# Evaluation of soil testing strategies

## Introduction

Soil testing is an important comment of civil engineering and must be completed to gain an understanding of the soil stratigraphy and its relevant properties. Soil testing is also used in ground improvement verification by testing before and after ground improvement techniques have been implemented. Soil testing can be conducted within a lab or in-situ, which each having their own benefits. When conducting lab tests, there is total control of the stresses the soil is experiencing, but tests are conducted on disturbed samples not matter how carefully they are extracted. Lab test are also expensive and time consuming. In-situ test are completed much faster and measures the soil properties in their natural state. The downside is that often soil samples are not gathered and as result, geotechnical engineers are required to rely on empirical correlations, to classify the soil and its properties. This literature review will detail some of the in-stu ground investigation techniques utilised for classifying the stratigraphy.

Cone Penetration Test (CPT)

The cone penetration test (CPT) is widely used throughout the world to identify strata and gain an understanding of the relevant geological properties (Rogers, 2006). It is a favourable test to complete due to its high speed, repeatability and low-cost nature (Peter K Robertson, 2010). To conduct a CPT, a probe with a cone tip is pushed into the ground using a hydraulic ram, with sensors providing continuous record of the soil properties. The soil properties the CPT measures are cone resistance, sleeve resistance and pore water pressure. Cone resistance is indicative of the bearing resistance the probe experiences and is measured by a load cell behind the tapered cone (Rogers, 2006) while the sleeve resistance measures the friction along on the side of the probe and is measured with a tension load cell in the sleeve (Rogers, 2006). Friction ratio is calculated as sleeve resistance divided by cone resistance and is used to classify the soil based on its reaction to the probe being pushed through it. Higher friction ratios indicate clayey materials while lower friction angles indicate sandy materials (Rogers, 2006). CPT cannot be used to confidently identify the soil classification because soil classification is based on grain-size and soil plasticity, which require a sample to be collected. Instead CPT measures the in-situ mechanical behaviours of the soil which is used to define the behaviour type (Peter K Robertson, 2010). By using these measured properties, correlations can be used to identify the soil behaviour type. Charts providing these correlations were originally proposed by Douglas and Olson, but in subsequent years the chart proposed by Robertson has gained popularity among geotechnical engineers. Robertson’s chart uses Friction ratio and Cone resistance to define Soil behaviour types from “ Sensitive fine grained” to “ sand to clayey sand” (1986).  In 2010 Robertson released an update to the chart which contains less soil classes than the chart proposed in 1986, but is now more accurate (Peter K Robertson, 2010). The parameters measured from CPT can be further used to empirically estimate parameters. The standard cone penetration test can be altered to complete a Seismic Cone penetration test (sCPT). sCPT is used to measure the shear wave velocity, which is commonly used to calculate the small strain shear modulus but can also be used to calculate other parameters. Due to its association with small strains, the small strain shear modules is particularly sensitive to disturbance, as such to get an accurate representation, it must be non-invasively measured(McGann, Bradley, Taylor, Wotherspoon, &

Cubrinovski, 2015). To conduct a sCPT one or more geophones are attached to the probe and inserted into the ground. When the probe is at a required depth a seismic shear wave is induced on the ground surface of which vibration is recorded in the geophones. These shear waves travel through the soil skeleton and are thus related to soil shear modulus (ROBERTON SCPT 1986). By completing this test at subsequent depth one can use the change in height between each test and the time from wave initiation to geophone recording the wave, to calculate the shear wave velocity. This method of measuring shear wave velocity requires specialized equipment and training which is commonly not used in projects of lesser significance (McGann et al., 2015). If a seismic CPT can not be conducted due to this limitation, shear wave velocity can be estimated using empirical correlations between CPT data and shear wave velocity. Seismic CPT can also be used to identify liquefaction potential as many of the properties that impact shear wave velocity, impact the liquidation potential of the soil (P. K. Robertson, Woeller, & Finn, 1992). These properties include soil density, confinement, stress history and geologic age (P. K. Robertson et al., 1992). Liquefaction occurs when granular materials densify due to cyclic loading and the water in the voids are unable to drain resulting in an increase in pore water pressure. It has been found that soils which have a normalised shear wave velocity less that ~120 m/s are prone to liquefaction as they develop an excess pore pressure.

Dilatometer Test (DMT)

A flat dilatometer test is conducted much like a CPT, with a hydraulic ram pushing a probe into the ground. Unlike a CPT test the probe is a flat blade rather than a cone and has steel membrane on one side (Marchetti, 1979).

When at rest, the steel membrane is flush with the surrounding surface of the blade. At 20mm intervals the membrane is inflated by pressurised gas and a reading is taken of the pressure required to just move the membrane and then again, the pressure required to expand the centre of the membrane 1mm from its resting position. When the membrane is at rest it is contact with sensing disk emitting a signal that it is in contact. It is known when the membrane just moves as this signal is no longer emitted. The signal is then emitted again once the membrane has expanded 1. 1mm (S., P, G., & M., 2006). In the process of DMT probe penetrating the soil, the soil becomes prestrained. Shear strains caused by the probe at this volume are low compared to other penetrating devices, but the soil stiffness is sensitive to prestrains. To account for this, correction factors are required to evaluate the original stiffness of the soil. In extremely sensitive soils, this disturbance due to penetration is quite large, and undefinable so original properties cannot be calculated (Marchetti, 1979). Unlike the CPT, DMT only provides data at specified intervals, and because the push must be stopped for the expansion to take place, DMT takes s longer than other insitu test such as CPT. The properties directly measured with DMT are dilatometer modulus, material index and horizontal stress index. The dilatometer modulus is related to the soil stiffness, material index is related to the grain size and horizontal stress index is related to $K_0$ (Marchetti, 1979). Again, with these parameters further parameters can be estimated through correlations. Similar to CPT, the DMT can be adapted to measuring the shear wave velocity attaching two geophones to the shaft of the dilatometer and producing a seismic shear wave at the surface. The shear wave velocity is calculated using a similar method describes in sCPT. Because two geophones are attached, this test is not required to be completed at multiple depths in order for the shear wave velocity to be calculated.

Standard Penetration Test (SPT)

In order to conduct a SPT test a borehole must first be drilled to the required depth. Creating a borehole occurs in three steps, breaking of soil, removing soil and supporting the sides of the borehole to prevent collapse. Drilling is an intrusive process and will disturb the soil. The drilling technique used should be considered when determining what soil parameters we wish to find out, so we can use the technique that will minimise disturbance on the required parameters. If a sample is required, a rotary coring drilling bit can be used. This drill bit consists of hollow tube with an edge which cuts an annulus (BINNS, 2007). This drilling motion combined with pushing allows the soil to enter the hollow tube, which when removed, provides a sample. The edge is commonly made from either tungsten carbide or impregnated diamond. Tungsten carbide is used when drilling in to soil with small particles such as clay, while impregnated diamond is used for drilling into materials such as gravel. Both of these techniques will cut away materials using abrasive the abrasive edge of the hollow tube. In recent years swivel-type doubletube core barrels are used which allow the outer barrel to rotate doing the drilling while the inner barrel remains stationary reducing disturbance to the sample(BINNS, 2007). Another drilling technique which can be used if a sample is required is Hallow Stem augers. Hallow stem augers are an improvement on power-driven augers, as although the power driven-auger does provide a sample it cannot be determined at what depth this sample originates from(Thomas & Barker, 1974). Hallow stem augers are a continuous flight auger surrounding a central tube. The auger is placed on the ground and when rotated the angle of the flights drives the section into the ground, with soil entering the hollow tube providing a sample. Multiple sections can be screwed on, allowing drilling and sampling at great depths. To allow drilling and sampling to occur simultaneously the hollow sampler is extended beyond the mouth of the auger, ensuring the sampler is being pushed into undisturbed soil. If a soil sample is not required and only a borehole is required, drill bits such as the tricone can be utilised. A tricone is a drill bit that consists of three rotating cones, each with rows of teeth. As the tricone is rotated these, teeth will crush the rock as they roll over the rock face. Once the borehole has been drilled the cutting must be extracted from the borehole before any testing takes place. To extract these cuttings, fluids such as air, water or additives can be utilised. These fluids are pumped through the drill pipe and drill bit and into the bottom of the borehole. The fluid is continuously pumped until it arrives to the surface of the bore hole with the broken fragments of soil. If required, these fragments can be extracted from the fluid on shake table. It cannot be determined at what depth these samples haves come from so the stratigraphy cannot be identified, but this is still beneficial in determining if the drilling has reached bed rock. It is important that when fluid is pumped into the boreholes it is not done at high velocities such that it will disturb the soil at the bottom of the borehole as this could impact results obtained with the SPT test. With the borehole drilled and cuttings removed, in cohesionless soil, support must be provided to prevent collapse of the bore hole. Two common techniques for this include using the hydraulic pressure from drilling mud and inserting a steel casing. It has been found that the stabilisation technique does not have an impact on the SPT results in fine-grained soil. However in granular soils

SPT values obtained in boreholes that were stabilised with drilling mud differed from SPT values obtained in boreholes that were stabilised with steel casings (Whited & Edil, 1986). With the borehole drilled and support provided, the standard penetration test (SPT) can be completed. To complete a SPT a 63. 5-kg hammer is repeatedly dropped 0. 76m (Thusyanthan & Nawaz, 2017), to achieve 6 increments of 75mm, with the number of blow counts required to penetrate 75mm recorded each time. The first two increments (150mm) do not contribute to the N value, due to the disturbed nature of this soil and its effect on the results.  It is recommended to measure at 75mm increments to gain a higher “ resolution” of the results. The hammer is dropped on a split spoon sampler, which when extracted can be opened to produce a sample aiding in the identification of the soil type. There are many factors which can have an impact on the results obtained by the SPT. Some of these variable are due to human error while some are due to the equipment, but both impact the repeatability of the test due to the variability they cause in the results. These variations stem from 1) fall height of hammer 2) resistance of wire hammer falls down 3) inadequate cleaning of boreholes and 4) equipment maintenance. To minimise the effect of these variations it is recommended for SPT rig efficiency to be measured and for this efficiency to be supplied with the SPT results. Although a Standard penetration test can provide samples, many of the soil properties that are estimated using N values, are done so using correlations. Many of these correlations are based on tests completed on older SPT rigs that had efficiency of ~60% (Thusyanthan & Nawaz, 2017). Newer and modern SPT rigs are often automatic and much higher efficiencies and as such, in order to use these predefined correlations, the N value must be normalised to represent hammers of 60% inefficiencies (N60), to ensure the efficiency does not affect interpolated soil properties. N60 is calculated based on correction factors for 1) hammer efficiency 2) Borehole diameter 3)Sampler and 4) rod length (Rogers, 2006; Thusyanthan & Nawaz, 2017). Standard penetration tests are a useful tool in any geotechnical investigation, but like many other tools, it is vital that they are used correctly to avoid incorrectly identifying and parametrising the soil stratigraphy.

## References


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