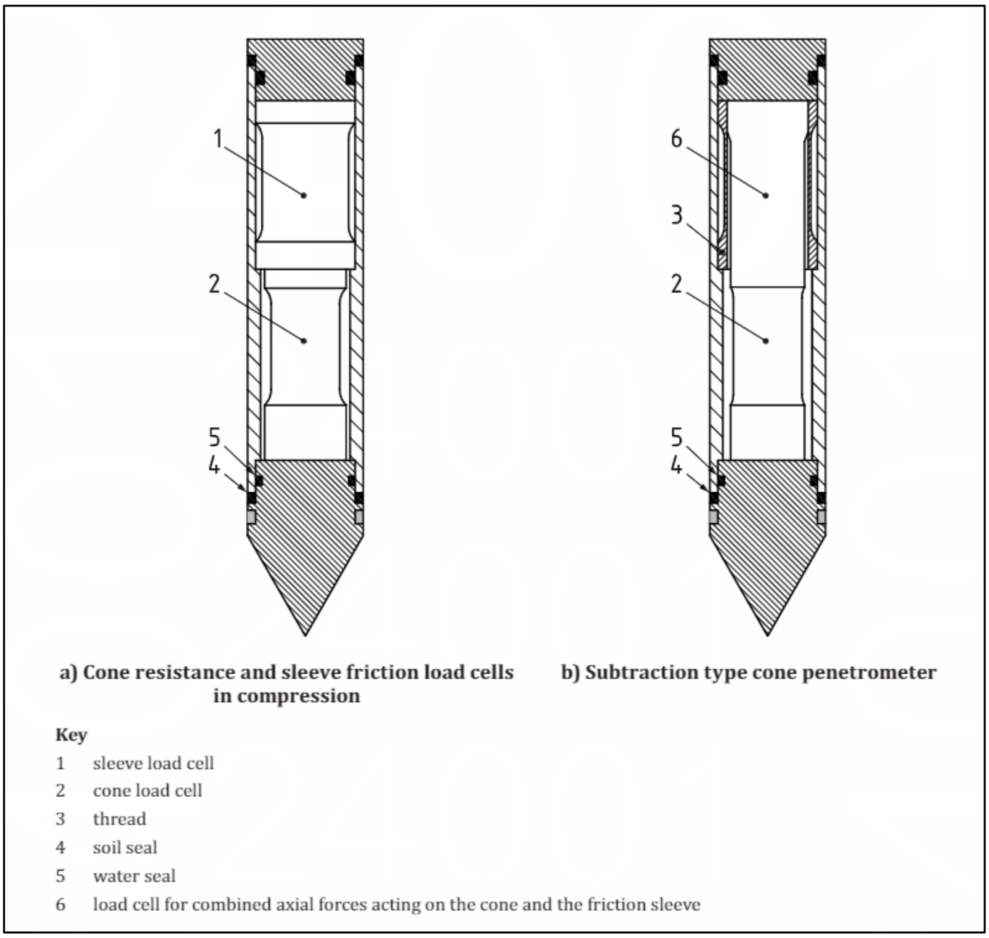

Figure 1 - Cross-section examples of Subtraction and Compression Cones

2.2 CPT CONE CALIBRATION

If you are testing very soft or soft soils, the expected range of q_c values of interest are 0-500kPa or even lower. Therefore, any CPT cone to be used for this purpose must be calibrated properly over that range. <u>There is an obvious and clear connection between the materials you intend to test and the appropriate capacity of the cone and the rigour of the calibration undertaken.</u>

The calibration report shown in Figure 2 shows how this is done for these 3MPa cones. Referring only to q_c for simplicity: calibration is made using several points over the very low range of 0-30kPa (1% of capacity); then again over the range 0-300kPa (10% of capacity); then over the whole range. Dead weights are used to apply the loads.

The same rigour is applied to calibration of sleeve friction f_s and pore pressure u.

During the calibration of pore pressure, q_c changes induced by the pore pressure changes are also plotted, yielding a very high quality and proper calibration of the Net Area Ratio; a cone parameter that is required for calculating q_t from q_c and pore pressure.

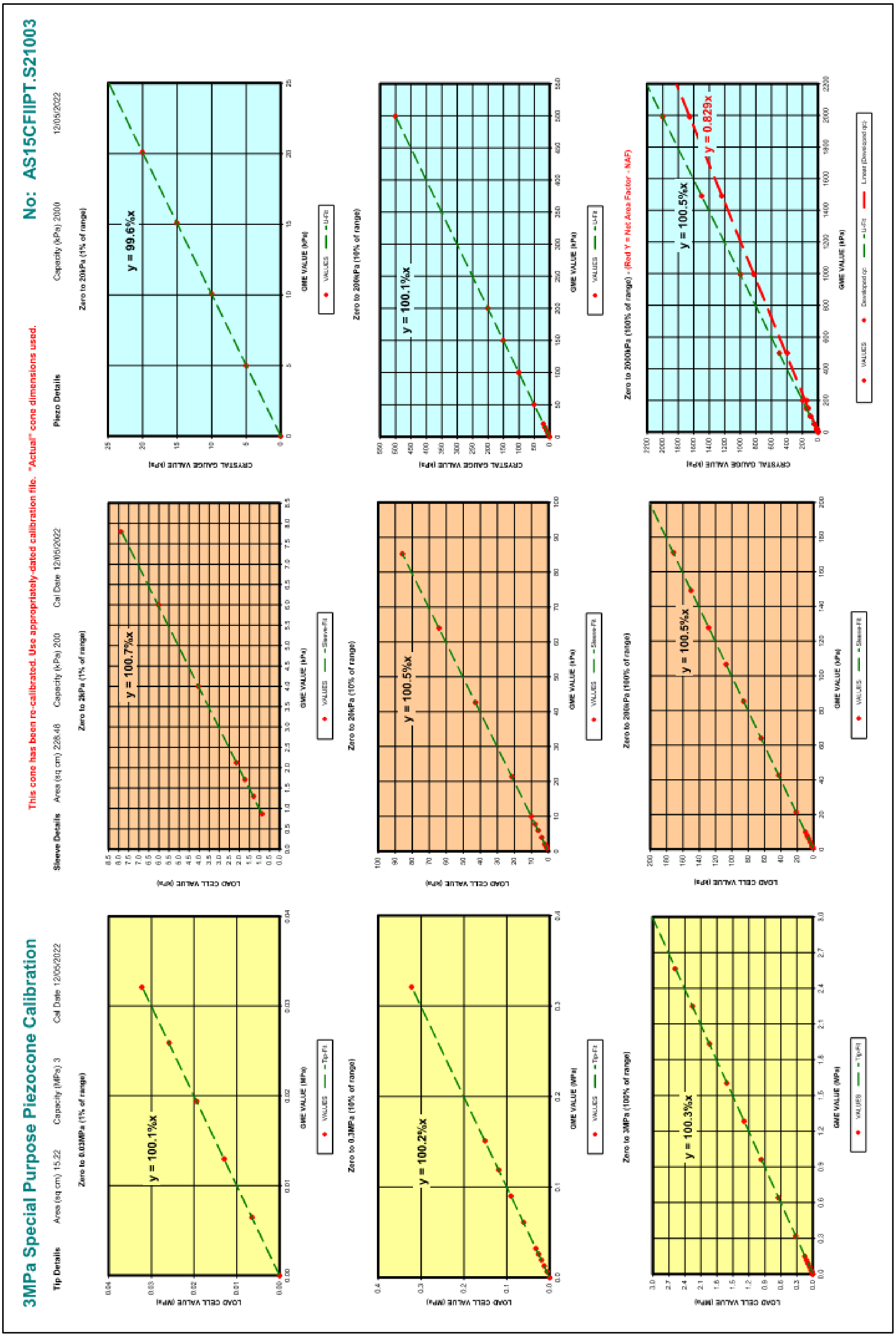

Figure 2 - Example Calibration of 3MPa Special Purpose Cone

2.3 CALIBRATION FREQUENCY

Load cells inside CPT cones are designed to work over a significant portion of their elastic range so that the strain gauges have something significant to measure. This leads to the load cells being susceptible to drift with test frequency. While this strain-related drift is typically relatively small, in a subtraction cone load cell accuracy is critical. Also, it just makes good sense to make sure that the gear you are using to test something (for someone) is actually measuring correctly.

None of the international standards seem to take calibration frequency very seriously – requirements range from six monthly to 12 monthly intervals or even intervals based on an operator's observations of "what looks right'. And reliance on Reference Value or Zero Offset drift, while convenient is "questionable".

The authors' company has a policy of calibrating before and after any and every project, and at no longer than seven working-days' intervals on longer jobs. This is a high-quality marketable process and one that leads to very good outcomes.

2.3 MANAGEMENT OF TRANSIENT TEMPERATURE EFFECTS

All respectable cone manufacturers provide CPT load cells that are accurate under any practical stable operating temperature; this is a relatively simple design feature and allows the manufacturers to state that their cones are "temperature compensated", which they mostly do claim. Note the emphasis here on "stable operating temperature".

However no CPT cones known to the authors are stable during the time in which the cone is changing from one temperature to another – the period of transient temperature change as shown in Figure 3. This effect is noted one way or another in all international standards but is pretty much ignored in much day-to-day testing practice by many/most operators (just ask them if you are in doubt about this).

The only practical way for this to be managed is to halt the CPT push progress when significant temperature changes are under way, and to wait for the cone temperature to stabilise – typically about 10 minutes. This effects: (a) the start of any CPT push as the ground is unlikely to be the same temperature as the cone; and (b) any push that penetrated strong material (which heats the cone) and then continues down through softer material (as the cone cools down).

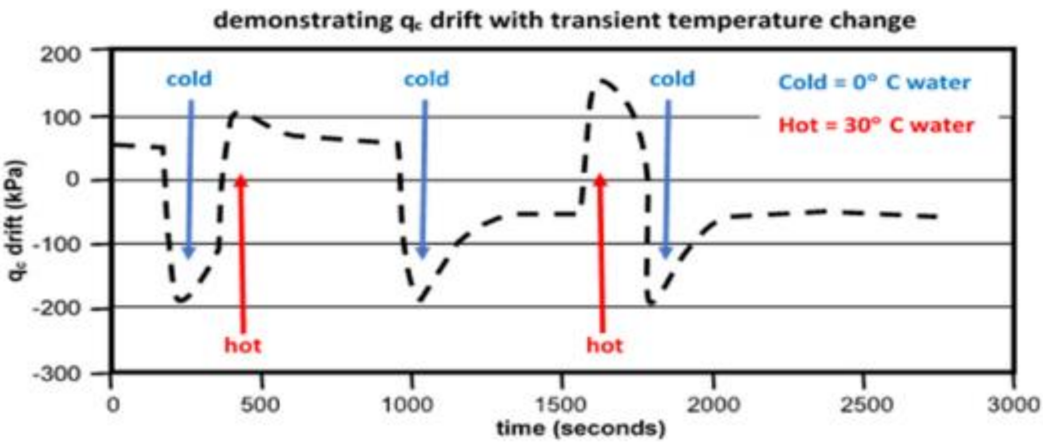

Figure 3 - Changes in zero load q_c values at varying temperatures

Insitu Geotech Services Test Methods and Improvement Bulletin #4 dictates:

a) At the commencement of any test - "conduct a cone stabilisation for 5 to 10 minutes to allow the temperature of the cone to stabilise. This stabilisation shall occur within the first 0.5 to 1.5 metres".

b) If penetrating into soft materials below strong materials (especially below dense sands) - "the push is to be interrupted for 5 to 10 minutes as close as reasonably possible below the interface between the high strength and low strength soils".

3 MEDUSA FLAT PLATE DILATOMETER

3.1 THE MEDUSA DMT

The Medusa DMT is a recent significant upgrade of the well-known mechanical DMT, invented by Prof Silvano Marchetti in 1977. The Medusa provides a hydraulic automation and measuring system for autonomously performing tests (Marchetti 2018). The device, see Figure 4, consist of: batteries; electronic board; motorised syringe; pressure transducer; and hydraulically operated flat dilatometer blade. The electric board controls the motorised syringe which applies hydraulic pressure to the DMT membrane, as distinct from the original system that used compressed gas. A pressure transducer monitors this hydraulic pressure directly above the membrane as it is inflated to A, B and C readings. The Medusa is connected via a cable to a laptop at the surface giving the technician full control over the testing.

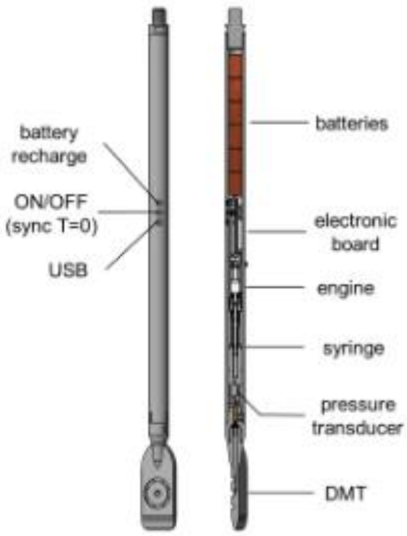

Figure 4 - Medusa DMT

3.2 ADVANTAGE OF MEDUSA DMT OVER TRADITIONAL DMT

Despite the relatively simple nature of the traditional pneumatic DMT there have always been several flaws which are overcome by the Medusa DMT.

a) The equipment required to conduct the testing is smaller, simpler and less prone to equipment faults. The Medusa DMT does not require a gas tank, trying pneumatic electric cable, or pressure control unit. Advantageously the Medusa can be powered by the same cable used to conduct CPTu testing. This means that there is no need to change over the cable between test types.

b) The motorised syringe, controlled by an electronic board, applies the pressure to the diaphragm in a controlled operator independent manner. This allows for repeatable and accurate timing for obtaining pressure readings.

c) In the Medusa DMT the pressure to inflate the diaphragm is generated by a syringe and is measured by a electronic pressure transducer directly above the diaphragm . This eliminates any possible problems of pressure equalisation and/or time-lag along the pneumatic cable of the traditional DMT equipment.

By generating and measuring the pressures directly above the blade in a controlled manner the Medusa DMT is able to repeatedly and defensibly measure parameters in very soft and soft soils, including tailings ooze This is detailed and demonstrated at the Sarapui 1 and 2 test sites in Brazil by Marchetti el al (2021), the paper concluding that "for very soft soils the use of the Medusa DMT is therefore recommended".

4 DOWN-THE-HOLE VANE SHEAR DEVICE

4.1 THE VANE SHEAR TEST

The vane shear test is one of the best-known field tests to determine the undrained strength of saturated cohesive soils (Duncan et al 2014). This is due to the fact that it is intended to give an almost direct measurement of the in-situ undrained shear strength (Selanpaa et al 2017).

The test as detailed in ASTM D2573-18 and in other standards, consists of inserting a blade in the shape of a cruciform into the soil and applying torque to rotate the device, as depicted in Figure 5 below. The measured torque is then used to calculate shear stress on the sheared surface. The blades are typically pushed into the ground via either predrilled holes or they are pushed into the ground with or without casing.

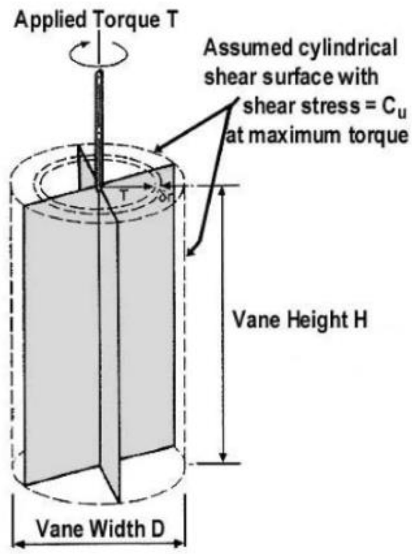

Figure 5 - Vane Shear testing blade

As described by Salanpaa et al (2017) there are many factors that influence the Field Vane Shear test accuracy;

a) Soil disturbance induced by predrilling

b) Uncertainties of soil-rod friction evaluations

c) Accuracy of measurement systems and measurement errors

d) Malfunctioning during the test such as rods twisting, joints tightening, malfunctioning of slip coupling or change in vane position.

e) Lack of apparatus maintenance and calibration

f) Influence of waiting time between vane insertion and rotation

g) Strain rate effects

4.2 THE DOWN-THE-HOLE VANE SHEAR DEVICE

The Dutch equipment manufacturer A.P. van den Berg introduced a new down-the-hole vane shear device as shown in Figure 6 below. This tool is computer controlled and connects directly to standard CPT rods or casings. It can be direct-pushed into the ground, without the need for a predrilled borehole. Data is transmitted directly through the standard CPT cables, eliminating the need to thread and unthread cables.

The technician can precisely control the rotation rate at speeds between 0.1 to 60 degrees per second and the amount of rotation of the test.

Figure 6 - The Down-The-Hole Vane Shear Device

The significant design feature of A.P. van den Berg vane shear devices is that the torque motor and torque sensor are built into a unit directly above the vane blade. This eliminates errors and uncertainty associated with rod friction correction, slip joint operation, rod twisting and joint tightening, all of which have the potential to swamp shear strength data when testing in very soft and soft soils. This swamping of values was observed by Gylland et al (2016) and Schaeffers et al (2012) where they concluded that devices that measure torque at the surface are “not able to measure reliably the low torque values”. They recommended that for the measurement of low shear strength value it is best to “use a VST device with torque registration close to the vanes cross”. (Gylland et al 2016)

4.3 VANE CALIBRATION

Like all geotechnical in situ testing tools, Vane Shear equipment must be properly calibrated. It makes no sense at all to use Vane Shear Test data to “calibrate” CPTu data (a statement often made) unless the equipment itself is calibrated. Calibration using dead weights is simple and is preferred. The photo below shows such a calibration in progress.

Figure 7 – A Vane Shear Test Apparatus Under Calibration Using Dead Weights

5 TEST RESULTS FROM THE SYDNEY HARBOUR PROJECT

5.1 THE 3MPA SPECIAL CPTU CONE

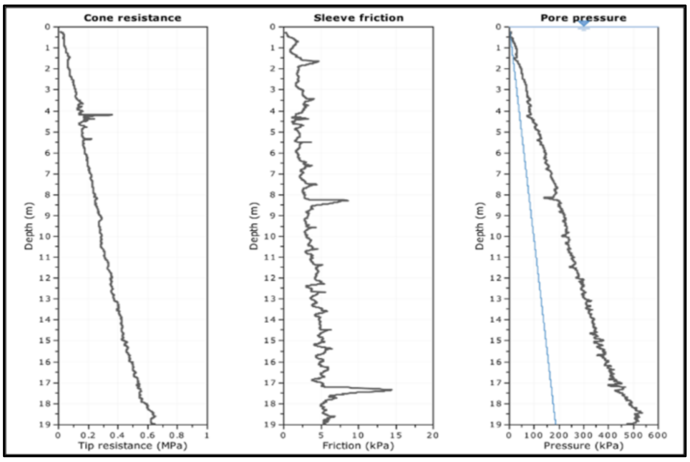

Figure 8 - Special Purpose 3MPa CPTu Test Results (depth measured from seabed)

5.2 THE VANE SHEAR TEST RESULTS

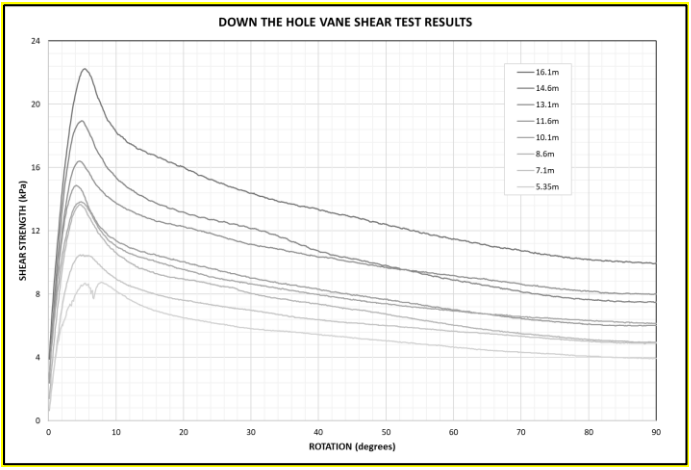

Figure 9 – Vane Shear Test Results (depth measured from seabed)

5.3 THE MEDUSA DMT RESULTS

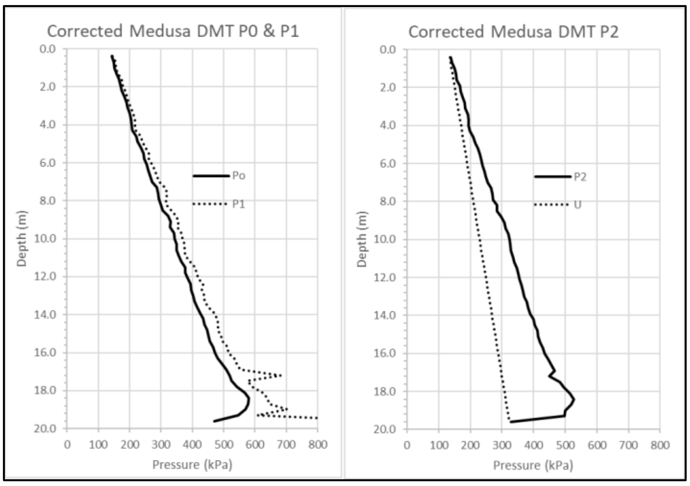

Figure 10 – Medusa DMT – Raw Data (depth measured from seabed)

5.4 THE RESULTS PLOTTED TOGETHER

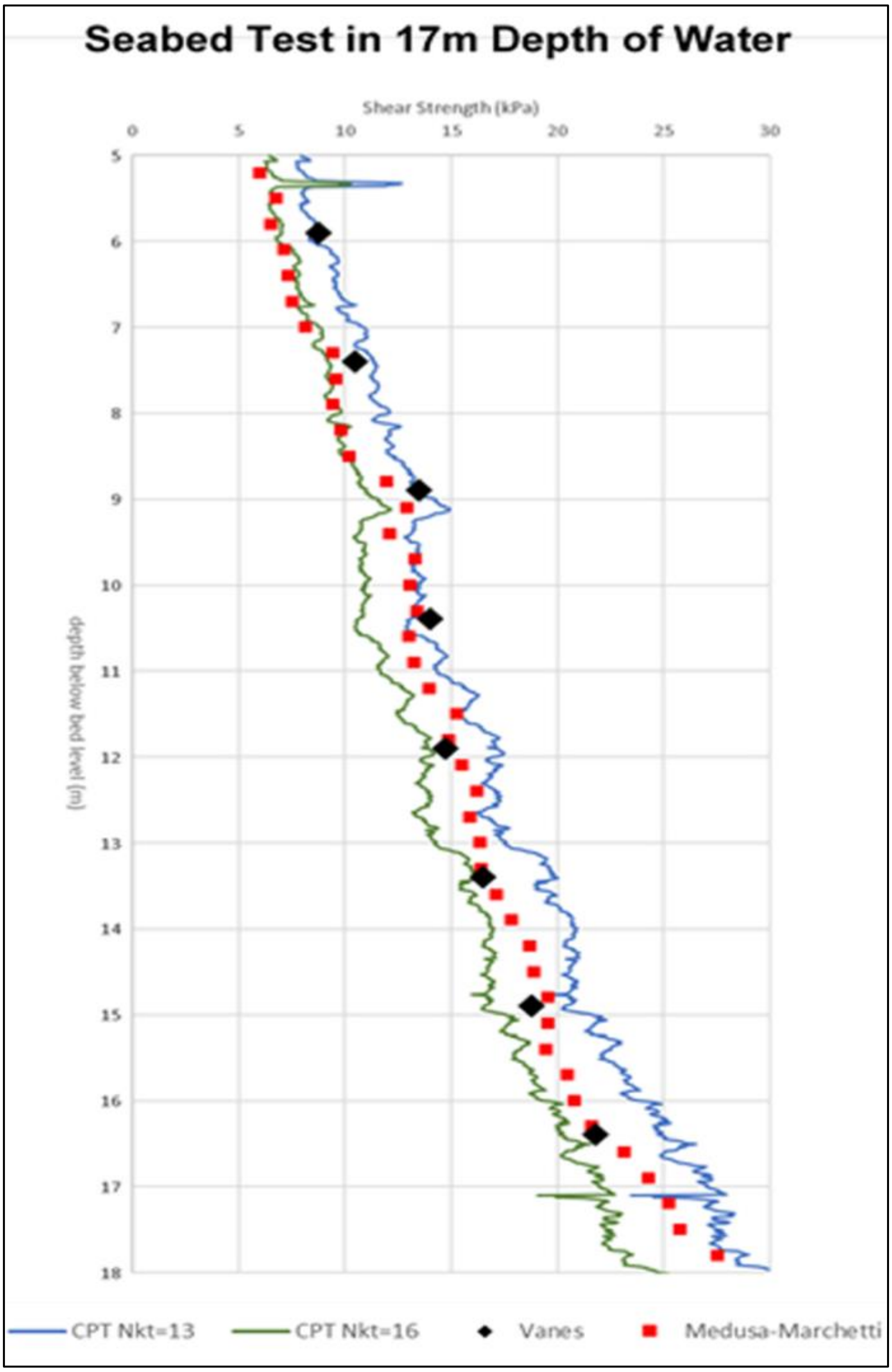

Figure 11 – All Results Plotted Together (depth measured from seabed)

6 CONCLUSIONS AND RECOMMENDATIONS

In situ testing of a very soft and soft marine soil deposit in Sydney Harbour was conducted using the latest in situ testing tools and methodologies: a special 3MPa CPTu cone; a Medusa DMT; and a down-the-hole Vane Shear Test device.

Using the three different tools in combination is a powerful and conclusive way to provide geotechnical engineers with confidence regarding key soil strength parameters and should be considered essential practice.

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