Geotechnical Characterization of Hard Till for Pile Driving

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ABSTRACT
Hard till is encountered through most of Canada. The most common tool in the geotechnical investigation is the standard penetration test. In hard till, SPT usually reaches refusal, with limited split spoon penetration. The material can have a wide range of composition but is predominantly cohesive in nature. Hard till is difficult to sample with a Shelby tube sampler and often results in a limited and highly disturbed sample recoveries. Often hard till profiles end up with sparse data or sometimes even no data. Better sampling techniques and in situ testing are required for realistic characterization of hard till. For the installation of deep foundation systems using driven piles, a realistic estimate of resistance to driving is required in order to select a suitable pile driving hammer(s) for successful installation of the foundation system. Results from fully instrumented pile testing is utilized here to provide some insight into the response of “hard” till to pile driving and pile load applications.

RÉSUMÉ
Le till dur se rencontre dans la majeure partie du Canada. L'outil le plus commun dans l'enquête géotechnique est l'essai de pénétration standard. En cas de labour dur, le SPT atteint généralement le refus, avec une pénétration limitée de la cuillère fendue. Le matériau peut avoir une large gamme de composition mais est principalement de nature cohésive. Le till dur est difficile à échantillonner avec un échantillonneur à tubes Shelby et entraîne souvent des récupérations d'échantillons limitées et fortement perturbées. Souvent, les profils de till dur se retrouvent avec des données éparses ou parfois même pas de données. De meilleures techniques d'échantillonnage et des essais in situ sont nécessaires pour la caractérisation réaliste du till dur. Pour l'installation de systèmes de fondation profonde utilisant des pieux battus, une estimation réaliste de la résistance à la conduite est nécessaire afin de sélectionner un ou des marteaux de battage appropriés pour une installation réussie du système de fondation. Les résultats de tests de poils entièrement instrumentés sont utilisés ici pour donner un aperçu de la réponse de la caisse «dure» à la mise en pile et aux applications de chargement de pieux.

1 INTRODUCTION

For the installation of deep foundation systems using driven piles, a realistic estimate of resistance to driving is required in order to select a suitable pile driving hammer(s) for successful installation of the foundation system. Results from fully instrumented pile testing is utilized here to provide some insight into the response of “hard” till to pile driving and pile load applications.

Hard till is encountered through most of Canada. The most common tool in the geotechnical investigation is standard penetration test (SPT). In hard till, SPT usually reaches refusal with limited split spoon penetration. Hard till is also difficult to sample with Shelby tube samplers and often results limited and highly disturbed sample recoveries. The material can have a wide range of composition but is predominantly cohesive in nature. Commonly, hard till profiles end up with sparse data or sometimes even no data.

Realizing these challenges associated with sampling, in situ testing and the need for better characterization of hard tills, from time to time geotechnical engineers have attempted many different methods both in situ and in laborites to characterize the till more accurately, depending on the design objectives and project size (Klohn, 1965), (Radhakrisha and Klym, 1974).

Using techniques similar to rock coring through hard tills, core samples can be obtained. However smaller core sizes tend to be highly disturbed and smeared while larger-size cores can be trimmed to result in relatively undisturbed samples. Large-size block samples have also been carried out successfully however at limited depths. Further advanced laboratory investigation such as triaxial and consolidation tests have been performed on hard till samples. Among advanced in situ testing are pressuremeter, plate load test and shear box tests have been carried out successfully.

Results from fully instrumented pile testing carried out at several sites across Canada and with different deep foundation systems (driven and cast in place piles) have been analyzed and these provide some realistic design soil parameters for had till for estimating/capacities of deep foundation systems in hard till.

2 STANDARD PENETRATION TEST (SPT)

The most common tool in the geotechnical investigation is standard penetration test (ASTMD 1586). SPT is usually stopped (also called refusal) after the blow count (N) reaches 50 (or in some cases to 100). Typical representation of a SPT N-value profile is shown in Figure 1.

This test method is limited to use in non-lithified soils and soils whose maximum particle size is approximately less than one-half of the sample diameter (sample diameter is typically about 1.5 inch or 35 mm).

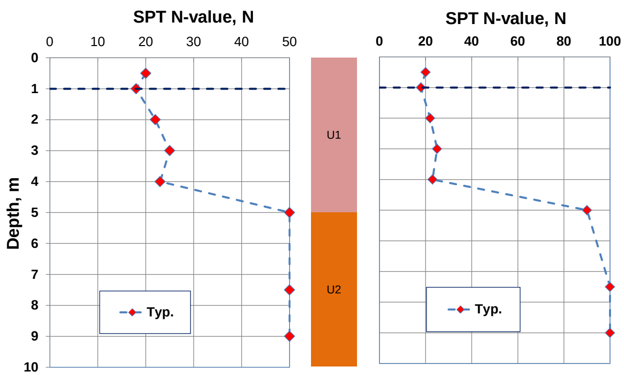

Figure 1. Typical SPT N-values Profile where SPT N-value of 50 or 100 is considered as refusal.

3 SOIL SAMPLING

3.1 Split-Barrel (SPT) Sampling

Hard till is difficult to sample with SPT when refusal ends up with a limited penetration of few centimeters. Figure 2 shows a sample retrieved at a transition zone where hard till was encountered, having 50 blows recorded a 5 cm penetration.

Figure 2. Photo of a hard till sample retrieval with a Split-Barrel Sampler (SPT).

3.2 Shelby Tube Sampling

The next best sampler for hard tills is a thin-walled tube sampler also known as a Shelby Tube (ASTM D 1587). There has been varying successes with Shelby Tube sampling. Samples from tills having low SPT N-values have been retrieved successfully with Shelby Tube sampling (see Figure 3) while due to presence of coarse particles and other reasons (lithification) there has been limited success in retrieving relatively undisturbed finite samples.

This sampling method is not recommended for sampling of soils containing coarse sand, gravel, or large size soil particles, cemented, or very hard soils.

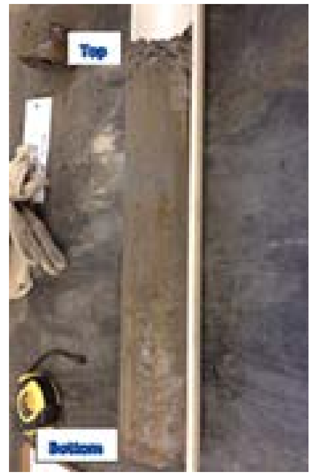

Figure 3. Photo of a till sample retrieved with Shelby Tube.

3.3 Core Sampling

Since a typical till profile is most commonly heavily over consolidated it is possible to obtain core samples with drilling techniques similar to the ones used for rock core drilling to obtain rock samples (ASTM D 2113). Minimum H-size (HQ) cores are preferred for sampling using a minimum 100mm hole and about 88mm sample size, see Figure 4.

Figure 4. Photo of a till sample retrieval with core drilling.

Obtaining till core samples with sonic drilling with success has also been reported.

4 SHEAR STRENGTH PROFILE

If the database is exclusively based on SPT, then it is almost impossible to ascertain the true strength of the till layer. Reported SPT N-values 50 or 100 considered as refusal actually represent values exceeding 50 or 100. Therefore, using standard correlations between Unconfined Compressive Strength (UCS) and SPT N-values will place the UCS in the range ≥ 300 kPa. It is difficult to idealize the profile with either the upper-bound or realistic value of the strength purely based on SPT N-values. Strength testing on Shelby tube samples wherever successful further enhances the database. UCS testing performed on core sampling and its SPT N-values for a borehole from project site is shown in Figure 5.

Many investigations reported UCS based using a hand held penetrometer at 4.5 kg/cm^2 (or 450 kPa) which is the limit of testing tool.

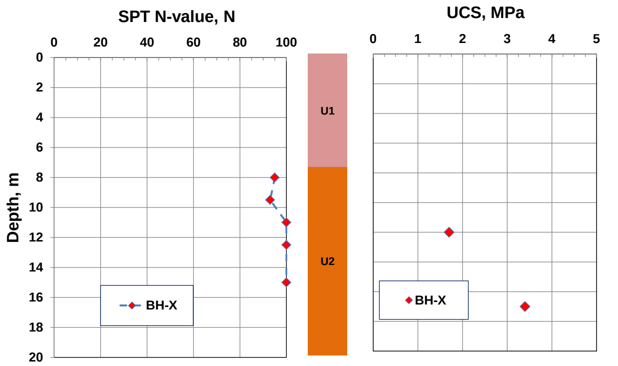

Figure 5. SPT N-values and UCS Profile for a BH Location.

5 PRESSUREMETER TEST (PMT)

Pressuremeter test (ASTMD 4719) offers a better assessment of the strength of the till. It is an in situ stress-strain test performed on the wall of a borehole using a cylindrical probe that is expanded radially, see Figure 6. Geotechnical engineers have attempted correlations between pressuremeter test results and SPT for tills: for example, Balachadran et al (2016) for the Toronto area glacial tills with SPT N-values N ≤ 100.

Figure 6. Pressuremeter Probe

Pressuremeter test results parameter such as the limit pressure profile for hard till is shown in Figure 7.

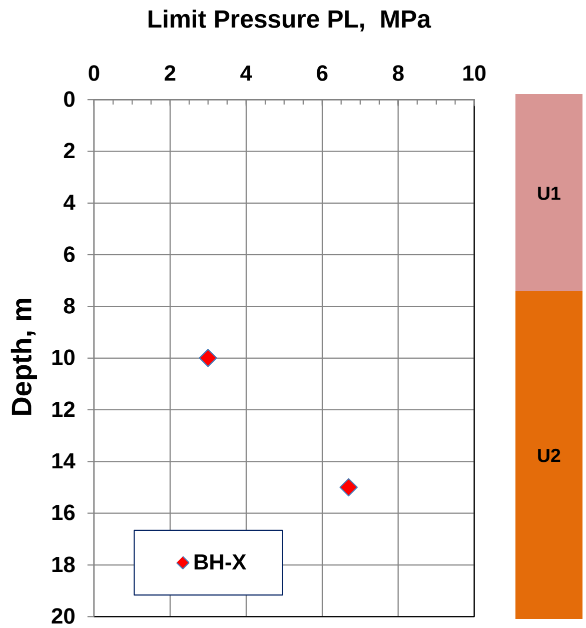

Figure 7. Limit Pressure Profile

6 PILE TESTING

Results from fully instrumented pile testing is utilized here to provide some insight into the response of hard till to pile driving and pile load applications. Dynamic testing (PDA) testing results and the Osterberg Method (O-cell) testing results using bi-directional axial load application and with displacement measurements above and below the O-cell assembly (instrumented with telltales, strain gages and displacement transducers) are analysed for this purpose. These two test methods are more reliable and allow measurement of applied end bearing and side friction.

Dynamic testing (PDA) was carried out at the end of initial driving and also re-strikes on driven steel tubular piles through hard till, for PDA set-up refer to Figure 8. Case Pile Wave Analysis Program (CAPWAP) by Pile Dynamics Inc. 2000 was utilized to calculate soil resistance forces acting on the pile.

Results from several Osterberg Method (O-cell) tests, with the axial load application in two opposing directions and with displacement measurements above and below the O-cell assembly (with telltales and displacement transducers) on cast in place concrete piles (Continuous Flight Auger, CFA and Drilled Shafts) installed through hard till are reported here. During the O-cell test the load increments are applied using the Quick Load Test Method for individual piles (ASTM D 1143), For O-cell assembly set-up refer to Figure 9.

These results have been selectively used here to draw attention to the challenges associated with predicting pile capacities (both static and resistance to driving) through hard till and how these can be overcome.

At the site of driven steel tubular piles the till characteristics varied across the site. Hence, a selection of representative data is presented here where comparable data inputs were available.

Figure 8. PDA Testing Set Up.

Figure 9. O-Cell Assembly

6.1 Side Friction

From our project files we looked at some O-cell test results for bored piles (CFA and drilled) and PDA test results for driven steel tubular piles and prepared a summary shaft friction mobilized against SPTN-values observed, see Figure 10.

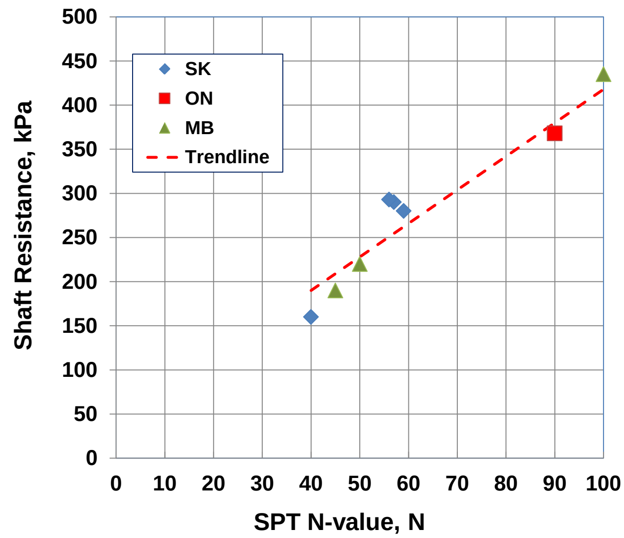

Figure 10. Mobilized Shaft Resistance

Co-relations between in situ test results and soil parameters are useful but in hard glacial till SPT N-values exceeding 100 are unreliable and shall therefore be limited to SPT N = 100.

6.2 End Bearing

From our project files we looked at some O-cell test results for bored piles (CFA and drilled) and PDA test results for driven steel tubular piles and prepared a summary of end bearing mobilized against SPTN-values observed, see Figure 11.

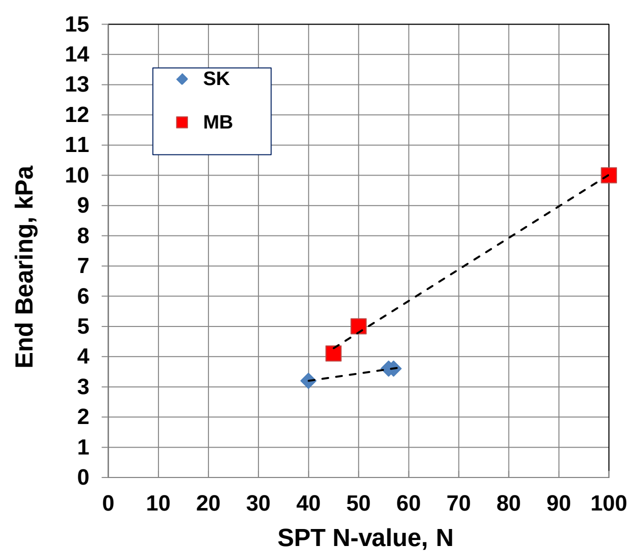

Figure 11. Mobilized End Bearing

The manner that bored piles are constructed results in stress relief and often results in lower end bearing than driven piles at the same elevation and in the same stratigraphy.

PDA results from driven piles in hard till indicated unit end bearing at 15 m depth typically in the range of 10 to 25 MPa.

Co-relations between in situ test results and soil parameters are useful but in hard glacial till SPT N-value exceeding 100 are unreliable and shall therefore be limited to SPT N = 100.

7 PILE DRIVING

For this paper we tried to located some project files where pile driving data, PDA pile load test data, and other pertinent geotechnical information was available. Pile drivability data was obtained using Junttan HHK 6S/7S hammers for an open ended steel pipe pile 356 mm x 16 mm, driven typically to 15 m as shown in Figure 12.

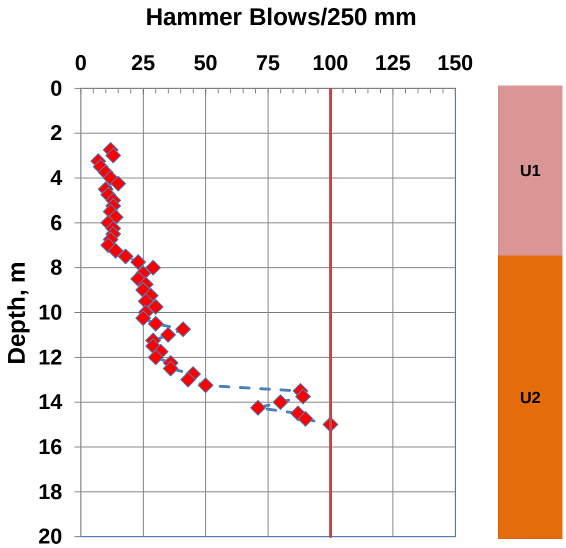

Figure 12. Pile Drivability Graph – Hammer Blow Counts v/s Depth

8 CONCLUSIONS

Based on our experience and lessons learned in dealing with deep foundation systems embedded through "hard" tills from numerous sites across Canada, the following are our conclusions:

- SPT does provide an initial assessment as to whether the till layer can be treated as soil or as intermediate material between soil and weak rock.
- If the material is hard to very had (intermediate material between soil and rock) and depending upon the project size and design objectives advanced sampling methods and in situ testing techniques may be required for the characterization till.
- The sample inventory and the project database can be enhanced using Shelby tube and/or coring sampling methods.
- Laboratory testing could include strength tests varying from simple UCS to advanced triaxial testing.
- Furthermore, to address uncertainties associated with sampling disturbance or sampling issues given the heterogeneous nature of hard till composition, in situ tests such as the pressuremeter can be incorporated in the investigation program.
- For pile driving predictions realistic estimates of soil resistance to driving are required and in hard till where SPT N-values are > 50, advanced sampling and in situ testing are a must.

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