Application and Use of Continuous Flight Auger Piles in Western Canada

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ABSTRACT
Continuous Flight Auger (CFA) piles were first used in Europe over 25 years ago. Similar technology has been used in the United States under the product name Auger Cast-in-Place (ACIP) Piling.

The introduction of CFA piling to Western Canada began over 5 years ago and they have been used on a variety of commercial and industrial structures. Numerous load tests have been conducted in soft marginal soils, weak rock, and dense glacial tills common to Western Canada. CFA test piles with diameters from 410 to 610 mm have been installed to depths of up to 23 meters. Results have shown capacity in excess of 300% greater than that of the original drilled or driven pile design capacity, resulting in significant cost and schedule savings for project owners. CFA piles are an excellent alternative for sites where other deep foundation methods would either be too costly or take too long to construct.

This paper will describe the following as it applies to CFA piling: when they should be used, the design and installation methods, the load test history in Western Canada, the concrete mix design and steel reinforcement details used for successful installation, and quality control methods used during construction.

RÉSUMÉ
Les pieux forés en tarière continue ont été employés pour la première fois en Europe il y plus de 25 ans. Une technologie similaire a été employée aux États-Unis connue sous le nom commercial « Auger Cast-in-Place (ACIP) Piling ».

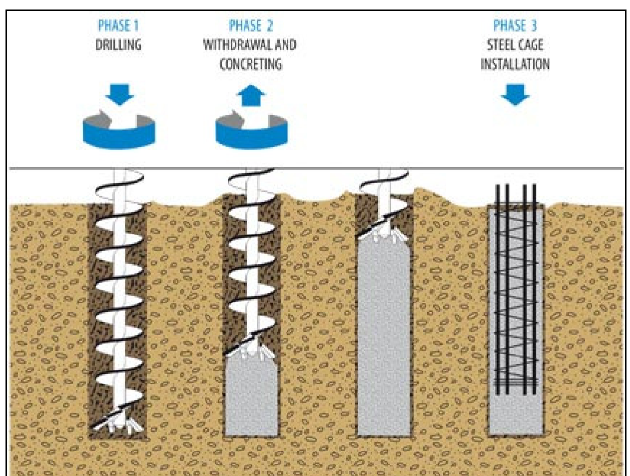
L'introduction de pieux forés en tarière continue dans l'Ouest Canadien a débuté il y a plus de 5 ans et ils ont été employés pour diverses structures commerciales et industrielles. De nombreux tests de charges ont été effectués dans les sols mous marginaux, roches molles, et tills glaciaires denses communs dans l'Ouest Canadien. Des pieux d'essais forés en tarière continue de diamètres de 410 à 610 mm ont été installés à des profondeurs allant jusqu'à 23 mètres. Les résultats ont démontré une capacité excédant 300%, supérieure à la capacité de conception initiale de pieux forés ou battus engendrant en des économies significatives du coût et temps d'opération pour les propriétaires du projet. Les pieux forés en tarière continue sont une excellente alternative pour des sites d'emplacements où d'autres méthodes de fondation seraient coûteuses ou prendraient trop long à construire.

Cet article décrira les points suivants s'appliquant aux pieux forés en tarière continue: quand ils doivent être employés, les méthodes de conception et d'installation, l'historique des tests de charges dans l'Ouest Canadien, la formule de béton et les détails d'armature d'acier employés pour la réussite des l'installation, et les méthodes de contrôle de qualité employées pendant la construction.

1 INTRODUCTION

Continuous Flight Auger (CFA) piles are a type of cast-in-place concrete piling that have been widely used in Europe and the United States for over 25 years. Other trade names for this type of piling are auger cast piling, drilled semi-displacement pile, and in Europe they are called screw piles.

A CFA pile is constructed by drilling a continuous flight hollow stem auger with a plugged end to the required depth below grade. As the auger penetrates the subsurface the flights fill up with soil and provide lateral support to the pile shaft (act as casing). Once the design tip elevation is reached, a high slump concrete is pumped down the hollow stem under pressure. This forces the plug at the base of the auger to open, and allows concrete to fill the pile shaft while the soil filled auger is extracted. When the auger tip reaches the surface the pile bore is completely filled with concrete. Steel reinforcement is then placed down into the fresh concrete. The CFA pile construction sequence is illustrated in Figure 1.



Source: Soil Mec S.p.A.

Figure 1. CFA Pile Construction Sequence

2 WHEN TO USE CFA PILING

CFA piling can be used to support a variety of different structures: single and multi storey buildings, industrial process units, transportation structures, retaining walls, wind turbine foundations, secant pile walls, ground improvement/reinforcement, and many more. They are capable of resisting axial compressive and tension loading, including cyclic loads, and can also be designed for lateral or moment resistance as required.

Typical axial compressive pile loading can range from 200 to over 2,000 kN per pile. CFA piles can be constructed as a single pile group, or a multiple pile group, depending upon load resistance required. Typical center to center pile spacing is 2.5 to 5.0 times the shaft diameter.

CFA piles can be installed in a variety of soil conditions. They are most suited for sites with soft or loose low strength soils with high groundwater levels. If a traditional drilled pile would require casing to prevent sloughing of soils and water infiltration, then CFA piles could be considered in place of the drilled piles.

Advantages of CFA piles are:

- No vibration,
- Low noise levels,
- No temporary casing required,
- Speed of installation, and
- Lower unit cost.

Disadvantages of CFA piles are:

- Temperature limits on installation, and
- Difficultly penetrating very hard bearing layers.

3 DESIGN AND INSTALLATION METHODS

Past studies have shown that the performance of properly constructed CFA piles tend to fall between that of a drilled pile and a driven pile (Brown, et al 2006). During construction of a drilled pile the soil stresses remain constant or may be slightly relaxed. Driven piles tend to displace soil laterally during installation which causes an increase effective stress level in vicinity of the pile. With CFA piling the controlled rate of auger advancement does not “flight” the entire volume of soil during drilling. In fact the soil volume is slightly compressed on the flights due to the large diameter of the auger stem (typically 200 mm in diameter). In addition, the concrete placement is completed under a pressure of between 25 to 75 kPa which increases the soils effective stress to a level higher than what you would normally see in that of a drilled pile.

When load tested, CFA piles exhibit the same load settlement behaviour of drilled concrete piles. So it is has become common practice to use drilled pile design methods for CFA piles. Since the CFA pile is a semi-displacement type pile the use of the drilled pile design method will tend to provide a conservative estimate of ultimate pile capacity in most soils.

CFA piles will typically develop most of their load capacity in friction; however when a competent bearing layer is present at the pile tip significant additional pile capacity can be gained from end bearing. The total load capacity of a single pile (Q_T) can be calculated from:

$$Q_T = Q_S + Q_B \qquad [1]$$

Where Q_S is the sum of the skin friction capacity along the length of the pile and Q_B is the end bearing resistance. There are numerous published methods for the calculation of the skin friction and end bearing values for the different soil types with different soil strength data. The reader is referred to the Canadian Foundation Engineering Manual (2006) or Brown, et al (2006) for further details on those methods.

4 CONSTRUCTION MATERAILS

The two primary materials used in CFA piles are ready mix concrete and steel reinforcement.

4.1 Concrete

In Western Canada it is standard practice to use a normal Portland cement based concrete for CFA piles. For a successful installation the concrete mix design must have good workability and flow ability. Typical mix design parameters are: 28 day compressive strength of between 25 and 35 MPa, a water/cement ratio of 0.45, and a slump 180 to 220mm. Typical mix designs contain proportions of Portland cement, fly ash, fine and coarse aggregate and water. They also include the use of chemical admixtures such as water reducing agents and set retarders. The exact composition of the mix design will vary regionally and by supplier but each mix must be pumpable, have good flow characteristic and allow for easy installation of the steel reinforcing after concrete placement is complete.

The replacement of cement with fly ash helps improve the workability of the mix designs by retarding the set of the cement, it also can result in low break results in the 7 to 14 day time period. However, this strength gain loss is not noticeable after 28 days. In practice CFA concrete with up to equal amounts of cement and fly ash have been used successfully in CFA pile construction, the common range is 25 to 35% of cement mass.

4.2 Fine and Coarse Aggregate

As the installation depths of CFA piles and the lengths of steel reinforcing cages increase, greater attention must be given to the aggregate proportions, gradations and maximum particle size. Better overall mix performance has been observed when natural aggregate particles (rounded) vs. that of a crushed aggregate are used. Also, for best workability the fine aggregate proportion should be greater than that of the coarse aggregate.

4.3 Admixtures

In order to achieve the high slump levels and workability times required, most CFA pile concrete mix designs include the use of chemical admixtures to enhance the performance of the mix designs. The correct combination and dosage of these admixtures become more and more important as the pile installation depths get deeper and deeper. The common admixtures used are air entrainment agents, low and high range water reducing agents, retarders, hydration stabilizers, and anti wash out agents. In the right proportions these admixtures will reduce the water content, retard the setting time, reduce segregation and slump loss, and improve workability.

4.4 Reinforcing steel

The steel reinforcing cages used in CFA piles may be either tied or welded. When cages are welded they should be constructed of weldable grade reinforcing bars. The cages must be fabricated to resist the stresses from hoisting and placement into the fresh concrete. For short cages (less than 6 m) tied cages are suitable, for depth greater than 6 meters a fully welded cage is recommended.

Under normal axial compressive loads the total steel area (A_s) should be equal to 0.05% of the gross cross sectional area (A_g). In order to resist higher bending and lateral loads an A_s of up to 2% can be used. The typical cage lengths are up to two thirds of the total pile length. It is not normally necessary to extend the pile reinforcing deeper than 12 to 15 meters due to the fact that relatively little if any bending stresses are transferred to such depths below grade (Brown, 2005). If CFA piles are to resist high tension loads a single full length large diameter center bar (typically 30M or 35M), or a bundle of bars can be used to provide the required steel reinforcement area. When a CFA pile has to resist extremely high tensile loads the use of a high strength steel threadbar (f_Y = 1050MPa) can be used as the full length center bar reinforcement.

Since the CFA pile cages are installed into the freshly placed concrete the specified clear cover is normally increased from 75 mm to 100 mm to allow for easier cage installation. Plastic spacers are used on the upper reinforcement cage to provide the specified clear cover. For the center bars, a steel centering guide or “football” type spacer is used on the bottom of the single or bundle of bars. The size of this spacer will depend on the sequence of installation. The center bars can be installed first and the upper cage over top of the center bar, or they can be installed last down through the center of the upper steel cage.

5 QUALITY CONTROL

The Quality Control work for CFA piling begins at the site investigation stage. The work completed by the geotechnical engineer should be detailed enough to obtain a understanding of the site stratigraphy, ground water regime, and soil strength parameters used in CFA pile design. For multi-story structures or heavy industrial facilities it is recommended to drill a number of boreholes to depths greater than the expected pile lengths, this could be up to 25 meters below final grade.

The project specifications for CFA piles need to address the required properties of the concrete mix design to be used, the allowable spacing for installation of adjacent piles (typically 3D), required field quality control expected from the contractor, materials testing, and non-destructive testing if any is required.

In order to ensure a successful CFA pile installation it is important to have experienced contractor personnel and pile inspectors on site during the course of the work. The pile inspector should review the plans, specifications and geotechnical report prior to the start of work. Once on site they should confirm: the auger diameter and length, steel reinforcing cage diameter, length and bar size and the volume of concrete pumped per stoke of the pump. When concrete arrives on site the mix specifications should be confirmed, along with batch time, air content, slump, etc. The concrete testing and cylinder casting should be completed in accordance with CSA A23.1.

During construction the contractor will achieve a satisfactory installation if they install the piles with the required diameter, to the correct depth, with materials meeting the project specifications. This is confirmed in the field through the observations of the experienced geotechnical inspector and the pile contractor’s construction record. The contractors drilling equipment should be equipped with electronic Pile Installation Recorder (PIR) equipment. These electronic systems are used to supplement, and not replace the full time geotechnical inspection required by the local building codes. The PIR typically display the depth, torque, rotation speed, and penetration rate during the drilling phase. Once concrete placement commences the PIR records concrete pump pressure, counts pump strokes, and extraction rate. Once concrete placement is complete the PIR generates a theoretical profile for each pile along with calculations for the concrete overconsumption. A sample of the typical PIR pile printout is shown in Figure 2.

If the construction records indicate a possible problem with the pile installation it may be necessary to conduct some non-destructive testing (NDT). The most common method used for post-construction pile evaluation is low-strain impulse testing (LSI). Testing a pile using the LSI method requires the attachment of a sensor to the top of the pile and then the pile is struck with a hammer. The sensor records the arrival time of the reflected impulse waves. When the test is completed by a skilled practitioner it is possible to determine the installed pile length, and diameter. If the testing is not done properly it raises more questions than answers and results in needless delays to the project.

6 LOAD TESTING METHODS

It is a common misconception that load testing of piles is expensive and takes a long time. In fact, a basic static load test can cost as little as $50k (for a 500 kN capacity pile, excluding site mobilization) and take one week to complete. Design engineers and owners need to keep in mind that the benefits of load testing far exceed the actual costs of the tests. When a load test is successfully completed the Ultimate Limits States Design (ULS) parameters can be increased by 50% through the use of the higher resistance factor (0.6 vs. 0.4) allowed by the National Building Code of Canada (2005). This is in

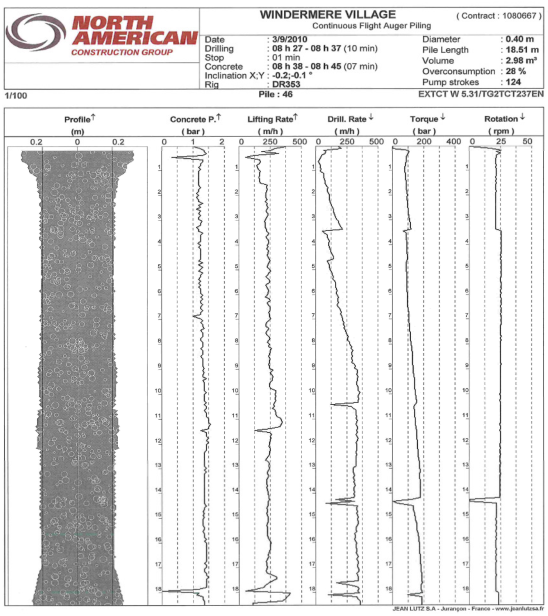


Figure 2. Typical PIR Print Out

addition to any calculated increase in soil strength parameters determined by the geotechnical engineer from the testing data. The resulting cost savings can be up to 25 to 30% of the total foundation costs.

When selecting the load testing method to be used on a pile there are 4 possible choices. Of the four options three have been used on CFA piles (Dynamic, Top Load Static, and O-cell testing).

6.1 Dynamic Pile Testing

The fastest lowest cost test method is dynamic pile testing. The test pile is struck by a drop hammer and the dynamic response of the pile is recorded with a Pile Driving Analyzer (PDA) and the load capacity calculated. It is recommend to conduct dynamic testing at least 7 to 14 days after installation. The use of a drop hammer type ram with a mass equal to about 1-2% of the test load is required to fully mobilize the pile. While the dynamic test method is a quick and inexpensive way to confirm pile capacity, it is limited in terms of the ability to fully mobilize higher capacity tests pile and often provides conservative results.

6.2 Top Load Static Tests

The top load static test is the most common method of load testing and provides good data, either manually recorded from dial gauges or electronic measurement with data loggers can be used. The typical load test set up has four reaction piles and one test pile. A large test beam ties the reaction piles together to provide the load resistance. A large hydraulic jack along with a vibrating wire load cell is used to apply the test load to the pile. Many contractors in western Canada have standard test equipment for test loads up to 4.5MN in compression or tension. Larger test loads can be achieved, but may require special test frame fabrication.

6.3 Rapid Load Tests

Rapid Load Testing uses the inertia of a reaction mass to apply a load to the test pile. The trade name for this type of testing is Statnamic load testing. The duration of the Rapid test is reported to be between 100 to 120 milliseconds. Rapid load testing does not use reaction piles, beams or hydraulic jacks. Instead a load frame and reaction mass are set up on top of the pile and a controlled reaction creates a pressure increase that puts an upward force on the reaction masses while an equal and opposite force pushes downward on the pile. The duration of the loading and unloading forces allows an accurate measurement of the load-displacement behaviour for the pile.

The rapid load test measurements provide a high degree of resolution fully defining the piles load and deflection response with as many as 100,000 data points recorded during a typical ½ second test. For more detailed information the reader is refered to the American Society for Testing and Materials designation number ASTM D7383-08.

6.4 Osterberg Cell Test (O-Cell)

The Osterberg Cell (O-Cell) is named after it's inventor Dr. Jorj O. Osterberg**.** The O-cell is a sacrificial hydraulic jack cast directly into the test pile. The O-Cell is typical cast somewhere in the bottom third of the test pile. Once activated it applies load to the pile in both the upward and downward directions. The O-Cell test method does not require any reaction piles, frames or other equipment to complete the test.

The O-cell derives all reaction from the soil and/or bedrock strata the pile socketed into. End bearing provides reaction for the skin friction portion of the O-cell load test, and skin friction provides reaction for the end bearing portion of the test. Load testing with the O-cell continues until one of three things occurs: ultimate skin friction capacity is reached, ultimate end bearing capacity is reached, or the maximum O-cell capacity is reached. Details of the O-cell test set up are shown in Figure 3.

Each O-cell test pile is instrumented with multiple levels of sister bar type strain gauges to measure load transfer along the pile shaft and movement transducers for direct measurement of the cell expansion. All test data is recorded in a data logger and provide a direct indication of the pile skin friction and end bearing values, along with pile movement.

O-cell test capacities range from 0.5MN to upwards of 50 MN. It is also possible to use 2 or more o-cell is a single test pile for special tests.

Special considerations must be made when using the O-Cell method of load testing on CFA piles. In order to install the cell the contractor must use a fluid sand/cement grout mix design capable of achieving the required design strength for testing. A full length steel reinforcement cage or steel channel carrying frame can be used to install the O-Cell. Consideration should be given to completing a test pile using a dummy-cell to ensure the contractors' installation methods are appropriate.

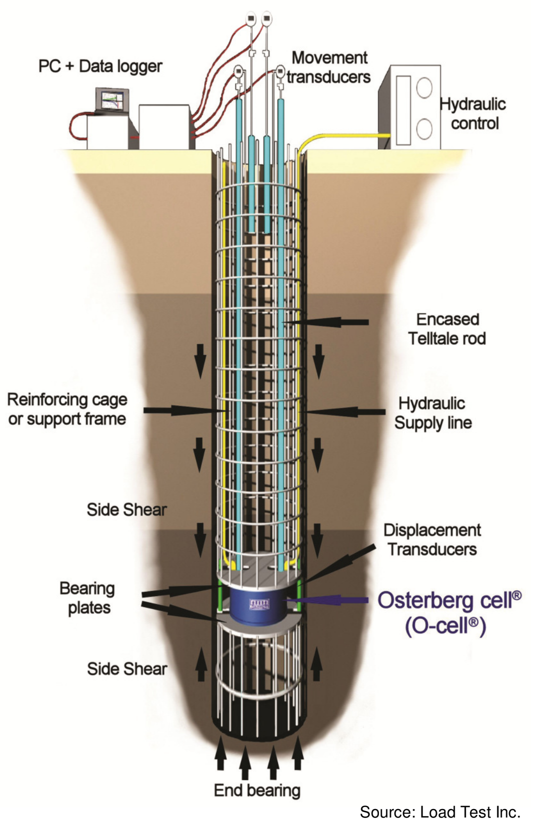


Figure 3. O-cell Test Schematic

7 LOAD TESTING HISTORY

Since 2005 over 40 CFA piles on more than 20 project sites in Western Canada have been load tested with one of the methods described above. Of the 40 load tests 23 have been load tests using a full scale static or O-cell test method on 12 different project sites. In addition another 18 piles on 6 project sites have been proof tested with the dynamic test method.

7.1 Dynamic Load Test Results

The dynamic test results are summarized in Table 1. All dynamic pile tests have been limited to 400 mm diameter piles to avoid mobilization of very large drop hammers to impact the piles. In each case the testing confirmed the design load on each pile length and in some cases indicated that there was significant excess capacity. There is significant variation in design load to calculated maximum capacity (varies from 1.5 to 12.5) in each test. The author recommends the use of dynamic load testing for the conformation of load capacity only. An increase in the resistance factor from 0.4 to 0.5 should only be used if a minimum of 10% of the piles on a project site are tested using the dynamic method.

Table 1. Dynamic Load Testing Data

Site	Soil Conditions	Pile Diameter (mm)	Pile Length (m)	Design Load (kN)	CAPWAP Calculated Maximum Capacity (kN)
1A	Silty Clay/Siltstone	410	8	325	540
1B	Silty Clay/Siltstone	410	13	766	1,960
1C	Silty Clay/Siltstone	410	19	1,773	2,940
1D	Silty Clay/Siltstone	410	19	1,773	2,820
2A	Silty Clay	410	10	155	1,200
2B	Silty Clay	410	13	348	1,400
2C	Silty Clay	410	16	541	1,700
3A	Silty/Sandy Clay	410	6	200	427
3B	Silty/Sandy Clay	410	11.5	400	1,100
3C	Silty/Sandy Clay	410	17.5	1,300	1,312
4A	Sand/Silty Clay	410	6.5	58	720
4B	Sand/Silty Clay	410	11.5	245	1,120
4C	Sand/Silty Clay	410	14	334	1,110
5A	Silty clay Till	410	6	150	2,075
5B	Silty clay Till	410	12.5	700	1,855
6A	Silty Clay/Clay Till	410	8	296	530
6B	Silty Clay/Clay Till	410	12	381	1,100
6C	Silty Clay/Clay Till	410	16	520	1,600

7.2 Full Scale Load Test Results

The results of 22 full scale load tests are summarized in Table 2. The design loads for each pile have been calculated using the site specific allowable skin friction and end bearing values for traditional drilled cast-in-place concrete piles. The average CFA pile displacement at the design load is 2.03 mm. When you subtract the elastic compression of the pile your total settlement at design load is just less than 2 mm, well below the typical structural criteria of 6 to 12 mm of acceptable settlement.

A number of the load tests conducted were to pile failure and some of those were instrumented with strain gauges so it is possible to see how the total load is shared between skin friction and end bearing, as well as the pile settlements at ultimate capacity. When piles were terminated in a competent bearing stratum 25% of the test load, at ultimate, was resisted in end bearing, the balance in friction capacity.

8 SUMMARY

Over 4,000 CFA piles have been successfully installed on more than 25 projects across western Canada over the last 5 years. The test data from the more than 20 full scale load tests completed in the last 5 years indicates that the pile displacement at the design load level is well below the typical range of acceptable settlement values proposed by designers of 6 to 12 mm of pile head movement. When used properly CFA piles can provide projects the following benefits:

- CFA piles can be used in soft soils were traditional drilled or driven piles may be impracticable,
- The load settlement behaviour of CFA piles is similar to traditional drilled cast-in-place concrete piles,
- Working Loads of over 2,000 kN have been applied to single pile groups,
- Load testing of CFA piles can save between 20 - 30% of total foundation costs, and
- Using drill pile design methods/parameters for CFA piles typically results in pile head movements of less than 3 mm at working load levels.
- If there is an intention to optimize piles on the basis of load test data it is recommended to conduct a full scale type load test to ensure the actual pile capacity is fully mobilized

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Table 2. Static Load Testing Data

Location	Soil Conditions	Pile Diameter (mm)	Pile Length (m)	Design Load (kN)	Displacement at Design Load (mm)	Maximum Test Load (kN)	Displacement at Maximum Test Load (mm)
NW Edmonton, AB	Silt/clay/Clay Stone	400	20	1,000	4.5	2,000(1)	15.5
NW Edmonton, AB	Silt/clay/Clay Stone	400	10	260	1.8	788	10.8
NW Edmonton, AB	Silt/clay/Clay Stone	400	20	1,000	3.2	2,750	31.3
NW Edmonton, AB	Silt/clay/Clay Stone	600	10	400	1.4	1,800	26.4
NW Alberta	Silty Clay	610	14	600	1.70	1,300	21.58
NW Alberta	Silty Clay	610	18	800	0.70	1,600	22.71
W Edmonton, AB	Silty Clay/Clay	510	20	600	3.2	2,150	24.1
SE Calgary, AB	Clay/Clay Till	410	21	750	3.0	2,450	19.1
SW Edmonton, AB	Silty Clay	410	16	350	1.4	875(2)	6.74
SW Edmonton, AB	Silty Clay	410	24	650	1.6	1,950(2)	4.03
NE Alberta	Sitly Sand	610	14			3700	27.5(3)
NE Alberta	Silty Sand	610	14			2850	9.1(3)
NE Alberta	Silty Sand	610	14			2450	7.0(3)
Regina, SK	Clay/Sand	410	6	260	0.6	1,250	13.6
Regina, SK	Clay/Sand	410	9	380	0.35	1,950	19.1
Regina, SK	Clay/Sand	410	12	500	0.74	2,700(2)	9.8
Regina, SK	Clay/Silty Sand	410	7	150	1.44	800	13.8
Regina, SK	Clay/Silty Sand	510	12	375	0.68	1330	9.0
SE Saskatchewan	Clay Till	610	22	1800	1.02	3600(2)	2.4
E Saskatchewan	Clay Till	610	16.5	650	0.75	2,000	4.1(3)
Saskatoon, SK	Silty Clay/Glacial Till	410	12	600		1,730	12.84
Saskatoon, SK	Silty Clay/Glacial Till	410	24	1,200	8.54	3,350	21.16

[1] Pile failure above grade

[2] Limit of Test Frame

[3] Osterberg Cell (O-Cell) Test Equivalent Top Load Displacement