

# SOFT SOIL SITE CHARACTERISATION BY *IN SITU* TESTING

Allan McConnell

*McConnell GeoServices (MGS) & Insitu Geotech Services (IGS), Brisbane, Qld*

## ABSTRACT

The most commonly used *in situ* testing tool in site characterisation, the SPT, is more than 100 years old. While it's still a useful tool for many purposes there have been significant advances in technology over those 100 years, including advances in the tools that can be used for geotechnical site characterisation. Some very useful tools have evolved.

This paper discusses some up-to-date methods of site characterisation, focusing on those up-to-date tools that are now available in Australia and some that will be arriving soon. The paper also provides beginners-level guidance on "where to go" regarding interpretation of data that comes from these tools.

## 1 INTRODUCTION

Site characterisation is the most important step towards the design or construction of any geotechnical project. In the author's opinion it is also the step that has highest potential to be poorly done and, if poorly done, it makes the whole of the rest of the processes of analysis, design, documentation and tendering dubious.

Sophisticated analytical tools exist and are used by geotechnical engineers on a day-to-day basis, but these tools are only as good as the data that is input to them. This paper is about:

- Improving the data we input into soft soil geotechnical models.
- Reducing our reliance on field interpretations that are open to error, such as borehole logging from drill wash, cuttings and spaced-out samples.
- Markedly speeding-up the process of site characterisation and getting better site coverage.
- Improving the quality of life of the young geotechnical professionals who usually get the job of supervision of field testing work.

All of which are related to *in situ* testing in one way or another.

## 2 *IN SITU* TESTING – A BRIEF HISTORY AND OVERVIEW

### 2.1 THE STANDARD PENETRATION TEST (SPT)

The most commonly used *in situ* testing tool in site characterisation, the Standard Penetration Test (SPT), is more than 100 years old. It was invented by the Raymond Piling Company around 1903 to provide a tool that could be used to help predict the depth of their piles. It is a very simple test that we all know well; a thick-walled sampler of set proportions is driven into the soil from the bottom of a borehole using a hammer of set proportions. It is not intended to discuss this tool to any extent within this paper other than to say here that the author believes:

- It will be around for a long time yet and that it has legitimate application, particularly in probing very dense granular soils.
- It is used to interpret many soil parameters by correlation, some of which correlations are incongruous when one considers the actual process of the test (banging a sampler into the ground): strength, modulus, OCR, etc. In soft soils this is particularly incongruous, given that often the N-value from the test may be 0, 1 or 2.
- It is a remarkably un-repeatable and imprecise test when one compares tests by differing operators using differing rigs, rods and hammers (all "standard" and all meant to give the same result). Some comparative tests reported by Dr Paul W Mayne (Mayne 2004) are shown in Figure 1.
- It requires a drilling rig and must be supervised in the heat or cold or rain; it is expensive, noisy and uncomfortable to implement. Minor flaws in the drilling process can lead to major undetectable flaws in measured SPT N-Value.

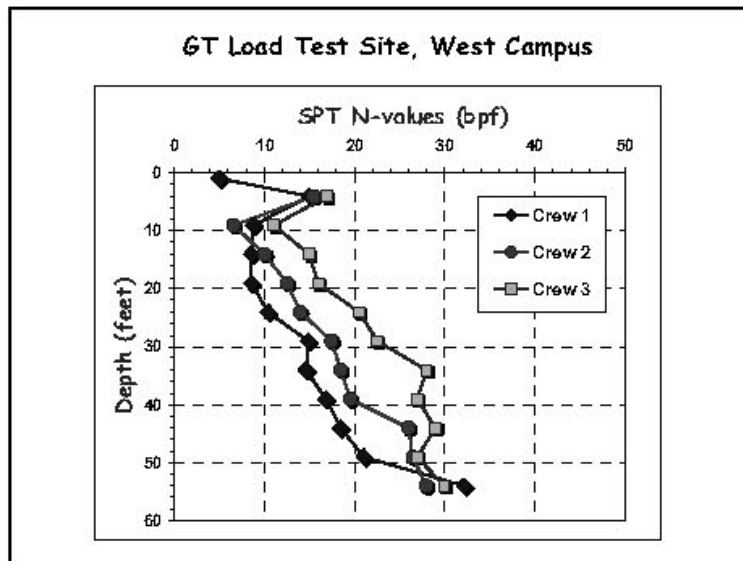


Figure 1: Comparison of SPT N-Values at a Test Site (Mayne 2004)

2.2 THE VANE SHEAR TEST

The vane shear test appears to have been invented in 1919 by John Olsson in Stockholm (Brand and Brenner, 1981). So it is almost as old as the SPT. However, while not new, vane shear testing will be promoted within this paper as this test varies from the SPT in that it does not try to be all things for all purposes, and because it is still a valid test for measuring clay shear strength, particularly the strength of soft clays, and because it has “evolved”. It is a simple tool that is commonly cited by geotechnical engineers as being more-or-less “pure” in its measurement of shear strength of clay; it is often cited as the benchmark when comparing other methods to their correlations. However it is typically a clumsy and slow tool to use.

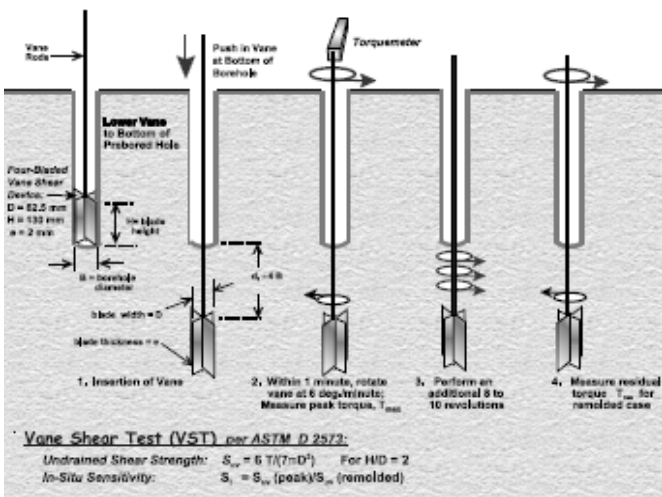


Figure 2a. Vane Shear Test Principles



Figure 2b. Geomil's Electrical Vane

The CPT manufacturing company Geomil (Netherlands based) has recently made a significant advance in the evolution of the vane shear tool, developing a system intended to be pushed using a CPT rig, with inner torque rods protected against friction by the CPT rods as a casing. The system is fully automated and data logged and compensates for rod friction. Other similar systems exist and at least one specialist contractor in Australia offers vane shear at this time.

2.3 THE CONE PENETROMETER TEST (CPT)

Various forms of penetration tests have been around for a long time, one of the earliest being a reported 12 m steel rod pushed into the ground in Norway in 1736. The first description of a Dutch Cone Penetrometer (forerunner of the modern CPT) appears to have been in 1936, and the general proportions of the current CPT applied at that time (Brand and Brenner, 1981).

This first simple Dutch Cone Penetrometer has gradually evolved into the current CPT which is usually fitted these days with sensitive electronic load cells and often with a piezometer to measure pore pressure at the cone tip. As far as the author can ascertain the first electric cone penetrometer was introduced in 1948 but this technology did not come into use until the late 1960s (Meigh, 1987). The piezo-cone (CPTu) started to evolve in the early 1970s but, in the author's experience, has only really become a commercially useful and readily available tool in Australia during the last 10 years or so.

It is the author's view that the piezo-cone (CPTu) is one of the most valuable advances in characterisation of soft soil sites. It certainly replaces the SPT in terms of quality and repeatability of data, and it is now commercially available on a day-to-day basis. It is currently clearly the best tool available for developing a profile of site conditions but, because of its availability, it is at risk of also replacing the SPT as the "all things for all parameters" tool. The author believes that the geotechnical community should take care that this wonderful tool, with its many correlations against many parameters, does not become degraded by over-reliance. There are some tools that can perform some tasks better, or in concert with the CPTu.



Figure 3a. IGS 20t All-Terrain Test Rig

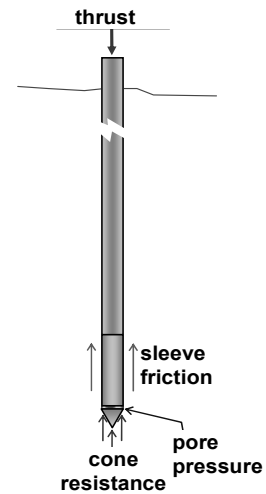


Figure 3b. CPTu – General Principles

The CPT "format" has become the vehicle for a number of other useful tools that can sometimes be used in conjunction with the CPT or sometimes are simply pushed into the ground using the CPT's rods and pushing system. These include: seismic cone (fitted with a geophone behind the usual CPT device); video cone (you can look at the soil, see some grain sizes and observe colour changes and other things); moisture content cone (self-explanatory); a range of "enviro cones" such as: pH and Redox Potential; Hydrocarbon Fluorescence; Electrical Conductivity, Magnetometer (useful for unexploded ordinance); Hydraulic Conductivity; etc.

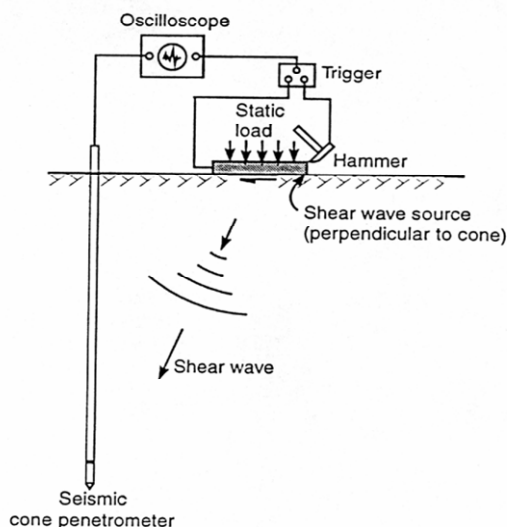


Figure 4a. Seismic CPT

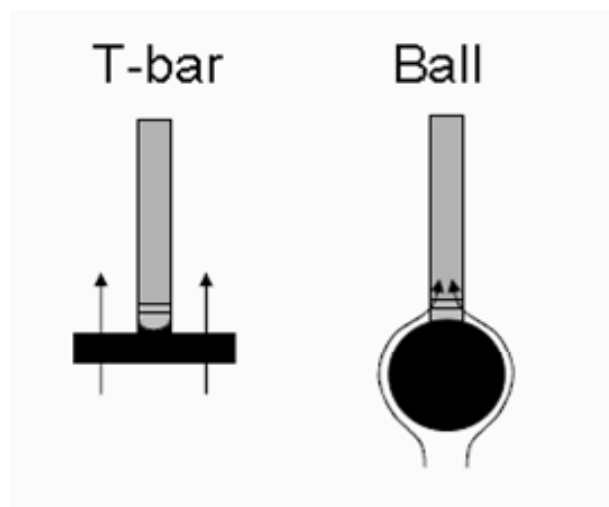


Figure 4b. T-bar and Ball Penetrometers

So, the CPT has been around for 60 years or so – hardly new in concept – but has recently evolved into a very powerful site characterisation tool in the form of the CPTu and has in the last few years become readily available to geotechnical engineers for day-to-day use in Australia. Figure 3a shows IGS’s 20 t capacity test rig. The author is a director of IGS.

A soft criticism of the CPT or CPTu is that it relies on factors or correlations for determination of soil properties and that some of these cannot be verified analytically. One recent evolution to overcome this criticism as it applies to measuring strength of very soft soils is the “flow penetrometer” that has two main types – a Ball Penetrometer (a ball of relatively large diameter replaces the usual conical tip) and a T-Bar Penetrometer (where a horizontal steel bar about 150 mm or 250 mm long x 40 mm diameter replaces the tip). The author anticipates that these two innovations, both being researched in Australia and internationally, will soon be available from at least some specialist contractors.



**Figure 5a. NewSyd CPT Truck**



**Figure 5b. Lankelma (UK) Subsea Crawler (working in surf zone)**



**Figure 6a. CPTS Truck Rig**



**Figure 6b. CPTS Tracked Rig**

**2.4 THE FLAT DILATOMETER TEST (DMT)**

The DMT is a type of simplified, low-cost, highly efficient, very robust, push-in pressuremeter, that is well-suited to use in characterisation of soft soil sites (and other sites). It can be pushed into the ground by a CPT rig or alternatively by a drilling rig, by pushing below the base of a borehole. The test principles are shown in Figures 7a & 7b.

The DMT was introduced to geotechnical engineering via a paper by its creator Professor Silvano Marchetti in 1980 (Marchetti, 1980). In 1986, under Dr John Schmertmann’s chairmanship, an ASTM subcommittee developed a “Suggested Methodology” and in 1997 and 2001 Eurocode 7 and ASTM published standards for the test procedure.

The DMT is thus a more recent development than any of the preceding discussed *in situ* test methods, but it is still more than 20 years old and has certainly been in use commercially for 20 years.

There have been two international conferences that focused specifically on the DMT. The most recent of these was in Washington DC, earlier this year (April 2006) and was attended by the author who has a great interest in this tool and its evolution. At this conference Professor Marchetti released the first commercial Seismic DMT (SDMT, See Figure 8). This new tool is fitted with two geophones above the DMT testing blade and the author can announce here that this new site characterisation tool will become commercially available for day-to-day use in Australia in the very near future (possibly before the date of this symposium).

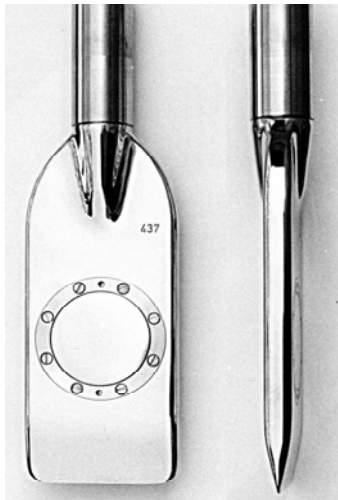


Figure 7a. DMT Blade Showing Diaphragm

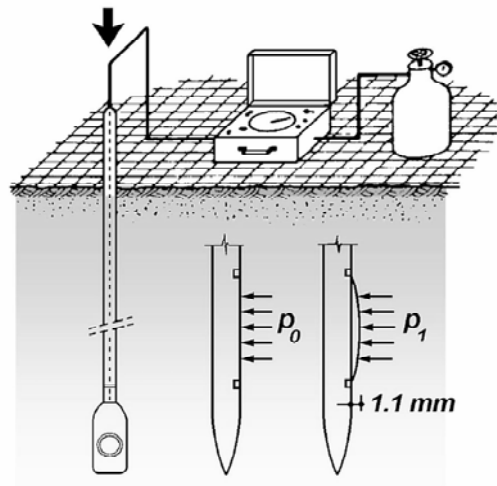


Figure 7b. DMT Operating Principle

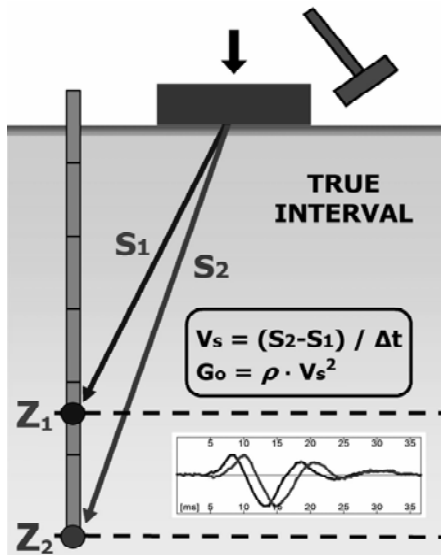


Figure 8a. SDMT Principles



Figure 8b. The Author With Dr Paul Mayne Inspecting SDMT No 1 (Washington 2006)

### 3 WHY USE *IN SITU* TESTS? - WHAT'S IN IT FOR YOU?

#### 3.1 TIME & COST SAVINGS AND/OR BETTER SITE COVERAGE

Compared to the alternative approach to site investigation, boreholes, sampling and laboratory testing, the *in situ* tests that are discussed in this paper offer any or all of the following:

- The process overall is significantly quicker. Usually *in situ* tests provide a test data sheet or report more-or-less immediately they are completed, whereas a borehole takes much time and samples taken are typically sorted then chosen for laboratory testing that can take days and sometimes weeks.
- The daily cost of a field team undertaking *in situ* tests is about the same as the cost of a drilling rig and crew. However test productivity is usually much higher. Typically a well-organised CPTu testing rig and team can accomplish around 100-150 m of site testing per day (e.g. 6 x 20 m tests), which is about 4-5 times faster than a usual careful geotechnical drilling operation. Thus the cost per test is much lower.
- The corollary to (b) is that it has become possible to plan for much better site coverage using *in situ* testing than would normally be accomplished by drilling and sampling. In about the same time, for about the same budget, 4-5 times more tests can be done. A common approach is to “grid” a site with CPTu tests, then to choose just one or

two locations to drill boreholes, whereas past practice would have been a few more boreholes, but nowhere near as many as will now be tested by CPTu.

### 3.2 MORE PRECISE PROFILING

Using CPTu, site profiling is now very precise. The CPTu test equipment typically “samples” ground conditions each 20 mm vertically, allowing delineation of thin strata and precise determination of depths at which strata change.

With boreholes, samples can be taken as frequently as decided; however usual practise is to take SPTs or sometimes undisturbed samples at 1.5 m intervals and rely on the supervisor's impressions and interpretations of stratum changes that might occur between these test intervals.

It is common to find, where CPTu and boreholes are made adjacent to each other, that the borehole might have completely missed some thinly bedded strata and also that stratum change levels have been misinterpreted.

Following on from the strategy mentioned in Section 3.1(c), boreholes can be very strategically used if drilled after CPTu tests. Sample and test types and depths can be pre-decided based on the CPTu data and thus less sampling is needed and sample usefulness can be maximised.

### 3.3 BETTER DATA?

The author does not represent that in all cases and for all purposes *in situ* testing will be technically better than some other form of site investigation. The author acknowledges that it is “horses for courses”:

- There are some situations where samples must be taken and laboratory tests must be made to achieve certain results. One case is secondary consolidation characteristics of soft clays; no *in situ* test that the author knows can measure  $C_{\alpha}$ . Neither can any normal *in situ* test penetrate into bedrock and sample it for its engineering properties. Nor can normal *in situ* tests quantify soil plasticity or shrink-swell potential.
- However for a high percentage of sites and ground conditions there is a valid argument that *in situ* tests will probably provide better data than drilling and sampling can and, as described above, if drilling and sampling is needed for some reason (even just for confirmation), then at least the locations and numbers of boreholes and samples can be reduced.
- There will always be debate about the correlation factors to apply to *in situ* test values to convert these values to geotechnical design parameters. But frankly the same debate occurs in regard to laboratory measured soil properties. A mature view is that almost all geotechnical tests yield “index” parameters that must be used with intelligence and with the wisdom of experience. It is the same with *in situ* tests as it is with other methods; the difference is that with *in situ* tests you usually have more precise data and very much more of it to consider.

Certainly one can be confident of the following from *in situ* testing (focusing on soft soil sites):

- Site profiling will be very much better due to almost continuous “sampling” from CPTu testing (see example plot in Figure 9). Also due to the likelihood of better site coverage associated with lower cost.
- Knowledge of the *in situ* strength of soft soils will be much better, particularly when comparing *in situ* test methods with SPTs. An SPT N-Value of zero could mean a shear strength anywhere between 1 kPa and (say) 15 kPa; a CPTu will define this much better even using correlations, and an *in situ* vane shear will quantify it very precisely.
- CPTu equipment can be used to measure *in situ* permeability of low permeability soils by Pore Pressure Dissipation testing (the CPTu advance is halted and the rate of pore pressure decay is monitored). While debate could easily apply to the precision of such tests they must be more meaningful than laboratory tests on tiny samples, as they take into some account the influence of structure in the soil such as thin sandy lenses.

To conclude this section the author advises that his experience-based opinion is that, while nothing is perfect, *in situ* testing is in many ways more perfect than other methods at measuring the properties of soft soils.



**5 CHARACTERISING A SOFT SOIL SITE**

It is this author’s view that the most rational and solution-focused approach to characterising a soft soil site is as follows:

<b>Step 1:</b>	Undertake a grid or pattern of CPTu testing to profile the site and determine any patterns to soil variability. Often this may be enough; data from CPTu testing is commonly used by correlation to determine relevant soil properties; strength ( $C_u$ or $\phi$ ), compressibility ( $M$ , $M_v$ , or $E$ ), permeability ( $k$ or $C_v$ ).
<b>Step 2:</b>	If compressibility is critical, particularly in soft-firm clays or in sands, undertake DMT profiles at selected locations, based on the CPTu data. Seismic CPT and Seismic DMT can be introduced to enhance compressibility data, or (particularly) if liquefaction is deemed a potential issue, or if cyclic loads will apply.  If consolidation time is important, undertake some pore pressure dissipation tests using the CPTu, at selected locations. If possible make these tests long enough to measure $t_{50}$ at least. Overnight testing is possible.  In very soft to firm clays, if shear strength is critical, undertake vane shear profiles at selected locations. Note that vane shear testing can be misleading in fibrous soils (eg peaty stuff) or soils with shells or significant granular content.
<b>Step 3:</b>	Consider the data. If sampling and laboratory testing is still necessary (which may sometimes be the case), then select one or two locations based on the CPTu data, and undertake sampled boreholes. Use the CPTu data to pre-determine stratum boundaries and sampling depths and types. Note that some of the <i>in situ</i> testing contractors also have push samplers that can take useful samples in some conditions.

The above site characterisation process is not only possible, it is rational, best-for-project and very cost-efficient. Any one of the specialist contractors listed above can provide a range of the test methods needed.

**6 INTERPRETING THE *IN SITU* TEST DATA**

Most up-to-date geotechnical texts have valuable information on interpretation of *in situ* test data. For a sound starting point, the author recommends the following sources:

<b>Cone Penetration Testing</b>	Lunne Robertson & Powell (1997)
<b>Geotechnical and Geophysical Site Characterisation</b>	Proceedings ISC’2 (2004)
<b>Flat Dilatometer Testing</b>	Proceedings of 2 <sup>nd</sup> International Conference on the Flat Dilatometer (2006)
<b>Professor Marchetti’s Web Site (DMT Papers)</b>	<a href="http://www.marchetti-dmt.it/">www.marchetti-dmt.it/</a>

**7 REFERENCES**

Brand, W. and Brenner, P (1981). Soft Clay Engineering. Developments in Geotechnical Engineering 20. Elsevier Scientific Publishing Company.

Failmezger, R.A. and Anderson, J.B. (2006). Flat Dilatometer Testing. Proceedings from the Second International Conference on the Flat Dilatometer, Washington DC.

Lunne, T., Robertson, P.K. and Powell, J.J.M. (1997). Cone Penetration Testing In Geotechnical Practice. E & F N Spon.

Marchetti, S. (1980). In Situ Tests by Flat Plate Dilatometer. ASCE Journal GED, Volume 106, No. GT3, March, 299-321.

Marchetti, S. and Monaco, P. (2001). Short Course on Flat Dilatometer. International Conference on In Situ Measurement of Soil Properties and Case Histories. Bali.

Marchetti, S. (2006) Web Site Containing Many Papers on DMT. [www.marchetti-dmt.it](http://www.marchetti-dmt.it)

Mayne, P.W. (2004). Geotechnical Site Characterisation By Enhanced In Situ Testing. Short Course. The University of Sydney Centre For Geotechnical Research.

Meigh, A.C. (1987). The Cone penetration Test – Methods and Interpretation. CIRIA Ground engineering Report: In-situ Testing. Butterworths.

Trevor, F.A. and Mayne, P.W. (2004). Undrained Shear Strength and OCR of Marine Clays From Piezocone Test Results. Proc. ISC’2 Oporto. Geotechnical and Geophysical Site Characterisation. Millpress.