

PROCEEDINGS
2019 AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIAN SYMPOSIUM

**Geotechnical characterisation –
managing design and construction risk**

Wednesday, 30 October 2019, 8:00am – 7:00pm
Rydges Hotel, 186 Exhibition Street, Melbourne



AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIA CHAPTER



IGS
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PREFACE

The Victorian chapter of the Australian Geomechanics Society invited academics and practitioners in the field of geotechnical and ground engineering to attend the 2019 Australian Geomechanics Society Victorian Symposium held on 30 October 2019.

In recent years Victoria has seen significant growth in the construction industry. Investment in both public infrastructure and commercial real estate is growing, and as our cities and infrastructure grow, so too does the need to develop parcels of land with challenging ground conditions. Economical and safe geotechnical design requires efficient and well thought through ground investigation and characterisation to identify and manage ground risks and opportunities.

The 2019 Australian Geomechanics Society Victorian Symposium presents an overview of current state-of-the-art practices, innovation, new research results and case studies relating to geotechnical characterisation with an emphasis on its implications for addressing and managing design and construction risk. The 2019 Symposium brought together professional engineers, researchers, specialist contractors, regulators, educators and students to share and discuss their experiences on the topic of ground characterisation.

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Reducing geotechnical uncertainty to help manage risk – how to make CPT and vane shear work (together) for you

A. McConnell¹

¹ Founder of Insitu Geotech Services Pty Ltd (IGS), Honorary Life Member of Australian Geomechanics Society, TC102 Committee Member of ISSMGE, Member of ISO 22476-1-2012 review committee. 0417-748-669, allan@insitu.com.au.

ABSTRACT

This paper has explained that one valid reason for using in situ testing in geo-engineering is to improve site investigation data and in doing so to reduce geotechnical uncertainty and risk. This is real and can certainly be achieved; making everybody happy. The impact on reducing uncertainty can be outstanding.

But the paper has also deliberately set out to demonstrate, using just two common test techniques, CPT and Vane Shear, that maybe “*in situ ain't in situ*”. It's not quite that simple – as in situ test data can be wrong. In fact there is potential for poorly implemented in situ testing to be more misleading and risky than other methods simply because people trust it to be correct and may rely on that trust inappropriately.

Keywords: CPT, Vane Shear, Calibration, Standards, uncertainty

1 INTRODUCTION

There are several reasons that people might use “in situ” techniques for site characterisation:

- It's more time and cost efficient, maybe even cheaper.
- It's more enjoyable for consultant supervisors (compared to drilling, test pitting, etc).
- It can be (??) more precise, and in most soils it might possibly (??) markedly reduce geotechnical uncertainty.

Reasons (a) and (b) are pretty-well “givens” in most circumstances, but reason (c) while 100% legitimate and a great driver for in situ testing, is by no means always definite. An “all must be good ‘cos they told me it is so” assumption/belief can be misleading. If a geo-professional simply believes that his in situ data is good, because someone tells him it is, and it turns out not to be, for one reason or another, then big problems can evolve, particularly on soft soil sites or tailings dams.

The author has had a professional lifetime focused on managing geotechnical uncertainty, and, in the past two decades, on reducing it. This paper will present a little of that history and then, (i) “warts and all” discuss the merits and de-merits of two popular in situ methods that are often used together, (ii) show some examples, and (iii) explain what must be done to make this work for you. It will work for you, but only if it's done right and is properly understood.

Techniques to be discussed here will be CPT and Vane Shear Testing. On another occasion the discussion can be expanded to cover much more.

2 IN THE BEGINNING

The author was fortunate, as a young engineer, to be mentored by an intellectually very smart engineer, Peter McAnally. Peter asserted to him almost every day of his early evolution that “geotechnical engineering is fraught with uncertainty” and that the geotechnical engineer's job

is to unravel and manage that uncertainty so that people could build things that work.

From that beginning, the author's evolution progressed through: (i) guessing confidence levels based on honest knowledge of uncertainties in analysis and input parameters; to (ii) rather simple sensitivity analyses; to (iii) sophisticated spreadsheet modelling and intensive Monte Carlo analyses using commercial add-on packages like Crystal Ball and @Risk. Figure 1, below shows an example output of such analysis from 1998, for a major rail cutting that had some serious problems.

The author was proud to be part of teams that won awards from IE Aust and ACEA; most notably for settlement analyses of the Brisbane Airport reclamation and of Townsville Port reclamation.

The author was not proud though, that the more he learned and practised this black art of quantifying uncertainty, the more it became clear that uncertainty was greater than we all liked to think.

The transition from modelling to quantify uncertainty and thus manage it, to attempting to reduce geotechnical uncertainty, took place via a initial step into in situ testing and later to very high quality sampling by direct-push methods. The objective is shown in Figure 2, below, based around a stability analysis from 2002. The blue histogram shows reality; the line red shows the objective.

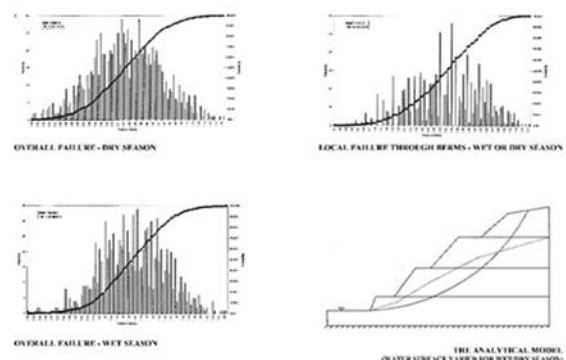


Figure 1

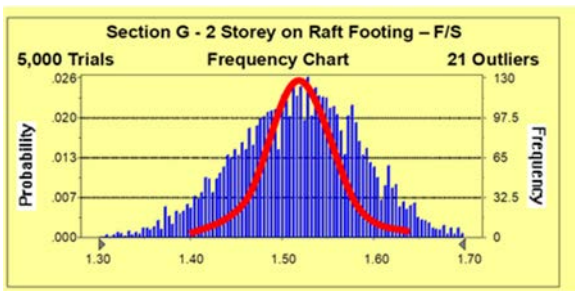


Figure 2

It's simple – if you have more certain data, you can reduce analytical uncertainty. That's the theory, but as stated in the introduction, talking about in situ methods, if a geo-professional simply believes that his in situ data is good and it turns out not to be, big problems can evolve.

3 HOW GOOD IS A CPT ?

3.1 Calibration and sensitivity

In training seminars that the author runs, he expresses his opinions that:

- a) One strength of CPT is the sensitivity of the equipment – so hey “this thing must be good”.
- b) One weakness is the sensitivity of the equipment – thinking that “this thing must be good” makes some people believe that hey “this thing really is unequivocally good”.

How good should a CPT be? This is covered in ISO 22476-1-2012, pretty much deemed to be the “benchmark” standard, see its Table 2 - “Application Classes”; Fig 3 below is an extract from that table.

Application class	Test type	Measured parameter	Allowable minimum accuracy ³
1	TE2	Cone resistance	35 kPa or 5 %
		Sleeve friction	5 kPa or 10 %
		Pore pressure	10 kPa or 2 %
		Inclination	2°
		Penetration length	0,1 m or 1%
2	TE1 TE2	Cone resistance	100 kPa or 5 %
		Sleeve friction	15 kPa or 15 %
		Pore pressure ^d	25 kPa or 3 %
		Inclination	2°
		Penetration length	0,1 m or 1 %

Figure 3

To summarise, ISO 22476-1-2012, Table 2 defines that required CPT sensitivity and accuracy “depends” on the soil type and the purpose of the test; it defines four “Application Classes”; only a portion of two of these are shown in Figure 3.

Let's talk here just about soft soils, and for simplicity just about Cone Resistance – similar comments apply to Sleeve Friction, Pore Pressure and Net Area Ratio.

ISO 22476-1-2012 specifies that for *Application Class 1*, ie for confident profiling and design in soft soils, Cone Resistance, taking all things into account, must be measured to an accuracy of <35kPa or <5% of the measured value. Whichever is the larger.

This means, assuming that N_{kt} is around 15, that a CPT undertaken to Application Class 1 may indicate undrained strength of very soft clay only to an accuracy of around +/- 2-3kPa.

But note here that no manufacturers known to the author claim or can defend Application Class 1 calibration accuracy from their cones “as delivered”. When Class has been responsibility quoted, the highest Class that the author has seen (quoted for a new cone by a reputable manufacturer) is Application Class 2. This means <100kPa Cone Resistance; +/- 5-8kPa shear strength in a soft clay.

If you want better strength determination accuracy than 2-3kPa or even 5-8kPa then the CPT calibration & test process, taking all things into account, must significantly exceed Application Class 1 requirements.

It can do, but it takes effort and commitment, and investment. ISO 22476-1-2012 makes reference to this possibility; and a new Class is evolving right now, most likely this will be designated Class 1+.

3.2 What Does This Author Say – No 1?

A significant percentage of end-users that this author works with would be horrified if they were told that the best interpretation they could expect from a CPT test made for them in soft or very soft ground was to be no better than the accuracy discussed above.

In other words, the ISO 22476-1-2012 standard, even if it is the defacto benchmark, is not good enough for them. Bring on Class 1+.

3.3 What Does This Author Say – No 2?

This author routinely explains and demonstrates that much higher sensitivity and accuracy is possible, using modern, good quality commercial CPT equipment; by adopting a CPT management process that goes way beyond the expectations of ISO 22476-1-2012 or of any other standard; in fact by more-or-less ignoring the standards themselves and going back to basic principles. These basic principles are rather obvious:

- Use very good quality CPT equipment. Keep the equipment in 100% pristine condition by maintenance and care.
- Calibrate and calibrate and adjust and adjust carefully enough and often enough that you know for certain that the numbers you are achieving and reporting are correct. As a minimum this means calibrating before and after every job; much more often on larger projects. This cannot be done “outside”; as the lead times and delays involved would make it impracticable; it is a continuous-flow process.
- Focus the calibrations to the part of the test range that matters most; usually the bottom 1% of range is the critical one; the very soft and soft soils range. It is possible to achieve close to 100% accuracy over this range by focusing like this. See Figure 4, an extract from a calibration for qc undertaken this way.

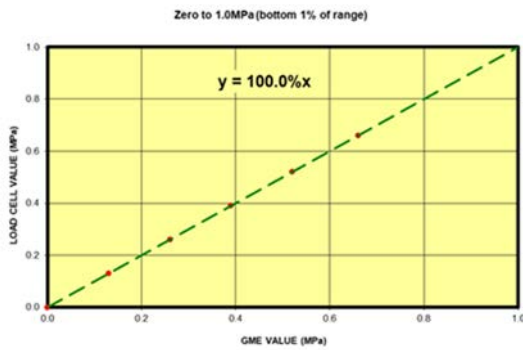


Figure 4

- Use the true cone dimensions during every calibration. ISO 22476-1-2012 and all other standards permit certain tolerances on dimensions; focusing here on qc, these tolerances permit 4% variation or error if not taken into account – Class 1 dictates 5% min accuracy – 4% might already be eaten up by permitted dimensional tolerance variations.
- Checking data as a project progresses, test-by-test and during a test, and observing changes and indicators that might imply a loss of precision. Instantly and unequivocally repeating any tests, using fresh equipment, if there is any doubt at all; no matter the cost. Immediately pulling a cone out of operation and having it re-calibrated if there is any slight possibility of a problem. It's a culture, not a chore.
- Understand what can happen during a test to upset the numbers, and take these factors into account in your operational process; instilling this as culture, not a chore. This is discussed in the next section of this paper.

3.4 Pushing a CPT – Just Pulling Levers?

On the surface of it, almost anyone could successfully undertake a CPT push: buy the stuff, screw the gear together, connect it all up, pull the levers and away you go. This is far from the truth; at least if the intention is to do the test to a high enough standard that the end-user can “design with confidence”. A number of matters must be very sensitively monitored and controlled:

- A CPT is a sophisticated device full of very sensitive calibrated load cells or strain gauges. We push this expensive and fragile device into the ground, and the ground almost invariably has “crunchy” zones or bands that are capable of damaging it. The operator must watch for these bands and react to them; slowing the push if necessary; watching for and reacting to subtle glitches in the data flow that might indicate a need to question that data.
- Assuming that we are talking here about piezo-cones, the cone’s filter will pass through bands that provide different pore pressure response. Sometime the piezo filter will be sucked hard as it passes through dry bands or fissured or otherwise dilatant bands. This can totally disrupt the pore pressure measurement system and require a response from the operator; maybe the test is stopped to let pore pressure re-build; maybe it is terminated and re-started with a fresh cone. This all

takes time and can be “in conflict” with a client’s expectations regarding productivity. Over-riding this is possible, and is in fact the default with most CPTs undertaken by poorer operators; but it must be a client decision (productivity vs results); and the client must be informed of this.

- Then there’s the “elephant in the room” (figure 5); cone temperature shift. All good quality cones known to the author are temperature compensated and hold their calibration pretty well at most temperatures, once stabilised (we have calibrated up to 80 deg C). But change in temperature is another matter; any CPT drifts around during the time-period of temperature change. The author has measured this drift in the general range 100-200kPa of cone resistance. So if you’re measuring 200kPa or so, the potential error is “out of control”.



Figure 5

3.5 Transient Temperature - The Elephant

As a CPT is advanced through different materials its temperature changes; the steel heats up penetrating tough ground and cools back to ground temperature afterwards. The load cells or strain gauges used to measure qc, fs, etc are mounted on the steel that is heating and cooling; and this disturbs their output. It is “dream time” to believe that this process is uniform or has predictable influence on CPT data. If someone tells you otherwise they are showing their ignorance. Figure 6 below plots qc for three tests next to each other, each passing through about 4m of dense sand fill (a preload) then entering soft clay that was in fact the main subject of the testing.

The black plot was a test simply pushed through the dense sand then continued. The red and blue plots were both paused and rested for 10 minutes after breaking through the sand; allowing the heated-up cones to cool off to a stable temperature before continuing.

This is a very big deal. These tests were intended to monitor the preloading of the soft clay. The black plot indicated no strength increase from preloading, or even a strength reduction; the red and blue plots showed that the preload had been 100% successful.

If you look at the plots it is clear that it required about 5m of penetration through the soft clay for the black plot to “catch up” with reality as it cooled down – about five minutes of time during which the CPT data from that test was useless for its intended purpose.

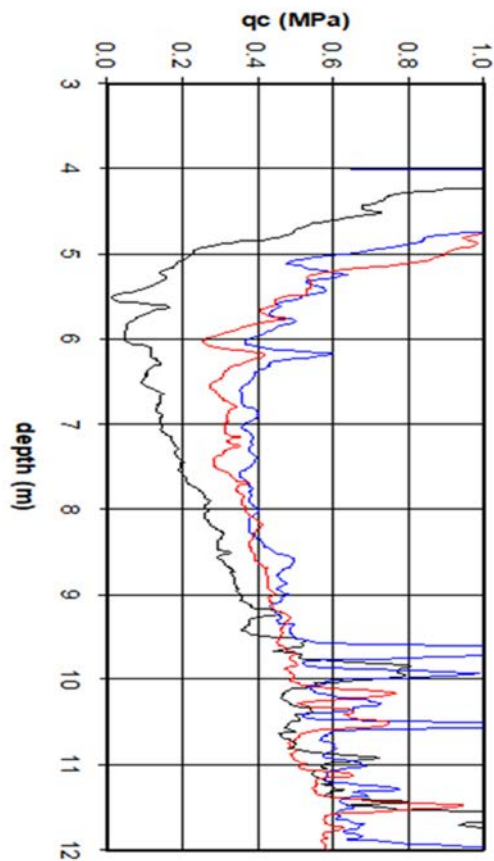


Figure 6

This incredibly important matter is more-or-less put into the too hard basket in all standards the author has seen (even if mentioned at all). ISO 22476-1-2012 Annex E, page 35, mentions it in an “information only”, almost throwaway manner.

Transient temperature is truly the “elephant in the CPT room” – it’s known to be there but not talked about very often; at least not by polite people.

4 HOW GOOD IS A VANE SHEAR TEST ?

4.1 Quoted from Wikipedia

“The test was pioneered by L Carlson and AW Skempton in 1948. There has been some dispute over its accuracy since then”.

The author is surprised about this reported 1948 beginning of the Vane Shear Test; thinking most likely it is much older than that.

The author is not surprised at all though that even Wikipedia questions the test’s accuracy.

Some of the author’s concerns are discussed in the following, and are considered by this author to be a big deal.

4.2 Why Be Concerned About Vane Shear?

For some reason that escapes the author, a significant number of geo-professionals place tremendous and unerring faith in Vane Shear Test data. The author’s company does many direct-push Vane Shear Tests and

considers them to be so “potentially at risk” that they are the only test type that must be double-checked by senior management before they are released to a client.

The reason is simple – if a Vane Shear Test is incorrect for any reason, it will almost certainly “read high”; thus potentially leading to client or end-user over-optimism.

4.3 Why Most Clients Request Vane Shear

There is of course a connection between q_c or q_t from a CPT and shear strength in cohesive soils. The connector is the parameter N_{kt} , a quasi-constant that divides into corrected cone resistance to give S_u , undrained shear strength. In normal clay soils N_{kt} is normally thought to lie between 10 and 20, and unsurprisingly the value 15 is adopted over and again.

But some/many clients want a better handle on the important constant, and decide that they will use Vane Shear Test data to “calibrate” the CPT data to determine this important number for their site.

They may instruct their field supervisor to instruct the tester to undertake Vane Shear Tests at predetermined spacing or depths – eg “take a Vane Shear Test every 1.5m”.

4.4 Choosing Test Depths Properly

Figure 7 below shows an example where this approach was taken. A total of 22 Vane Shear Tests was made over 15m depth. These have been plotted against Shear Strength that was “determined” by establishing N_{kt} from the Vane Shear Test data and applying it to the CPT data. The solid black line is the adopted strength vs RL profile for that site. Only part of the plot is shown.

This is a classic plot demonstrating that the majority of these Vane Shear Tests were a basic waste of time for this process. They did not show a clean linear strength increase with depth, most likely because most of them

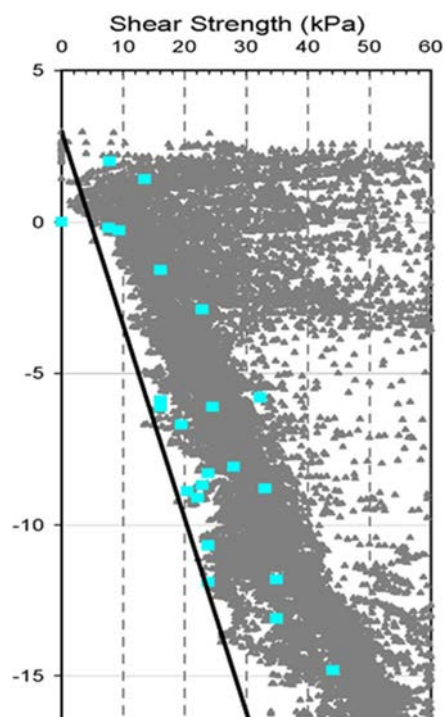


Figure 7

were wrong and “read high”; almost certainly because they were undertaken in layers that were not really suited to Vane Shear Testing. This is the main cause of error in such tests. In this case, the end-user, wisely, drew the strength profile below almost all of the data, as can be seen on the figure.

Vane Shear Testing is expensive. If a test is undertaken according to any one of the available standards, a typical test taken to determine residual strength or high-strain strength, takes around one hour. Looking at Figure 7, many hours of testing time were wasted on that occasion.

This author believes unequivocally that:

- Vane Shear Testing should only be undertaken after a CPT test has been made at the same location.
- The CPT plot should be scrutinised at “high resolution” to precisely determine depths that are suited for Vane Shear.

Any “bumps” in the CPT plot (see figure 8 below) indicate anomalies that will negatively impact on the Vane Shear result; always bumping the numbers upwards. Such anomalies must be avoided.

Doing less tests, but choosing the depths carefully, will (i) save lots and money and (ii) improve the usefulness of the Vane Shear Test data, so that it might meaningfully be used for its intended purpose.

4.5 Advocated Deviation From Standards

As far as this author knows, all standards say something like: rotate the vane very slowly to beyond peak strength; then rotate rapidly several times; then continue at a very slow speed until a “uniform” residual is reached. Figure 9 below shows a typical result of this process. Note that the “residual” achieved is by no means “uniform”. According to the standards this would be repeated until the Holy Grail uniform result occurred.

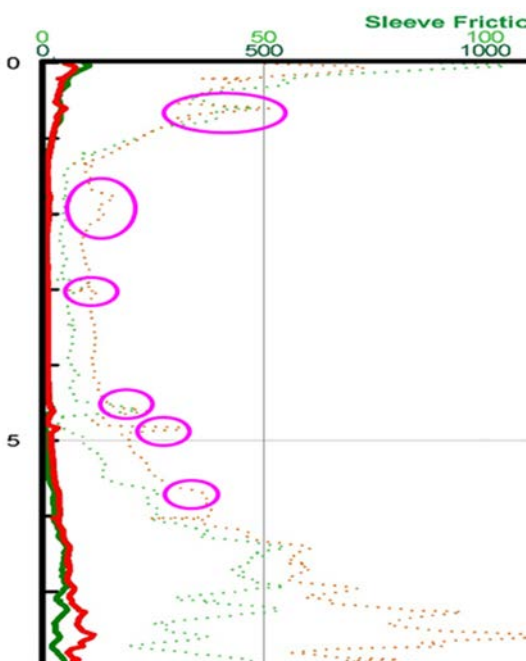


Figure 8

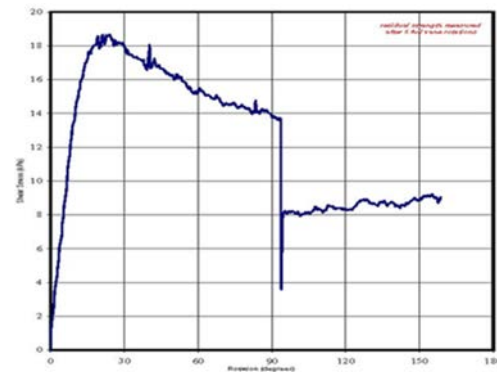


Figure 9

This author has seen hundreds, maybe thousands, of vane tests, and has observed very often that if the standards are followed as described above, weird residual strength behaviour evolves. Values typically rise after the fast rotations then bounce or jag up & down; seldom is a nice “uniform” residual achieved, no matter how many times the process is repeated. Others may differ, but this author thinks it’s the speed changes; also that the only reason for the rapid rotations is to try/perceive to save time and hence \$.

The author’s firm has made many non-standard tests by simply continuing the vane rotations at a single constant slow speed until a nice steady “uniform” residual is reached. See Figure 10 below.

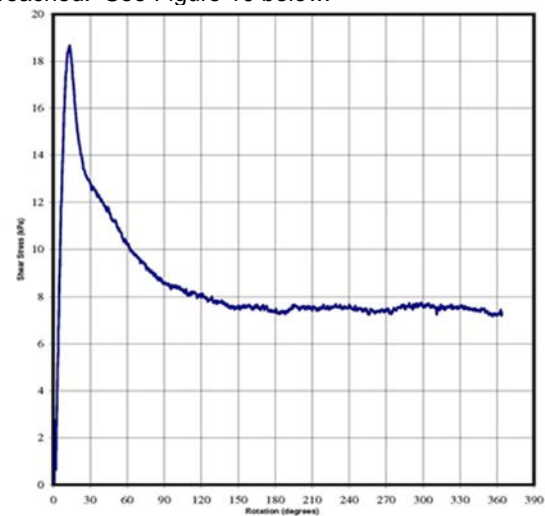


Figure 10

This seems to work very much better than following the standards. The data makes sense - a peak is passed - a residual is achieved. And frankly it really doesn’t take any more time overall. It normally takes about 360° of total rotation to achieve this or to asymptote to it.

As our client, the author says clearly that it’s your choice of course, every time, but experience indicates that the above is a better way to make a Vane Shear Test.

4.6 Vane Shear System Calibration

Referring back to Section 4.3, it is common for Vane Shear Testing to be chosen to “calibrate” CPT data; ie to determine N_{kt} .

The author thinks that overall this is a good idea and if both the CPTs and the Vane Shear Tests have been

done carefully then there is no reason not to adopt this rational-sounding process.

But “wait a minute”:

- Everyone talks and debates continuously about the precision and calibration of CPT equipment, and there are standards that specify calibration standards, etc.
- There appears to be no standard that comprehensively (if at all) specifies Vane Shear Test system calibration. And sensitivity is managed as a one-line throwaway.

This author thinks that it’s “interesting” (read weird, stupid, thoughtless, negligent) that many geotechnical professionals use results obtained from uncalibrated Vane Shear Test systems to so-called “calibrate” CPT data.

Vane Shear Test equipment can be calibrated and should be calibrated, at least with the same degree of solemnity as is CPT equipment. Figure 11 below shows the Vane Shear system calibration apparatus used by the author’s firm.



Figure 11

5 CLOSURE & SUMMARY

This paper has explained that one valid reason for using in situ testing in geo-engineering is to improve site investigation data and in doing so to reduce geotechnical uncertainty and risk. This is real and can certainly be achieved; making everybody happy. The impact on reducing uncertainty can be outstanding.

But the paper has also deliberately set out to demonstrate, using just two common test techniques, CPT and Vane Shear, that maybe “*in situ ain’t in situ*”. It’s not quite that simple – as in situ test data can be wrong. In fact there is potential for poorly implemented in situ testing to be more misleading and risky than other methods simply because people trust it to be correct and may rely on that trust inappropriately.

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