The Application and Development of Continuous Flight Auger (CFA) piles in the Prairies

Fazli R. Shah & Naresh Gurpersaud
Keller, Edmonton, AB, Canada

ABSTRACT

Continuous flight auger (CFA) pile is a cast in-situ concrete pile constructed by using a fully flighted hollow stem auger. CFA piles were introduced in the UK in 1960s as a solution to the construction difficulties associated with conventional piling techniques especially the need for temporary casings or slurry. Over the years, CFAs has spread across the world making its way into many construction markets, including Canada.

Initially, CFA piles were limited in diameter and depth and were used to carry light to moderate loads as a structural support element and were constructed in soft to medium stiff soils. Technological development has expanded its use and constructability enormously. Today, it is very common to install CFA piles of diameters ranging from 300mm to 1200mm and as deep as 50m or more as well as in a variety of subsurface conditions. Technological development has also led to numerous enhancements in CFA drill rig instrumentation with Data Acquisition (DAQ) systems which provides key quality assurance and quality control parameters on a real-time basis related to geotechnical and structural aspects of the pile.

Continuous flight auger piles have been successfully utilized in the Prairies over the last 15 years on numerous sites as a technically viable and cost-effective deep foundations system. This paper presents an overview of CFA pile background, technical considerations and case histories.

RÉSUMÉ

Le pieu à vis sans fin (CFA) est un pieu en béton coulé sur place construit à l'aide d'une vis à tige creuse entièrement volée. Les pieux CFA ont été introduits au Royaume-Uni dans les années 1960 comme une solution aux difficultés de construction associées aux techniques de pieux conventionnelles, en particulier le besoin de tubages temporaires ou de lisier. Au fil des ans, les CFA se sont répandus à travers le monde et ont pénétré de nombreux marchés de la construction, dont le Canada.

Initialement, les pieux CFA étaient limités en diamètre et en profondeur et étaient utilisés pour transporter des charges légères à modérées comme élément de support structurel et étaient construits dans des sols mous à moyens. Le développement technologique a considérablement étendu son utilisation et sa constructibilité. Aujourd'hui, il est très courant d'installer des pieux CFA de diamètres allant de 300 mm à 1 200 mm et jusqu'à une profondeur de 50 m ou plus ainsi que dans une variété de conditions souterraines. Le développement technologique a conduit à de nombreuses améliorations dans l'instrumentation des plates-formes CFA avec acquisition de données (DAQ) qui fournit des paramètres clés de contrôle de la qualité en temps réel liés aux aspects géotechniques et structurels de la pile.

Des pieux à vis sans fin ont été introduits avec succès dans les Prairies depuis 15 ans et installés sur de nombreux sites comme système de fondations profondes techniquement viable et rentable. Cet article présente un aperçu du contexte des pieux CFA, des considérations techniques et des histoires de cas.

1 INTRODUCTION

A CFA pile is a type of cast-in-situ concrete piles installed in one continuous operation or single pass consisting of advancing a hollow stem continuous flight auger of pile design diameter to the target depth. As the auger is advanced, its flights are filled with soils which provides lateral support to the drilled hole. Concrete is placed by pressurized pump method through the hollow core of the auger during auger retrieval which also support the surrounding soils by virtue of positive concrete pressure. Reinforcement is installed into the pile shaft filled with fluid concrete immediately after completion of withdrawal of auger and concreting. This operation is schematically shown in Figure 1.

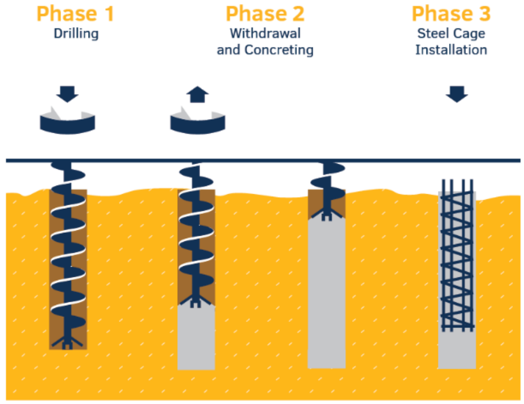

Figure 1. Installation sequence of CFA piles

2. BACKGROUND

CFA piles were introduced during the early 1960s in the UK as a performance-based pile type to overcome the construction difficulties associated with the then available piling techniques resulting in cost and schedule overruns and approximately around the same time similar systems were used under different patented names in the US which became commonly known as Auger Cast-In-Place (ACIP) piles at expiry of the patents in mid-1970s (DFI ACIP Manual 3rd Edition 2016). Back in the day, the most commonly used piling techniques were driven steel piles and drilled shafts also known as bored piles, drilled cast-in-place piles or caissons. The two main difficulties associated with driven piles were vibration and noise in addition to the higher material costs. On the other hand, drilled shafts or bored piles had faced construction related difficulties whenever a soft, silty, sandy and water bearing stratigraphy was encountered along the length of the pile shaft. Such conditions always required temporary casings and/or drilling slurry to stabilize the drilled hole during construction which in turn were not only driving the project costs upward but were introducing significant schedule impacts. These challenges led to the invention of continuous flight auger or CFA pile.

Initially CFA piles were limited to small diameter and medium depths rendering them as deep foundations elements used to resist light to medium loads and cost effectively practical in a limited range of soils such as soft clays, silts and loose to compact sands especially with presence of subsurface water. The smaller diameters and lack of full-length cages were another hindrance in CFA pile's efficiency to resist lateral and uplift force. With improvements in concrete quality, the piling industry found an easy fix for enhancing the uplift capacity by introducing installation of a so-called centre bar which is a single bar or a bundle of bars pushed through the centre of the pile to the design depth to transfer the uplift forces to the surrounding soils beyond the length of the partial cage resulting in a very cost effective design. However, with vast availability of self-compacting concrete (SSC) and high strength grout, installation of full-length cage is no longer impossible. Further development in the mechanical sector led to development of more powerful CFA drill rigs, enabling the piling contractors to construct larger diameter and longer CFA piles penetrating harder variety of soils as well some soft rocks. Today, it is common to install CFA piles raging in diameters from 300mm to 1200mm and up to 50m or more in depth.

In the Prairie region CFA piles were introduced in 2004-05 by Keller Foundations Ltd. (operating at the time as North American Caisson Ltd.) and since then has become one of the most common types of piles used for a variety of functions such deep foundations, support of excavation and slope stabilization. Keller has successfully installed more than 70,000 no. CFA piles since then and has demonstrated the efficiency and suitability of CFA piles as a technically and commercially viable pile type through research and development. However, there are still some sectors of the construction market which are hesitant to allow the use of CFA piles on their projects due to perceived difficulties in quality control and difficulties associated with incorporating a rapidly developing (often proprietary) technology into the traditional, prescriptive design-bid-build concept (FHWA GEC 08 , 2007). Recent advances in the automated monitoring and recording devices such as Jean Lutz's DAQ System and availability of non-destructive testing techniques e.g. PIT, PDA, and TIP will alleviate such concerns about quality control and provide more tools for performance-based design-build contracting process.

It is also important to note that CFA piles is a semi-displacement and low-pressure injection method of pile installation which means that not only construction, but also structural and geotechnical performance is dependent on the means and method of construction. For this reason, full scale load testing on a sacrificial pre-production pile provides confirmation of geotechnical capacity based on the contractor's means and methods of construction.

3. CASE HISTORY#1-CALGARY STUDENT RESIDENCE -2019

The Calgary Student Residence and Mixed-Use Development is a private development over a 0.65-hectares site located at 2416 – 16 Avenue northwest Calgary shown in Figure 2. The project is comprised of a 28- storey high rise residential development, an abutting restaurant and a 3-storeys commercial building with one level shared below grade parkade. It was initially designed on footing but upon completion of the geotechnical site investigation, pile foundations were recommended as the viable foundation system.

3.1 Sub-surface Conditions

The surficial geology of the area is known to consist of lacustrine sand and silt per geological mapping of Calgary Urban Area (Moran, 2005). The site-specific subsurface conditions below the single level underground parkade consisted of a sand & silt layer underlain by silt & clay layers. The sand & silt layer varied in thickness from 1.4m to 7.7m across the site, the silt encountered is of stiff to very stiff consistency and non-plastic in nature. The sand is fine to medium grained, non-plastic and loose to compact in strength. The silt and clay layers include interbedded sand lenses and generally of stiff to hard consistency. The ground water was found at 10m below grade (equal to 6m below the parkade level).

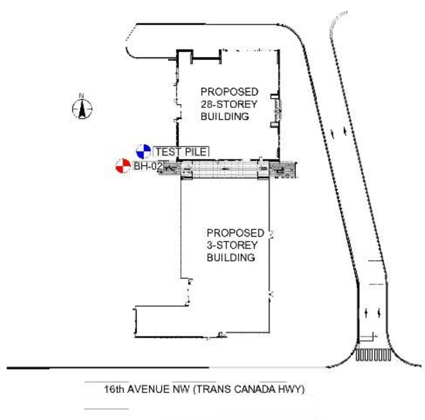

Figure 2. Calgary Student Residence – Layout and location

3.2 CFA Pile Design Approach

The geotechnical report consisting of drilled boreholes and CPT soundings with recommendations for both drilled cast-in-place piles and CFA piles. CFA piles were proposed as the most economical foundation system due to the wet and sloughing soil conditions. However, the client opted to try larger diameter shorter drilled shafts trying to limit the casing cost, but the load testing program did not meet the design requirements and CFA pile alternated was finally accepted. It was decided to take a full-scale instrumented static load test on a sacrificial pile to verify/optimize the pile design before commencement of the production piles. Static load test was performed in accordance with ASTM D1143 procedure A, on a 600mm diameter x 27m long CFA pile instrumented with five levels of VW strain gauges shown in Figure 3.

The load testing resulted significant design optimization as listed in the Table 1 below in comparison to the recommendation contained in the original geotechnical report.

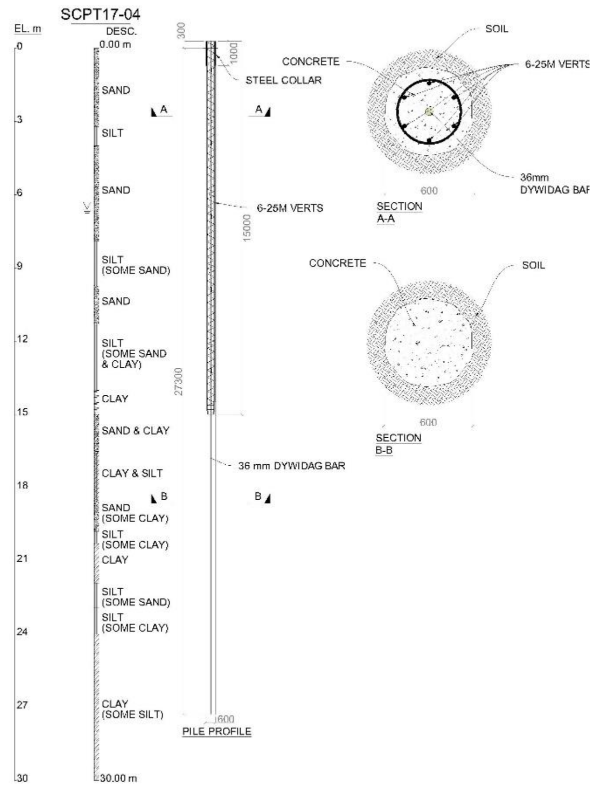

Figure 3. Calgary Student Residence – Sub-surface profile and configuration of sacrificial test pile

3.3 Production Piles

Table 1- Calgary Student Residence – Pile Design Parameters

Geodetic Elevation (m)	Pre-Load Test (mm)		Post Load Test	
	Skin Friction (kPa)	End Bearing (kPa)	Skin Friction (kPa)	End Bearing (kPa)
1093 - 1088	70	1000	91	-
1088 - 1084	50	600	105	-
1084 - 1081	50	600	97	-
1081 - 1073	50	600	35	-
1073 - 1066	50	600	187	1285

5. CASE HISTORY # 2 – AURUM ROAD CROSSING OF CLOVER BAR CREEK -2018

The last and 7th stage of Aurum Road extends between 9th and 17th street NE and crosses over the Clover Bar Creek to join Anthony Henday Drive. The major part of the project is the crossing of Clover Bar Creek consisting of MSE wall and arched culvert. Both arch culvert and MSE wall are founded on CFA piles. The preliminary geotechnical report had recommended driven piles as foundation system for the arched culvert and shear key for the MSE wall. However, the shear key was not constructible due to steep slope resulting in unstable conditions during construction which led to CFA piles being recommended as a replacement for the shear key.

5.1 Sub-surface conditions

The project site is located on a low-level terrace of the North Saskatchewan River and the Clover Bar Creek near the intersection of Aurum Road with 17th Street North East Edmonton as shown in Figure 4. The Clover Bar Creek leaves its ravine at this terrace at a location approximately 400m to the northwest of the project location. The topography at the project location is very is steep and elevation varied across the pile layout from 629m to 639m (Geodetic). In general, the soils encountered in the culvert and MSE wall footprint area consisted of topsoil overlying colluvium or clay till underlain by bedrock. In some part such as the east side of the ravine a sand and gravel layer of the Empress or Pleistocene Formation was sandwiched between the clay till and bedrock. The topsoil was clayey and ranged from 0.5m to 1m in thickness. The clay till encountered below the topsoil, varying in thickness from 1 to 5.5m consisting of silty, sandy and clayey matrix with trace gravel of very stiff consistency and was highly plastic. The bedrock comprised of stratified clay shale and sandstone of Edmonton Formation which was generally of highly to completely weathered condition and extremely weak strength. The bedrock included numerous coal seams and localized zones of medium strength.

5.2 CFA Pile Design Approach

The prime consultant had conceptually recommended CFA piles for the MSE wall foundation based on the sub-surface conditions observed during geotechnical investigation. The structural engineer had chosen driven steel piles for the arched culvert foundations. Upon thorough review of the scope and existing conditions, It was agreed to use CFA piles for both MSE wall and arch culvert foundations due to potential difficulties associated with pile driving and material cost. A comprehensive load test program was undertaken to verify and optimize the design. The test program consisted of two axial compression static load tests on sacrificial piles of same diameter and different lengths representative of the two pile types required for the arch culvert foundation. Static lateral load tests were performed on two sacrificial piles one representing the pile type required for culvert foundations and one representing the pile type required for MSE wall foundations. The sacrificial test piles for axial load tests were instrumented with VW strain gauges to evaluate the load carrying capacity resulting from skin friction in different soil layers and end bearing resistance. The sacrificial piles for lateral load test included an inclinometer casing to measure the pile head rotation and deflection along the length of the pile. The pile schedule for the load test program is summarized in Table 2.

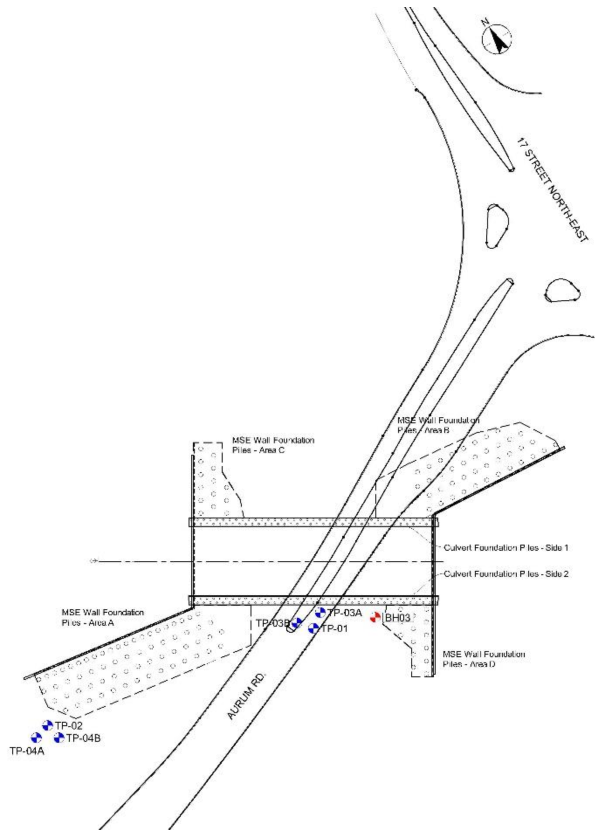

Figure 4 – Aurum Road Crossing of Clover Bar Creek – Layout and Location

Table 2. Aurum Road Crossing of Clover Bar Creek – Test pie schedule

SCHEDULE					
TEST PILE	Ø (mm)	PILE LENGTH (m)	REINFORCEMENT TYPE	REINFORCEMENT LENGTH (m)	DYWIDAG CENTRAL BAR
01	610	22.0	10x25M	11.4	1x30 mm
02	610	13.5	10x25M	11.4	1x30 mm
3A	610	22.0	10x25M	12.0	2x36 mm
3B	610	22.0	10x25M	12.0	2x36 mm
4A	1220	15.0	32x35M	15.0	1x36 mm
4B	1220	15.0	32x35M	15.0	1x36 mm

5.3 Production Piles

The load testing program and additional desktop studies to refine the slope stability analyses utilizing the data gathered during lateral load tests helped in optimizing the production piles and address all concerns such as mobilization of end bearing resistance in tandem with skin friction and constructability of 1200mm diameter CFA piles with heavy full length rebar cages. The final pile design is shown in Table 3 below.

Table 3. Aurum Road Crossing of Clover Bar Creek – Production Piles

Item No.	Structure	Pile Diameter (mm)	Pile Length (m)	Quantity of Piles (no.)
1.	Culvert- Inner Row	600	12	77
2.	Culvert- Outer Row	600	23	77
3.	MSE Wall	1200	17[1]	124

[1] Maximum length of pile under MSE wall was 17m.

The project quality control requirements were based on Alberta Transportation Specification for deep foundations which does not allow CFA piles for transportation projects. This led to some concerns from the project owner and additional testing program comprising of 20% low strain integrity testing on randomly selected piles was used. In lieu of cross hole sonic logging (CSL) testing vastly used for quality control and acceptance of drilled shafts, thermal integrity profile (TIP) were used. All piling work was successfully completed, and randomly selected piles were tested using PIT and TIP techniques to provide supplemental evidence of the quality of workmanship and materials in addition to the automated drill rig generated pile logs and material test reports.

6. CASE HISTORY #3 – AGLC 2016

The Alberta Gaming and Liquor Commission (AGLC) new distribution centre located in St. Albert, Alberta shown in Figure 5, is one of the major development projects undertaken by Alberta Infrastructure in 2016. The development consisted of a 75,000 sq. m single storey warehouse, a 2,300 sq. m three storeys office building and a 140 sq. m guard house. The warehouse also included a structural slab due to heavy live loads and therefore required piles to support the buildings and structural slab. This resulted in an overall 2921 no. of piles on the project. The tender documents had delegated the pile design to the specialty piling contractors based on the guidelines and options provided by the preliminary geotechnical data included in the bid documents.

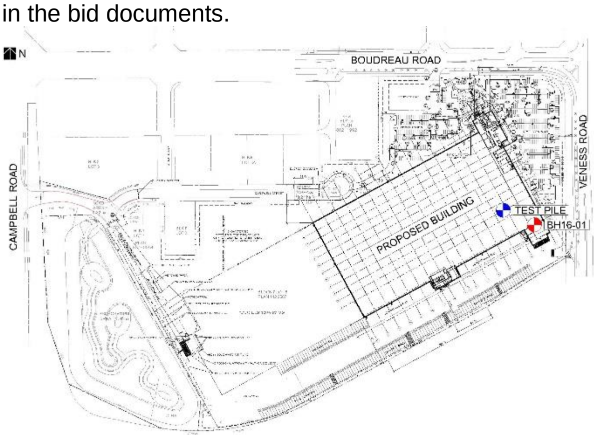

Figure 5. AGLC Project- Overall layout and location

6.1 Sub-surface Conditions

The soil stratigraphy on the site, generally comprised surficial organic and fill soils overlying native clay underlain by clay till and ice rafted bedrock that comprised of clay shale and sandstone. The surficial organic and fill soils are approximately 1m thick comprising of silty clay with trace sand, gravel and organics. The native clay extended to a depth of 7 to 10m and silty in nature with low to medium plasticity. The clay till is a 5m thick layer. It was sandy in nature with variable amounts of sand with traces of gravel. It also includes clay shale and coal inclusions. The ice-rafted bedrock comprised of clay shale and sandstone with coal layers. The strata included perched ground water varying in depths from 4.5m to more than 10m.

6.2 CFA Pile Design Approach

The geotechnical investigation report had provided initial recommendations for both CFA piles and Belled piles. After a thorough review of all the project documents such as loads, layout, local geological conditions and experience in the area, it was decided to propose CFA piles.

Keeping in mind the number of piles required and the required length of piles as well as the generic design approach adopted by the geotechnical engineering society, it was deemed necessary to undertake additional investigation and a full-scale instrumented load test on a sacrificial pile (Figure 6). The purpose of the additional investigation was to validate the assumption based on the locally published geological maps (Kathol and McPherson, 1975) and experience in the surrounding area. The sacrificial test pile was installed and tested to optimize the soil parameters based on site specific requirements and increase the geotechnical resistance factor from 0.4 to 0.6 in accordance with National Building Code of Canada (NBCC) and Canadian Foundation Engineering Manual. The above-mentioned design development and verification was completed simultaneously with site preparation by the general contractor to avoid schedule delays. The additional investigation and load test program resulted in substantial optimization of pile design as presented below in Table 4 in comparison to the original recommendations contained in the tender documents.

Table 1- AGLC – Pile Design Parameters

Depth Below Grade (m)	Pre-Load Test (mm)		Post Load Test	
	Skin Friction (kPa)	End Bearing (kPa)	Skin Friction (kPa)	End Bearing (kPa)
0 to 1.5	-	-	-	-
1.5 to 10.0	25	-	30	-
10.0 to 15.0	55	1200	120	1200
15.0 to 19.0	Not Investigated		140	1400
19.0 to 23.0			160	1600
23.0 to 27.0			180	1800

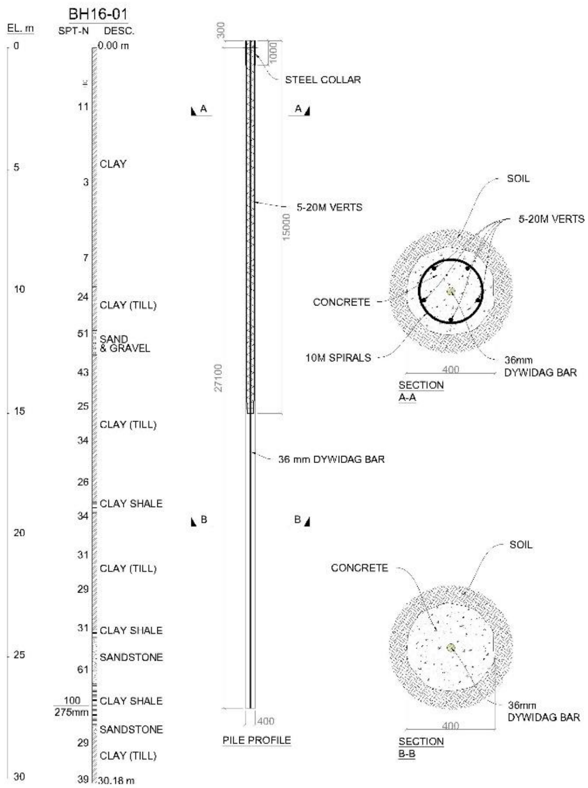

Figure 6. AGLC – Subsurface profile and configuration of test pile.

6.3 Production Piles

The successful load testing program resulted enhanced the geotechnical design capacity of the piles significantly resulting in a very cost and schedule effective pile design for the project. The final pile design is summarized in Table 5 below.

Table 5. AGLC – Production Pile Design

Item No.	Structure	Pile Diameter (mm)	Pile Length (m)	Quantity of Piles (no.)
1.	Warehouse-Columns Row	400	20 - 26	250
2.	Warehouse-Slab	400	17 - 21	2250
3.	Office and Guard house	400	6 - 28	421

7. CASE HISTORY #4 – KING STREET MANOR 2007

The King Street Manor also known as King Street on the Park is a private development consisting of Highrise building of approximately 2,300 sq. m with partial one and two level underground parkade. The project is located on 5th avenue and king street in Spruce Grove Alberta (Figure 7) which is part of Parkland county area of the greater Edmonton. The preliminary geotechnical report included recommendations for conventional end bearing piles terminating in the clay shale bedrock despite cautioning the contractor of the difficulties associated with wet and sloughing soils as the clay till toward the west side of greater Edmonton is sandier in nature with occasional sand and coal lenses.

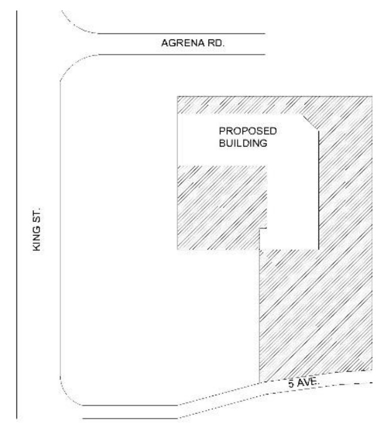

Figure 7. King Street Manor – Layout and location

7.1 Sub-surface Conditions

The sub-surface conditions at this site consisted of sandy and silty surficial fill up to a depth of 1.5m underlain by 3.5 to 4m thick layer of native clay of firm to stiff consistency and silty in nature. A glacial clay till layer encountered below the clay extended to approximately 14m below grade and was interbedded with wet sand lenses. Clay shale bedrock underlying the clay till continued to termination of all deeper boreholes. The ground water table showed some signs of artesian pressure in the clay shale layers.

7.2 CFA Alternate Design Approach.

In 2007, CFA was still very new and uncommon in the local piling industry and therefore was not recommend in the original geotechnical report but was proposed as a performance based alternate foundation system, The design methodology was based on preliminary design with verification by four (04) sacrificial test piles of same diameter and various lengths to determine the geotechnical performance of all soil layers. The soil profile and configuration of the test piles is are summarized in Figure 8.

7.3 Production Piles

Upon successful completion of the load test program, design for production piles was finalized using the measured soil parameters. This resulted in piles of three different diameters and various length for the different portions of the project. Some of the different pile diameter required were dictated by limitation of the drill rig maximum depth and/or structural pile capacity. The summary of the production pile design is shown in Table 5.

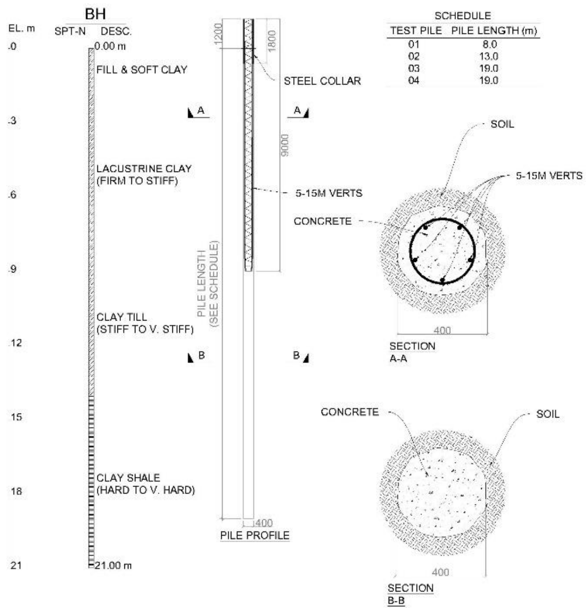

Figure 8-. King Street Manor- Sub-surface profile, test pile schedule and configuration

Table 5. King Street Manor- Production Piles Design

Item No.	Pile Diameter (mm)	Pile Length (m)	Quantity of Piles (no.)
1.	400	7 – 19	96
2.	600	12 – 25.5	164
3.	750	21 – 24.5	42

During installation of the production piles, artesian ground water conditions were encountered in some of the piles resulting in water overflowing to the installation grade during drilling. The artesian condition was sealed during concreting with slight modification of construction methodology such as maintaining marginally higher concrete pressure by slowing down the auger withdrawal.

The structural engineer on record raised concerns regarding the integrity of the piles where artesian pressure was experienced and recommended low strain integrity testing. The integrity testing performed by STS consultants confirmed the soundness of all piles.

7.0 QUALITY CONTROL

The geotechnical capacity of CFA piles is contingent on the subsurface conditions and the contractor's means and methods of installation. CFA piles are typically specified as an alternate deep foundations system by contactors and in some cases performance requirements are outlined by the Owner. The contractor is generally responsible for the quality control aspects by using a combination of data acquisition system (DAQ), field notes and laboratory test results. CFA rigs are typically outfitted with sensors to capture drilling parameters such as auger rotation rate, depth of auger injection point, toque and crowd force. The DAQ sensors also capture the installation data during concreting/auger withdrawal such as volume of concrete, concrete pressure, auger rotation and depth of the injection point. The Jean Lutz LT3 system has been used as a DAQ system to capture real-time data for all of the case histories presented in this paper. Remote viewing is also available of the installation records on a real-time basis with the Jean Lutz DAQ system for the contractor's design engineer and/or operations personnel to review and provide troubleshooting guidance to the field crews in a timely manner. This review process can be used to detect any anomalies or differing ground conditions.

All quality control requirements should be reviewed during the planning process of the project and outlined in the contractor's method statement and/or quality control plan. The implementation of DAQ provides a means of evaluating each pile for conformance to the desired installation criteria as specified and/or established during the pre-production load test program.

Contractors should not rely solely on automated monitoring for quality control of CFA piles (FHWA, 2007). Automated monitoring should be supplemented with visual observations, installation notes, challenging ground conditions, calibration checks and other site conditions and/or installation challenges because the quality and performance of the CFA piles depends on strict control of workmanship (Tomlinson and Woodward).

Quality assurance can be done by the Owner's representative and typically comprises of a review of the contractor's quality control plan, installation and testing records as well as field monitoring.

8,0 LOAD TESTING

Full-scale load testing on sacrificial pre-production elements installed in representative soil conditions using the means and methods proposed for production piles provides valuable data and verification of design parameters. If the subsurface conditions are uniform at the site one pre-production instrumented load test is sufficient. However multiple tests may be needed if the soil conditions vary significantly across the site. The pre-production load test program can result in significant cost-savings to the Owner based on reduced piling scope due to higher load capacities, reduced schedule and reliance on contractor's quality control program in lieu of proof testing.

Load testing of CFA piles is typically done with suitable jack, test beams and reaction piles. Load testing of CFA piles using other approaches such as O-cell and PDA have also been performed successfully in the Prairies. Test piles have been instrumented with strain gauges which provided valuable data to evaluate the load distribution (i.e. shaft capacity and end bearing). In most of the load tested CFA piles geotechnical failure was not achieved demonstrating reserved capacities. The limiting factors can be attributed to the pile's structural capacity, test jack and/or capacity of the reaction frame. The pile lengths have been optimized based on an extensive database, understanding of local geological settings and installation parameters.

Full-scale load testing of sacrificial pre-production piles is an effective means of verifying design parameters and validating the contractor's installation means and methods.

9.0 DISCUSSIONS

CFA piles have been successfully installed and tested for many projects covering a range of structures in the Prairies and pile functions such as deep foundations, slope stabilization and excavation support. It has been proven as a technically viable and cost-effective deep foundations technique. CFA piles are installed without the use of casing or drill slurry to stabilize the drilled hole. Drilling of the hole is done in a continuous operation by advancing the drilling string to depth and extracting while concreting the hole. The piles are installed using a low-energy process without inducing any noise and vibration. Additionally, CFA piles can overcome other challenges like mitigating the hazards posed by artesian pressure as demonstrated by case history #4. Another challenge often faced during drilled shafts in the Canadian oil sands is gas mitigation which is overcome by flooding the drilled holes with slurry to suppress the hydrocarbon emission, this can be automatically mitigated by using CFA piles which does not involve creation of an open hole.

High load capacities can be generated from CFA piles as presented in the case histories and other research projects e.g. Shah & Deng 2016 and Fellenius & Terceros 2017. The piles can be installed at a quick rate without over-drilling or over-flushing the hole. The auger remains in the hole with a column of soil that acts as a plug which is gradually removed during the concreting process. CFA piles can be installed in a wide spectrum of soil conditions.

Early engagement of the specialty contractor can result in significant savings to the Owner. A teaming approach can result in optimization by conducting the load test program in advance of the production work. This allows for re-engineering and further optimization of scope.

10. CONCLUSIONS

The case histories outlined in this paper provides a small sample of CFA projects that have been successfully installed and tested in the Prairies over the past 15 years. Static load testing has been conducted on most of the sites which resulted in a good understanding of geotechnical design parameters and allowable load capacities.

Collaboration with specialty contractors can result in optimization and significant cost-savings for Owners. Contractors can also provide useful feedback and ideas when engaged in front-end engineering and design (FEED).

Keller (formerly operating as North American Piling) has played a meaningful role in the introduction and advancement of CFA piling in the Prairies. The application of CFA piles will continue to grow and develop across Canada as a suitable deep foundations technique.

ACKNOWLEDGEMENTS

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