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GEOTECHNICAL SITE CHARACTERISATION USING SCREW DRIVING SOUNDING METHOD

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ABSTRACT

The Screw driving sounding (SDS) method developed in Japan is a relatively new in-situ testing technique to characterize soft shallow sites, typically those required for residential house construction. The method consists of driving a rod, equipped with a screw point at the tip, into the ground at different steps of loading while being rotated. The machine used to penetrate the rod can measure continuously the required torque, load, speed of penetration and rod friction; thus, compared to the more popular standard penetration testing (SPT) and Swedish weight sounding (SWS) techniques, the method can provide a better insight of the soil profile. In this paper, the SDS method is introduced and the results of its application to characterize Christchurch sites are discussed. Since most of the tests were conducted at sites where cone penetration tests (CPT) and borehole logs are available, the comparison of SDS results with this information shows that the SDS method has great potential as an in-situ testing method for geotechnical site characterization.

Keywords: site characterization, soil profile, penetration resistance, SDS method, CPT

INTRODUCTION

The conventional method to determine the soil stratigraphy in-situ is by laboratory classification of samples retrieved from boreholes. If a continuous, or nearly continuous, subsurface profile is desired, various field investigation techniques are commonly employed to provide economical alternatives over the traditional methods of sampling and testing. A number of field testing techniques are available to characterize sites, and these include standard penetration tests (SPT), cone penetration tests (CPT) and Swedish weight sounding (SWS) method, among others. Although SPT is still popular worldwide, it suffers from many disadvantages such as poor repeatability, no continuous soil profile and the SPT blowcount is dependent on soil type, particle size, and the age and stress history of the deposit, among others. CPT has been the preferred choice recently because it gives a continuous profile and is generally not operator-dependent; although sampling is not possible, soil type (or soil behavior type) can be inferred from the information collected during the test. On the other hand, SWS method is a highly portable and economical technique which provides a continuous profile of the soil. It is used very often in Japan to evaluate the allowable shear strength of soils for residential house construction, and it is officially recommended as an investigation tool by the Ministry of Land, Infrastructure and Transport (Japan).

The Screw driving sounding (SDS) method, which has been recently developed in Japan, is an improved version of the SWS technique. While the latter only measures two parameters during the test (weight during static penetration, W_{sw} and number of rotations during rotational penetration, N_{sw}), SDS measures four parameters: required torque, load, speed of penetration and rod friction; these provide

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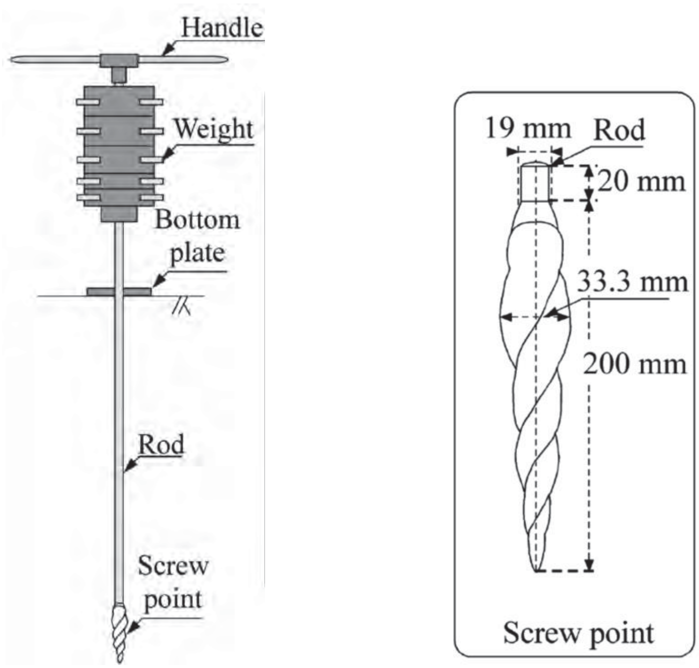
more robust way of characterizing soil stratigraphy. The principle behind the SDS method and the test procedure are discussed in this paper, together with its comparison to the SWS method.

Moreover, the authors conducted several SDS tests in Christchurch, which was affected by the 2010-2011 Canterbury earthquake sequence, with the aim of characterizing various sites in the area for the on-going rebuild programme and estimating liquefaction potential considering future earthquakes. Overall, SDS was performed at 68 sites in Christchurch – both in liquefied zones and no-liquefaction zones. At the tested sites, either CPT data or borehole logs were available and these were compared to the SDS results.

PRINCIPLE AND TEST PROCEDURE

Swedish Weight Sounding (SWS) Method

Before discussing the principle behind the SDS method, it is worthwhile to provide a background of the SWS technique. The testing procedure and the interpretation of test results are described by Tsukamoto et al. (2004). The SWS apparatus consists of a screw point, sounding rods, a rotating handle and six pieces of weights making a total of 100 kgf (980 N), as shown in Figure 1. The field test, which can be done either automatically (using a machine) or manually, is comprised of two phases: (1) static penetration; and (2) rotational penetration. In the static penetration phase, the screw-shaped point attached to the tip of the rod (weighing 49 N or 5 kgf) is statically penetrated by loading several weights (10, 10, 25, 25, 25 kgf) on top of the rod in stepwise increments until the total load is equal to 980 N (100 kgf). At each load increment, the depth of static penetration is measured and the total weight is denoted as W_{sw} (kN). If the screw point cannot penetrate under the maximum load, static penetration is ceased and rotational penetration is conducted. The horizontal handle attached to the top of the rod is rotated, and the number of half turns necessary to penetrate the rod through 25 cm is denoted as N_a. The values of N_a are then multiplied by 4 and are converted to the number of half turns per metre, N_{sw}.



(a) (b)

Figure 1. Swedish weight sounding (SWS) equipment; and (b) screw point (after Tsukamoto 2013).

According to Tsukamoto (2013), Swedish weight sounding tests are relatively good at detecting thin weak soil layers. Although it is sometimes argued that it is not directly feasible to determine depths of groundwater levels and types of soils and soil strata encountered during penetration, it is possible to tell whether the rod surface is dry or wet and also to classify soil particles which adhered to the surface of the penetrated rod during its extraction. In addition, whenever it is possible to acquire any borehole data from standard penetration tests nearby, it is possible to extrapolate the type of soils and soil strata encountered during SWS testing from this data.

Although the SWS test is highly portable and simpler than other sounding tests, this test has some disadvantages, such as the results being fairly influenced by rod friction. In cases where the soil contains gravel, the required load to penetrate, the number of half-turns and, consequently, the soil resistance from the SWS tends to be over-estimated as the rod friction becomes large.

Suemasa et al. (2005) investigated the interaction between the torque and the vertical load during SWS implementation and proposed an analogy model based on plasticity theory and the results of SWS miniature test results. Based on these, they noted that the coefficient of yield locus, c_y (which relates the normalized torque and normalized weight applied) and the coefficient of the plastic potential, c_p (which relates the normalized half-turns and the torque on the rod), vary depending on the soil type; i.e. clay, loam, medium sand or dense sand; hence, they proposed that soil can be classified based on the data obtained from SWS tests if the torque can be measured. This resulted in further refinement of the SWS method in terms of operating system, which led to the development of the SDS method.

Screw Driving Sounding (SDS) Method

A new system for conducting the SWS method has been recently developed in Japan to minimize the disadvantages of the SWS method and to incorporate a procedure to measure the rod friction. Such method has been referred to as the Screw driving sounding (SDS) test. For this purpose, a small portable machine is used to apply the load monotonically in 7 steps (250 N, 375 N, 500 N, 625 N, 750 N, 875 N, and 1000 N), i.e. the load is increased at every complete rotation of the rod until a 25 cm penetration is reached. During this time, the rod is always rotated at a constant rate (25 rpm). The process is repeated at every 25 cm of penetration. The parameters measured during the test are: the maximum torque (T_{max}), the average torque (T_{avg}), and the minimum torque (T_{min}) on the rod for each applied load; the penetration length (L), the penetration velocity (V) and the number of rotations (N) of the rod. These parameters are measured at every complete rotation of the rod. Note that after each 25 cm of penetration in the SDS method, the rod is lifted up by 1 cm and then rotated to measure the rod friction. Then it is moved down 1 cm back to its original position and the process is repeated. The procedure in performing the SDS test is outlined in Figure 2.

While the SWS method is usually performed manually (i.e. application of weights and rotation of rods are done with human effort), the need for measurement of torque and velocity requires the use of a machine. A machine originally used for the SWS test has been improved to be suitable for the SDS application. Figure 3 illustrates the small-scale machine used in the SDS test, which can be disassembled for ease in transport and handling. With the test capable of measuring more parameters, a better insight of the soil profile and penetration resistance of the layers can be obtained. Furthermore, as mentioned above, classification of the soil type can be performed with the measured torque using the plasticity-based analogy model. Tanaka et al. (2012) made use of this concept to classify soils based on SDS test results.

A comparison between the SDS method and conventional in-situ testing techniques are summarized in Table 1. As observed from the table, the SDS method has many advantages, such as simpler system, faster procedure, lighter reaction weight and better cost efficiency than other sounding tests. It has a lot of potential in terms of application especially to residential houses.

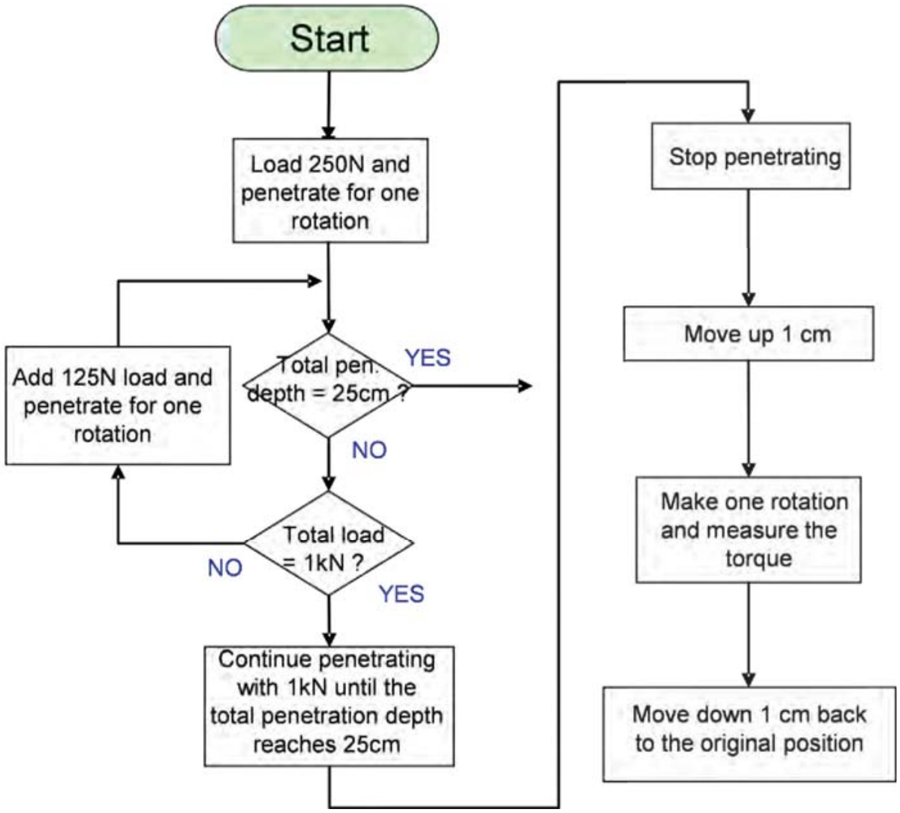


Figure 2. Test procedure for SDS method.

Figure 3. Screw driving sounding (SDS) equipment.

Table 1: Comparison between SDS method and conventional sounding methods.

		SDS	SWS (automatic)	SPT	CPT
Basic data	Penetration type	Static **and** rotational penetration	Static **or** rotational penetration	Dynamic penetration	Static penetration
	Penetration ability	SPT N value of around 10	SPT N value of around 10	High	Based on load ability
	Obtained Information	Three components: load, torque, and penetration depth	One component: load or half turns	One component: number of blows (soil type)	Three components: penetration resistance, friction, and pore pressure
	Estimated Information	Soil type, firmness, etc.	N value, q_u	Firmness	Soil type, strength, liquefaction, and consolidation
Workability	Efficiency	Good	Good	Bad	Acceptable
	Working space	Applicable to constricted space.	Applicable to constricted space.	Equivalent to two vehicles	A little wide
	Installation effort	Easy	Easy	Scaffolding and water supply are required.	Anchor casting
	Required skill	Not very high	Not high	High	High
	Environmental impact	Quiet	Quiet	With noise and vibration	Quiet
Cost		Low	Low	High	Slightly high
Remarks		Currently, only JHS	Lacks reliability. Widely used for residential buildings in Japan	Physical testing is available. Widely used in Japan	Difference in apparatus is observed. Widely used in Europe and America

APPLICATION OF SDS TESTS IN CHRISTCHURCH

The recent earthquakes that have rocked Christchurch and its environs resulted in extensive liquefaction which caused extensive damage to many residential houses, lifeline facilities and other civil engineering infrastructure (e.g., Orense et al. 2011a; 2011b; 2012). Following the major earthquake on 4 September 2010, the Earthquake Commission (EQC) engaged engineering specialists Tonkin & Taylor Ltd (T&T) to coordinate a subsurface investigation of the ground conditions in the Canterbury region. To date, more than 10,000 cone penetration tests (CPTs) have been carried out in addition to an accompaniment of boreholes, scala penetrometer tests and shear-wave velocity profiles. This information is currently stored in the Canterbury Geotechnical Database (CGD 2012).

The authors have taken the opportunity to use the SDS method at various sites in Christchurch for three purposes: (1) by comparing the SDS results with available data from adjacent CPT/SPT sites or borehole logs, provide further data to characterize sites in Christchurch and determine their geotechnical properties; (2) add data to the existing database of Japanese soils in order to improve the applicability of SDS method; and (3) explore the possibility of using SDS results to evaluate the liquefaction potential of Christchurch sites.

For this purpose, SDS tests were performed at 68 sites in Christchurch during the period June – August 2013. The locations of these sites are presented in Figure 4. These sites are located at both liquefied and non-liquefied areas following the recent earthquakes. SDS tests were conducted within 2 – 5 m from CPT/SPT sites, as described in the CGD.

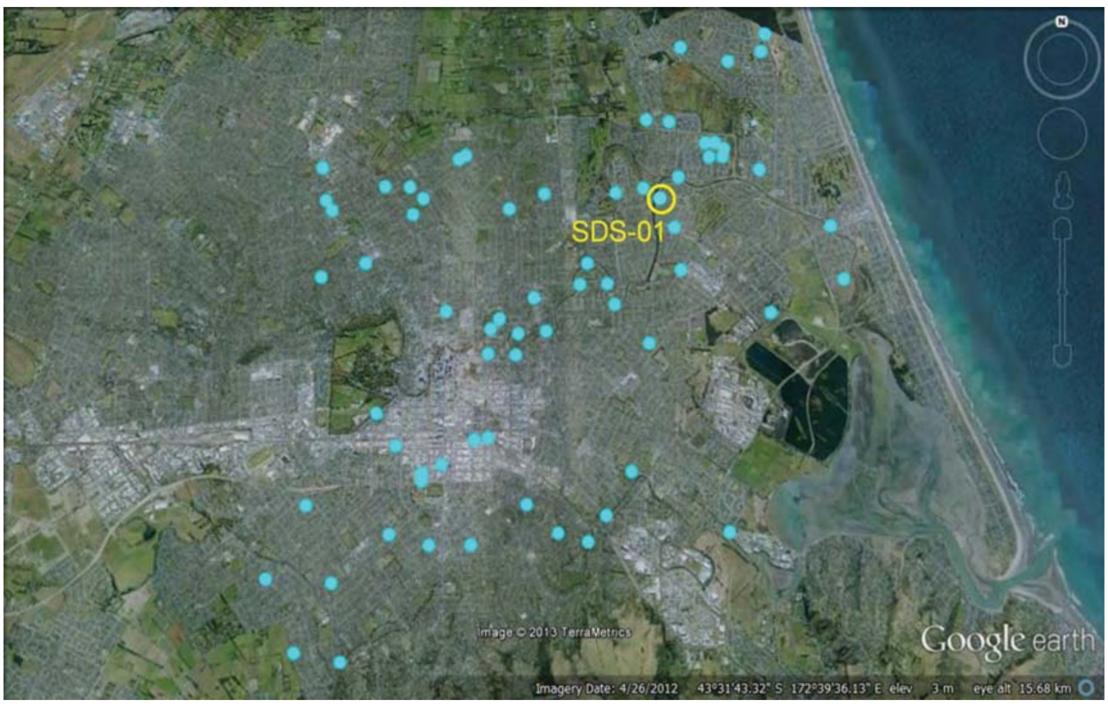


Figure 4. Location of SDS test sites in Christchurch.

A typical SDS result (SDS-01) is shown in Figure 5. The test was performed along Avonside Drive (see Figure 4 for location). The SDS test was conducted within 2 m of a CPT site and borehole. The SDS results reflect the corrected torque and load (including rod friction) and the penetration velocity at every 25 cm, up to a depth of 8 m. Also shown in the figure is the CPT profile available from the CGD. It can be inferred from the CPT profile that the site consists of loose deposits up to a depth of 4 m overlying a relatively harder layer. Comparison of the CPT tip resistance and measured torque indicates a good correlation between the two, i.e. the torque required to penetrate the screw point increases with increase in cone resistance. Within a given 25 cm interval, the change in torque with the applied load appears to increase when the penetration resistance is high; on the other hand, the change in torque in softer layer is small. Moreover, the penetration velocity significantly decreased when a hard layer is encountered. The corrected load, *W*, represents the strength of the layer.

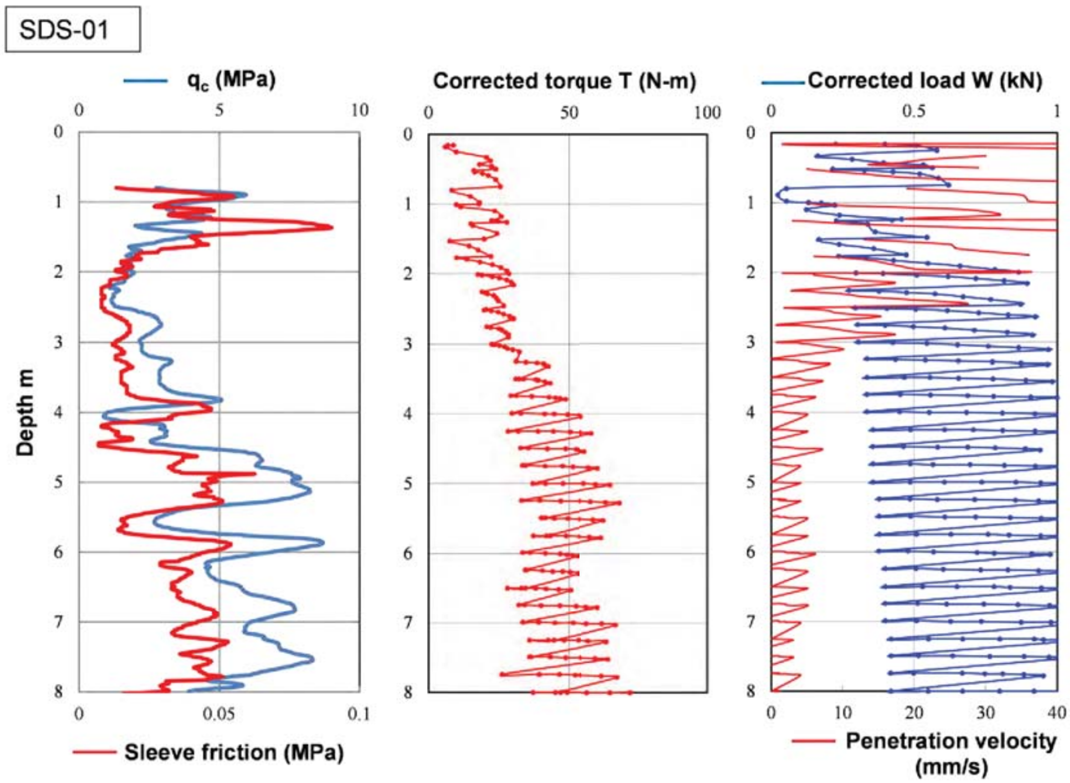


Figure 5. CPT profile and SDS results (torque, load and velocity) at Site SDS-01.

More information can be obtained by processing the initial information obtained from SDS tests. Some of the additional plots from the SDS test at site SDS-01 are illustrated in Figure 6. For example, $N_{SD}D$ is the normalized half-turns and is obtained by multiplying the number of half-turns for every 25 cm of penetration (N_{SD}) by the outer diameter of the screw point (D). This number gives an indication of the level of torque required to twist the rod. For the profile shown in the figure, $N_{SD}D$ is low in the upper 3 m and increases below it, reflecting the trend in the penetration resistance from the CPT. Another parameter, $\pi T/WD$, represents the normalized torque and is defined using the torque (T), the weight applied (W) and the outer diameter of the screw point (D). Based on plasticity theory, the coefficient of plastic potential, c_p, is defined as (Suemesa et al. 2005):

$$c_p = \frac{\pi T / WD}{N_{SD} D} \tag{1}$$

Thus, c_p is an indication of the difficulty of penetration. From the Japanese database, the appropriate range of c_p values for different types of soils is as follows (Tanaka et al. 2012): sand layer: > 1; silt and clay: 0.3 - 1; and peat and organic soil: < 0.3. The distribution of c_p in Figure 6 appear to indicate generally sandy soil profile in the top 8 m.

Moreover, a plot of the number of normalized half turns ($N_{SD}D$) and normalized torque ($\pi T/WD$) is also an indication of the soil type. The slope tends to have a positive value for frictional soil like sand, and a negative value or zero for clay and silt. $E_{0.25}$, on the other hand, is the total penetration energy for every 25 cm of penetration depth (considering the different increments of weight and torque applied and respective depths of penetration). This parameter is an indication of the layer stiffness. Finally, dT/dW represents the change in torque with the applied weight, analogous to the slope of the shear stress vs confining pressure plot in conventional laboratory testing.

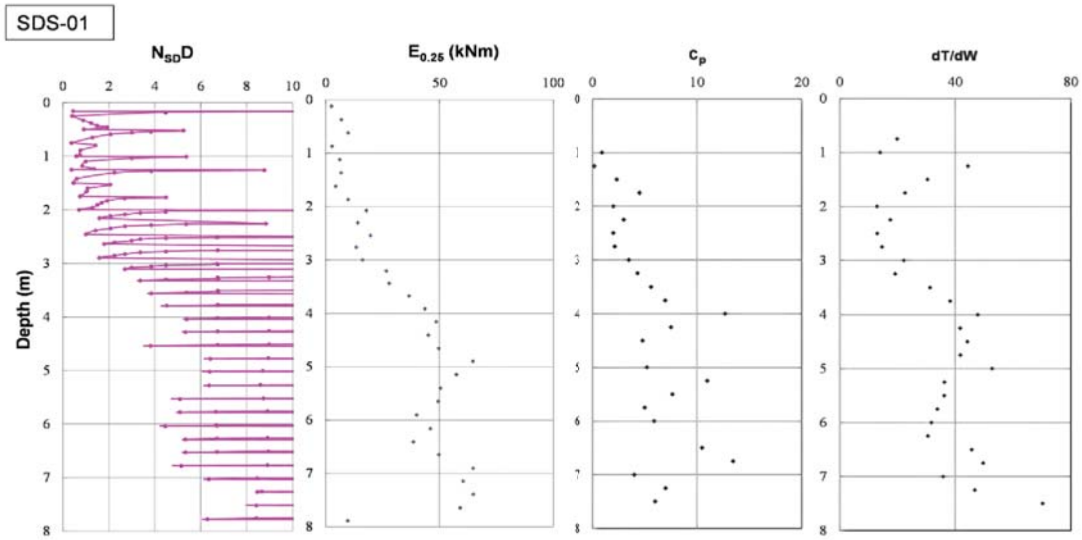


Figure 6. Additional information from test site SDS-01.

To illustrate the way SDS test classifies soil, consider again the results for test SDS-01. Based on the developed classification system using Japanese database, soils can be classified by using the change in torque with respect to the load, dT/dW, the average required torque, T, and the coefficient of yield potential, c_p. As shown in Figure 6, dT/dW is positive along the soil profile which suggests the soil is coarse-grained. From a depth of 1.0-2.75 m, the average values of corrected torque and c_p are around 20 and 3, respectively; because of these low values, the soil in this region can be classified as sandy silt. Below 2.75 m, the value of dT/dW gradually increased and this trend continues until 4 m. Similarly, the average required torque for penetration increased from 35 kNm to 45 kNm, indicating an increase in soil friction or density. In this region, the value of c_p also gradually increased from 3 to 13. It can be estimated that between 2.75 m and 4 m, the percentage of fines in sand dropped or the soil became more frictional. From 4 m to 5 m, dT/dW increased gradually. The required torque to penetrate this part of the deposit was approximately 50kNm and average value for c_p was around 8. An increase in dT/dW in this section of the soil profile indicates a medium sand soil type. There was a drop in dT/dW between 5 and 6 m indicating an increase in percentage of fines which reduced the frictional resistance of the soil. Below 6m depth, an increasing trend for dT/dW and c_p again continued, indicating a reduction in fines content. Soil in this layer can be classified as fine to medium sand.

The obtained soil classification from SDS test is compared with that derived from CPT using the soil behavior type classification proposed by Robertson (1990). Note that similar the SDS method, the classification scheme developed for CPT is for soil behavior type (SBT) because the cone responds to the in-situ mechanical behavior of the soil and is not directly applicable for soil type classification, which is usually based on grain-size distribution and plasticity index.

Table 2 shows the comparison of the soil classification using SDS, CPT and borehole log. As seen from the table, the results obtained from SDS are very close to those indicated in the borehole description. Thus, even without sampling, SDS can classify soils with acceptable degree of accuracy.

It should be again noted that the SDS-based classification was formulated from a database of Japanese soils. Thus, it is envisioned that these tests in Christchurch, as well as those planned in other parts of New Zealand, will increase the range of soil types in the database and will further refine/improve the proposed classification scheme. Moreover, from the tests conducted in Christchurch, further application of SDS results to identify regions of high liquefaction potential is currently underway and will be reported in the next opportunity.

Table 2. Results of soil classification using SDS, CPT and borehole data

CPT Soil description	SDS Soil description	Borehole		Depth (m)
		Strength/Density	Soil description	
-	-	Loose	FILL: Fine sand, dry, poorly graded	0.00-0.80
Silty sand- Sandy silt	Sandy Silt	Soft	Sandy silt, Moist, low plasticity, sand is fine	0.80-2.75
Sand and Silty sand	Silty Sand	Loose	Fine sand with trace silt, wet, poorly graded	2.75-3.00
Silty sand-Sandy silt	Silty Sand	Soft	Sandy silt, moist, low plasticity, sand is fine	3.00-3.50
Silty sand-Sandy silt	Sand	Loose	Fine sand with trace silt, Wet, poorly graded	3.50-3.75
Sand and Silty sand	Sand			3.75-4.70
Sand and Silty sand	Sand	Loose	Fine to medium sand with trace silt, wet, well graded	4.70-5.25
Silty sand	Silty sand			5.25-6.00
Silty sand- Sand	Sand			6.00-7.50

CONCLUSIONS

A new field testing method, referred to as the Screw driving sounding (SDS) method, has been recently developed. As an improved version of the conventional Swedish weight sounding (SWS) method, more parameters can be measured during the SDS tests, such as the torque, load and penetration velocity. Using a plasticity-based analogy model and miniature tests in Japan, soil classification can be performed, an added advantage compared to SWS tests.

Based on a large number of tests conducted in Japan, it was shown that soils can be classified using SDS parameters, such as c_p, average corrected torque and dT/dW. To increase the database and further refine/validate the correlations with various soil types, SDS tests were performed at 68 sites in Christchurch. The results of soil classification using SDS parameters were compared with those obtained from adjacent borehole and the CPT-based soil behavior type classification scheme. The results showed that SDS parameters give comparable results as those from CPT, indicating that SDS provides accurate soil classification.

More tests are currently planned in New Zealand to refine the current method of soil classification and to explore the possibility of estimating geotechnical properties from the SDS-measured data. As SDS is a simpler, faster and more economical test than the SPT, it can be a good alternative as an in-situ test for soil characterization.

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