SCREW ANCHOR TEST PROGRAM (Part I): INSTRUMENTATION, SITE CHARACTERIZATION AND INSTALLATION

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ABSTRACT: Helical Anchors, also known as Screw Anchors, have been used in many engineering applications. They provide structural stability against axial compression, uplift, overturning, and lateral forces. Predicting the loading capacity of helical anchors installed in Alberta is difficult because of the complexity of the sediments found in Alberta due to the glacial history. Therefore, a testing program, including compression, tension, and lateral pile loading tests, was carried out on screw anchors installed in typical Alberta soil. The Cone Penetration test (CPT) was adopted as the site investigation method for determining the soil parameters within the soil profile. The program is focused on developing a more reliable approach that incorporates an in situ testing method (CPT) into the design. This paper presents the development of the field testing program including site characterization using CPT, instrumentation, and installation of the test anchors.

Key words: pile load test, instrumentation, cone penetration test, screw anchor pile

1. INTRODUCTION

Multi-helix screw anchors have been used in various engineering applications for decades. They are particularly selected for resisting large uplifting forces associated with transmission towers, guyed towers, utility poles, aircraft moorings, and submerged pipelines. They can also provide structural support for excavations, tunnels, and hydraulic structures. Large capacities have been achieved using screw anchors because of technology improvement. Research has shown that uplift capacities up to 775 kN have been developed using multi-helix anchors (Hoyt and Clemence, 1989).

The screw anchor pile has a number of advantages. They are inexpensive to manufacture, and often can be re-used at new sites. The field installation cost is low because the installation process requires only two operators. The placement rate is high, typically 20 to 30 minutes per anchor installation and requires minimum equipment. However, the most desirable advantage of screw anchor is that they are an economical alternative for providing tension anchorage for foundations in difficult terrain. For instance, the power transmission industry utilizes these piles in the construction of power lines that traverse large areas and variable geologic conditions. In Alberta, screw anchor piles have also been used in foundation applications to resist axial compression, tension and lateral loads associated with drill rigs used in hydrocarbon exploration. In addition, they have been used as foundation support for pump jacks, pipelines, and light structures that are subjected to large wind loads.

Past research has been focused on predicting the uplift capacity of screw anchors. However, in Alberta, the screw piles have been used in many applications where the capacity in compression and lateral loading is also important. Besides, the sediments in Alberta are complex due to the glacial history. Consequently, the testing program, including axial compression, axial tension and lateral loading tests, was conducted by the University of Alberta at the request of ALMITA Manufacturing Ltd. The program was undertaken for the purpose of developing a more reliable design approach to predict the capacity of screw anchor piles installed in typical soil throughout Alberta.

This paper presents the results of the site investigation, the properties of the test piles, the instrumentation, installation procedures and the testing setups used in the field testing program. A companion paper presents the field results obtained from the testing program.

2. HELICAL ANCHOR AND ITS INSTALLATION

A helical anchor consists of a steel shaft with one or multiple circular plates (helices) affixed to the main shaft. Figure 1 shows a sketch of a typical helical anchor configuration for both single and multi-helix screw anchors. There are wide varieties of shaft sizes available for design ranging from 89 to 200 mm for axially loaded piles and up to 273 mm for laterally loaded applications. The pitch and center to center spacing of the helices can be varied so that the upper helices will follow the lower one when advancing into the soil. The helix can be manufactured in single pitch, multi-variable pitch, and multi-equal pitch. They can be welded, riveted, or bolted to the steel shaft, and the helical blades could be knife edged to facilitate their installation and minimize disturbance to the soil during installation (Bradka, 1997).

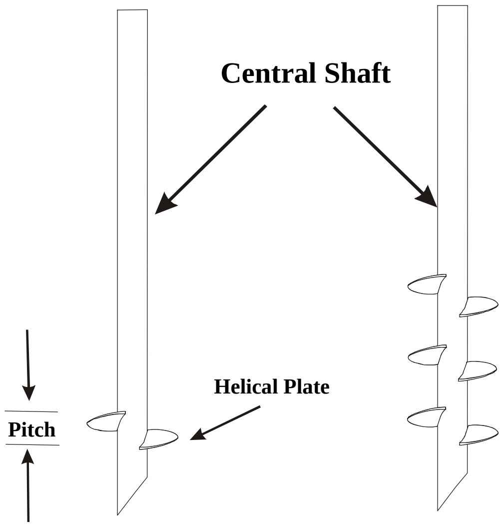

Figure 1. Typical Screw Pile Configuration

In Alberta, helical screw anchor piles are typically installed to a shallow depth of less than 6.0 m. They are installed by applying an axial compressive force to the shaft while rotating it into the ground with a hydraulic torque head mounted on a carrier. The rate of penetration should be equal to one pitch per revolution in order to avoid shearing of the soil (Bradka, 1997). A typical set up for installing screw anchors pile is shown in Figure 2.

3. TESTING PROGRAM

The original proposed field program included a total of 27 pile load tests to be performed at three sites underlain by different soil types that could be considered as typical Alberta soils. The soil types chosen are Lake Edmonton Clay (cohesive material), Sand dunes (cohesionless material), and Glacial Till. Six fully instrumented pile load tests including two compression piles, two pullout piles and two lateral piles would be performed at each site. Furthermore, three non-instrumented standard production piles would be loaded in compression and tension at each site to compare the result with the instrumented research piles. The information gathered would be used to study the influence of the embedment ratio (H/D), space to diameter ratio (S/D) on the ultimate capacity of the helical anchors (Figure 1).

The Cone Penetration Test (CPT) was adopted as an in situ testing method to determine the soil stratigraphy and basic soil properties measured within the soil profile. The penetration resistance measured will be correlated to the compression, uplift capacity of the pile, the installation torque required, and the soil stratigraphy. It is anticipated that its use will increase the reliability of predicting the capacity of the pile, simplify and reduce the cost of the site investigation for the future design of screw anchor piles.

However, Cone Penetration Test results demonstrated that the CPT profiles of the Lake Edmonton Clay and the Glacial Till around Edmonton area are very similar. The Glacial Till behaves comparable to a stiff clay according to the Soil Behavior Type based on CPT data (Robertson and Campanella, 1983). There was no justification to test two cohesive sites with similar CPT profiles. Therefore, the Glacial Till site was postponed until a more suitable location with a significantly greater cone resistance could be found. Consequently, a total of 18 pile load tests, were performed on two sites in the Edmonton area. Ten pile load tests including five compression tests, three tension tests and two lateral tests were conducted on the University Farm site (Figure 3). In addition, eight pile load tests, consisting of three compression, three pull out and two lateral pile load tests, were conducted at a Sand Pit site located at Bruderheim, Northeast of Edmonton (Figure 4).

Figure 2. Screw Anchor Pile Installation

4. SITE GEOLOGY

The surficial deposits of Edmonton consist mainly of well-sorted pre-glacial sands and gravels, glacial till and Proglacial Lake Sediments.

4.1 Glacial Lake Edmonton Sediments (University Farm Site)

Glacial Lake Edmonton deposits are lacustrine sediments, laid down in a large proglacial lake at the close of the Wisconsin glacial period (Bayrock and Hughes, 1962). The general composition of the material includes varved silts and clays, with pockets of till, sand, or sandy gravel (Godfrey, 1993). The lake deposits are more clayey in the uppermost few feet than in the lower bed. The lower lake sediment beds consist of fine sand and till-like lenses of clay with scattered pebbles. The University Farm site, marked in Figure 3, is located in central Edmonton between 115 ST, and 58 Ave.

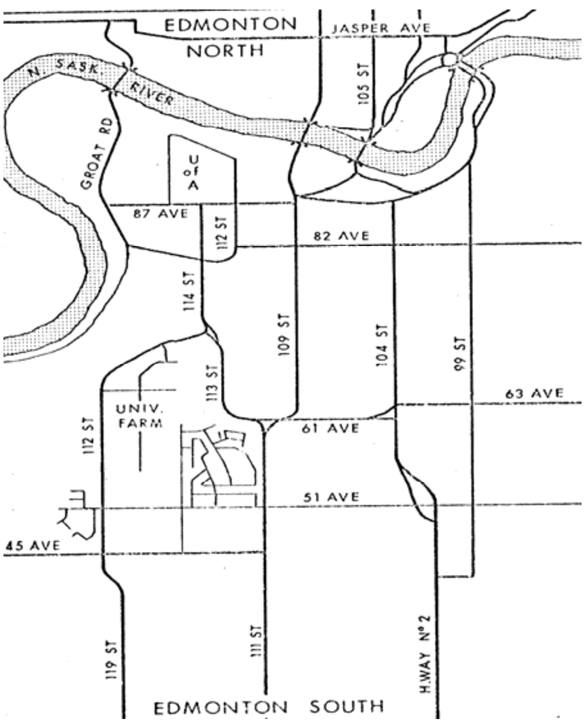

Figure 3. University Farm Pile Test Location (BHANOT, 1968)

4.2 Glacial Till

Sediments deposited by the glacier without washing or sorting are called the glacial till. Till is composed of mixed clay, silt and sand, with pebbles and boulders, lenses of sand, gravel and local bedrock. This material is the most significant parent material from which Alberta soil has developed (Bayrock and Hughes, 1962).

Cone Penetration tests were performed on a site located around 17 ST., and the highway 14 extension. The material is defined as lacustrine till but this site was later eliminated due to the similarity of the CPT profile with the University Farm Site.

4.3 Sand Dunes

Sand dunes with minor loess are medium- to fine-grained sand with silt. The material consists of dried sediments of the glacial lake, mainly lake-bed muddy silts and beach sand which is transported by wind and re-deposited in nearby sand dune field after the drainage of the glacial lake. The testing site is located outside of Bruderheim, Northeast of Edmonton. The Sand Pit site is approximately 7.5 km north of Bruderheim town center. Figure 4 illustrates the test site location.

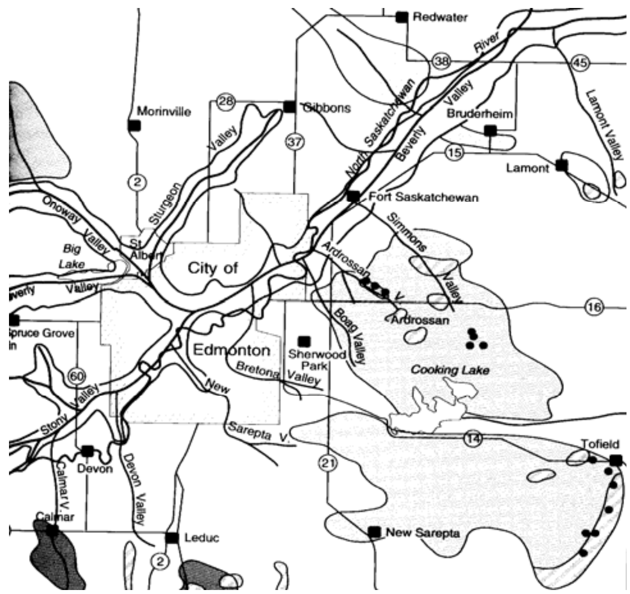

Figure 4. Sand Pit Pile Test Location (GODFREY, 1993)

5. SITE INVESTIGATION

The site investigation for the field testing program comprised both Cone Penetration tests (CPT) and Standard Penetration test (SPT) at each site.

Cone Penetration tests were performed at each site to a minimum depth of 7.5m to assist in determining the soil stratigraphy and variation in shear strength within the soil profile. Two types of Cone Penetrometer were used for the site investigation. The conventional electric piezometer with 10 cm^2 base diameter and 60° cone was used at the University Farm site where material is more cohesive, and uniform. At the Sand Pit site, a simple but rugged electric cone penetrometer was used. The new cone called the Downhole Cone Penetrometer (DCPT) developed at the University of Alberta, has a diameter of 46 mm with a projected area of 16.6 cm^2 (Treen et al., 1992). Both cone penetrometers were used at the University Farm site to compare the consistency of the field results. One conventional boring using a solid stem auger was advanced at the University Farm site and the Sand Pit site and the Standard Penetration Test (SPT) was performed at intervals of about 0.76 m interval using a safety hammer to a depth of approximately 6.0 m.

Summaries of the CPT soundings performed at each site are shown in Figure 5. The continuous CPT profiles of cone penetration resistance (q_c), sleeve friction (f_s), and friction ratio (R_f) of each site are summarized. Standard Penetration Test results and the SPT "N" counts at certain depth are shown in Figure 6.

The soil profile was interpreted according to the CPT data and the Borehole information available. At the University Farm site, the top 0.45 m of the soil consists of clay mixed with gravels which is a result of a nearby snow dump. The CPT profile shows that the upper 4 m of soil consists of uniform clay. From a depth of 4 – 7.5 m, the soil consists of interbedded silty clay and clay silt. The soil becomes more silty and sandy beyond 7.5m. The ground water level was located around 3.0 m in depth. At the Till site, the top 0.8 m was drilled out in order to avoid damage to the electronic cone because of the presence of pebbles. From 0.8 m to 1.2 m, soil consists of mainly clay. There is a thin layer of silt, approximately 0.3 m, located beneath the clay layer. From 1.5 m to 5.5 m, the soil profile was mainly clay, and the ground water table was found to be at approximately 3.5 m in depth. Between 5.5 m to 8.5 m, the soil consists of interbedded silty clay and clayey silt. For the Sand Pit site, the top soil are clean sand to a depth of 0.75 m. Between 0.75 m to 2.75 m, the soil is medium grain sand to silty sand. From 2.75 m to 5.0 m, the soil is a sand mixture of silty sand to sandy silt. Below 5.0 m, the soil is a silt mixture of clayey silt to silty clay. The ground water level was encountered at approximately 4.5 m in depth.

6. ANCHOR GEOMETRY AND INSTRUMENTATION

Figure 7 demonstrates the geometry of the screw anchor piles used in the testing program and Table 1 contains a summary of their characteristics. These screw anchor piles were instrumented with five levels of strain gages and a load cell at the base of the pile to study the load transformation phenomena during the installation and load testing of the anchor. Strain gages were installed inside of the 219 mm diameter steel pipes. The pipes were cut into short sections allowing strain gages to be installed inside. The parts were then welded back with 356 mm diameter helices affixed to the central shaft. All the strain gages were protected by a silicon shell and fiberglass insulation to avoid extreme heating during assembly of the pile and from moisture during testing.

A systematic design was created for the strain gage installation, wiring, and data collection. At each level, three strain gages were installed 120° apart to capture different loading conditions both for axial and lateral tests. Strain rosettes were used in this research. Each rosette has three gages whose axes are 45° apart. In addition, load cells were installed inside of the tip of the anchor. However, the load cell could only be installed about 0.3 m from the tip of the screw anchor to protect the load cell from damage during installation. Consequently, there was a total of 49 channels, including 45 sensors from the 5 levels of strain gages, 2 displacement transducers and 2 load cells, which require monitoring during the test. A data logger system, CR10 with 3 multiplexers (AM416), was used for monitor the real time results, and retrieve the stored data collected. Figure 8 shows the data acquisition system used.

7. TEST SITE LAYOUT

The site for the test piles was arranged in a systematic layout. Figure 9 illustrates a typical site plan and the location of the test pile, reaction piles, and in situ test locations. The test piles were installed in rows. Figure 10 shows a section for compression and tension tests. The arrays of the test piles minimize the number of reaction piles required. A total of six reaction piles were installed for the testing program. Timber cribbing was also used for tension pile loading test. The use of timber cribbing provides flexibility for the set up of tension tests.

8. PILE LOAD TESTING

8.1 Axial Compressive Tests

Reactions for the axial compression pile load tests were developed from two screw piles with 210 mm shaft diameter and three 406 mm diameter helices, installed to a depth of 5.18 m. A schematic of the axial pile load test arrangement is shown in Figure 11. Load was transferred to the reaction piles by 38 mm diameter, high strength steel bars. The bars were bolted to the reaction frame and were connected to the tension reaction piles. A 20 mm thick steel plate was welded on top of the reaction piles. Four slots were cut from the plate allowing the steel bars to connect.

A 20 mm thick steel plate was welded on top of the test pile and a calibrated hydraulic jack with 90 tonnes capacity was placed on the jacking plate. A 1500KN capacity electronic load cell with a set of spherical bearing plates was placed between the jack and the reaction frame. The hydraulic jack was controlled by supply fluid pressure through a manual hydraulic pump. The axial compressive load applied to the test pile was measured using the load cell and the pressure gage on the hydraulic pump as a backup. Both the electronic load cell and the hydraulic jack were calibrated before use in field. The vertical pile movement was monitored by two electronic displacement potentiometers attached to the two 300 mm H-section steel reference beams. The two potentiometers, calibrated prior to testing, were placed on each side of the test pile diametrically. Vertical deflection of the test beam was measured manually by a dial gage, accurate to 0.01 mm. In addition, a survey level reading on both reaction piles and the test piles was used as a backup measurement on the pile movement.

The load tests were carried out following a quick load test procedure, as described in ASTM D 1143-81. Each anchor was loaded to failure in increments of 10 to 15% of the proposed design load. Constant time intervals of a minimum of 5 minutes were used to permit adequate time for recording

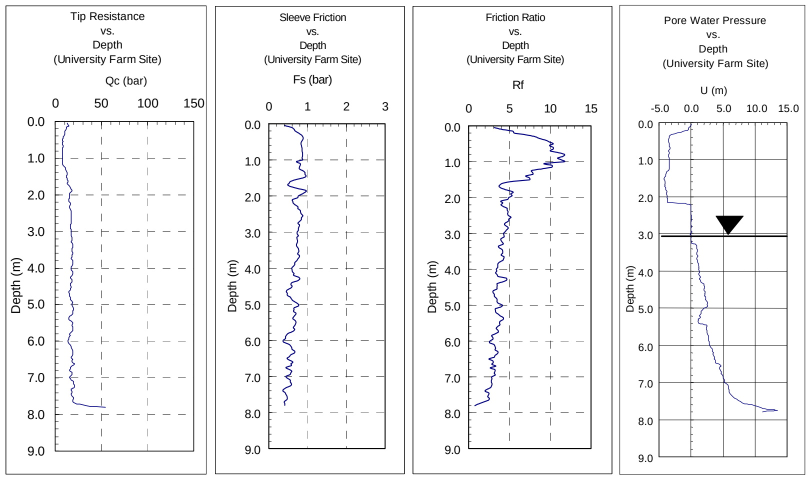

Figure 5a – CPT Profile at University Farm site (1 bar = 100 kPa)

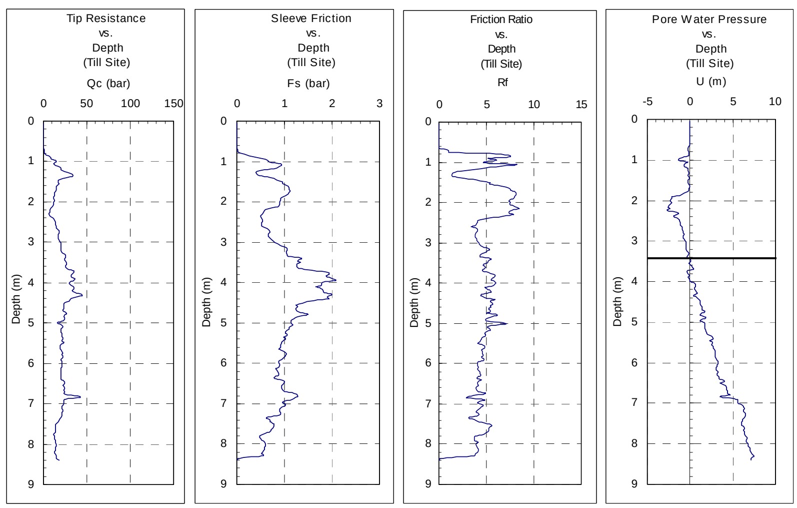

Figure 5b – CPT Profile at Till site (1 bar = 100 kPa)

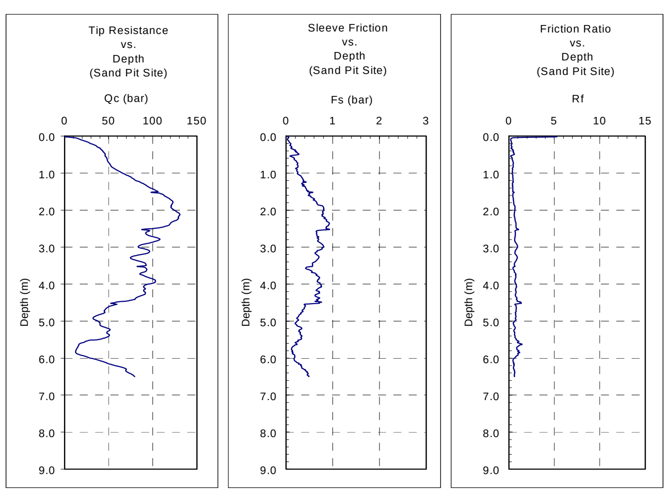

Figure 5c – CPT Profile at Sand Pit site (1 bar = 100 kPa)

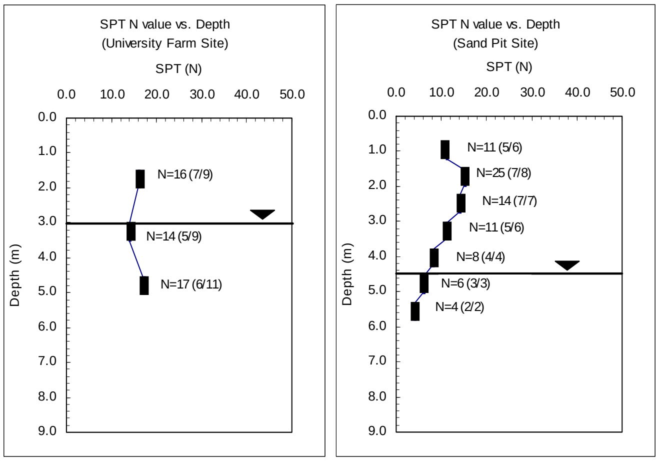

Figure 6 – SPT Result at University Farm Site and Sand Pit Site

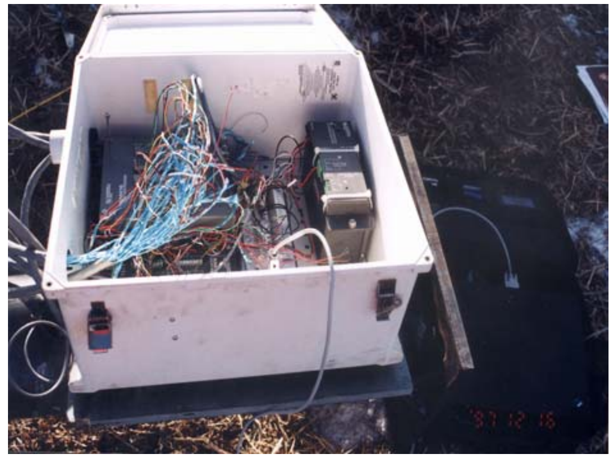

Figure 8. Data Acquisition System

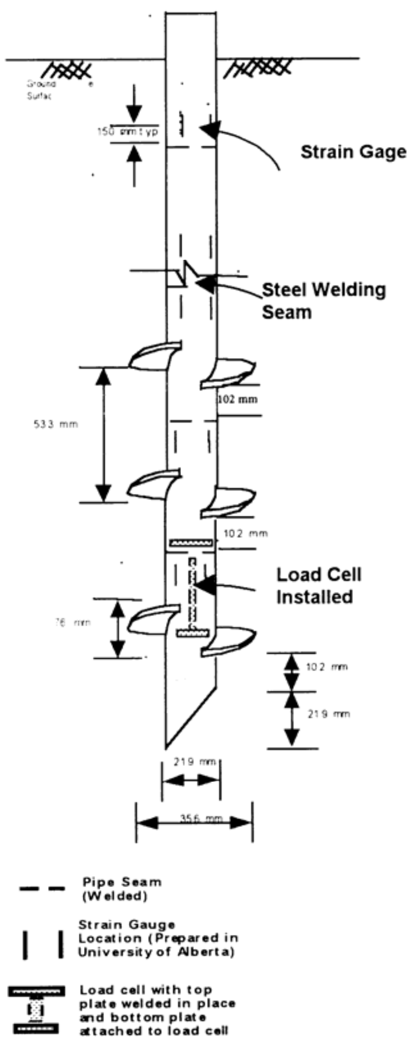

Figure 7. Research Screw Pile Used in Program (Not to Scale)

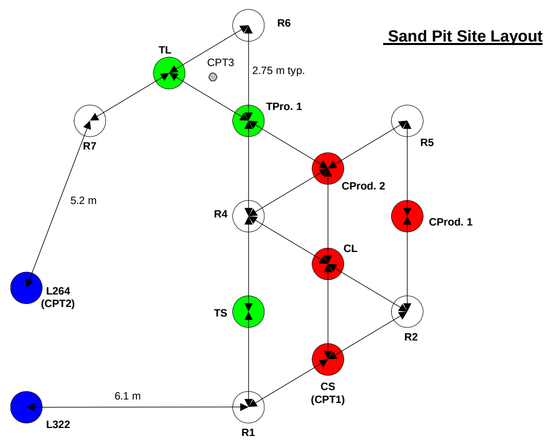

Figure 9. Typical Site Layout

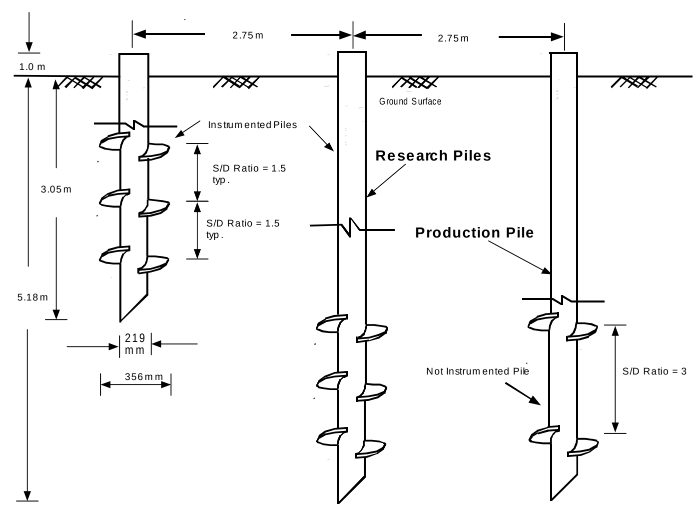

Figure 10. Site Profile for Compression and Tension Tests

Table 1 – Test Pile Properties

Test	Total No. of Test	Length L (m)	Shaft Dia. d (mm)	Helices Dia. D (mm)	No. of Helices	Wall Thick. t (mm)	Helix Spacing, S (mm)	H/D Ratio	S/D Ratio
Compression Long (CL)	3	5.18	219	356	3	6.71	533	10.7	1.5
Compression Short (CS)	2	3.05	219	356	3	6.71	533	4.69	1.5
Compression Production (CProd.)	3	5.18	219	356	2	6.71	1067	10.7	3.0
Tension Long (TL)	2	5.18	219	356	3	6.71	533	10.7	1.5
Tension Short (TS)	2	3.05	219	356	3	6.71	533	4.69	1.5
Tension Production (Tprod.)	2	5.18	219	356	2	6.71	1067	10.7	3.0
Lateral (L264)	2	5.18	219	356	3	6.71	533	10.7	1.5
Lateral (L322)	2	5.18	219	356	3	8.18	533	10.7	1.5

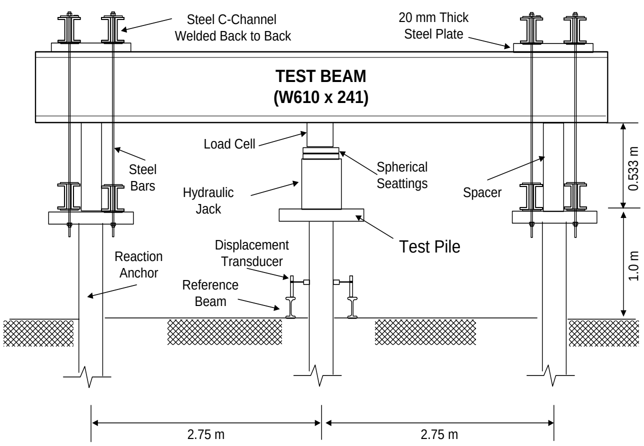

Figure 11. Axial Compression Test Setup

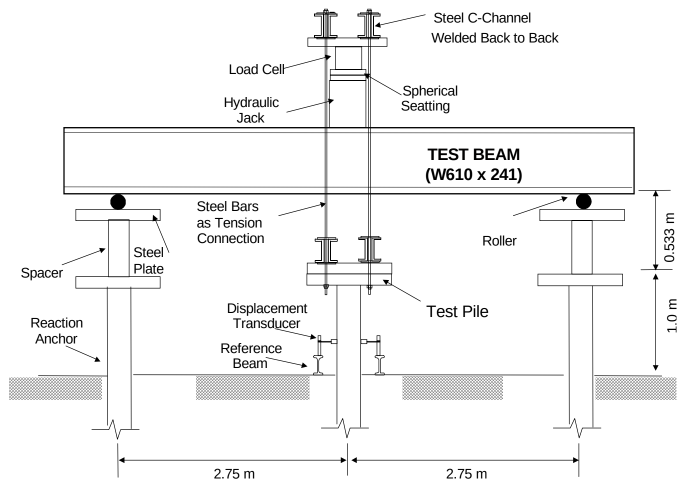

Figure 12. Axial Tension Test Setup

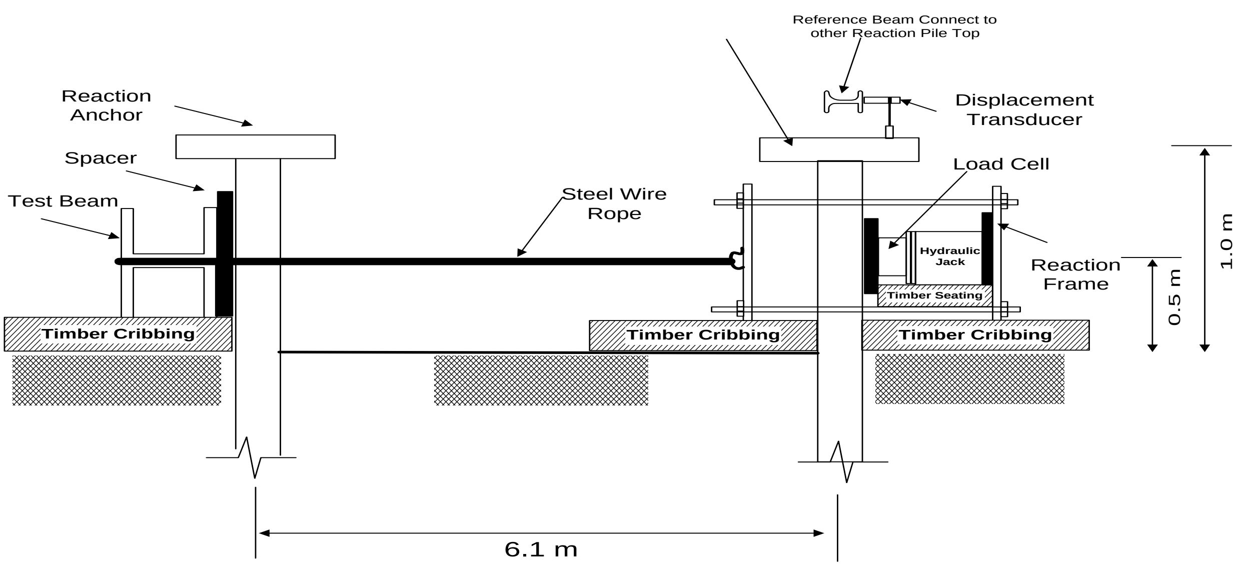

Figure 13. Lateral Test Setup

data between readings. Each loading increment was held until the rate of deflection was less than 0.25 mm per hour. Load increments were added until “failure” defined as continuous jacking was required to maintain the test load. This maximum load is held for 5 min and then removed. A similar procedure was followed for the “rebound” or the unloading portion of the test. The load was removed in increments of at least 2.5 min time intervals (Crowther, 1988).

8.2. Axial Tension Test

A similar setup as the axial compression test was used for the tension tests. The hydraulic jack and the load cell were placed on top of the test beam. High strength steel bars bolted to the reaction frame were used to tie the loading system with the test piles. The load tests were conducted following a quick load test as described in ASTM D 3689-90. Loading procedure was the same as the axial compression tests. Figure 12 shows a general setup for the axial tension test.

8.3. Lateral Load Test

Figure 13 shows a schematic of the lateral pile load test arrangement. The lateral load was delivered by pulling the test pile using a hydraulic jack connected to a reaction system with a tension member, such as steel wire rope. The tension member was then connected to an adequate anchorage system. The tension member was securely fastened so that the applied lateral load passed through the vertical central axis of the test pile. An electronic load cell was used to record the applied lateral load. The pile head deflection was measured by one displacement potentiometer and one dial gage attached to a 300 mm H-section reference beam. The load tests were conducted using the quick load test procedure as described in ASTM D 3966-81. Loading procedure was the same as the axial compression tests. Lateral load was applied in increments of approximately 20 kN. Each increment was maintained for period of 5 to 10 min.

9. CONCLUSION

This paper documents the first part of a field testing program conducted by the University of Alberta on two sites with soil typically found throughout Alberta. The second part of paper presents the test results and.

A total of 18 full scale pile load tests, including compression, tension and lateral tests, were performed using multi-helix screw anchor piles. The site investigation on the University Farm site (lacustrine clay) and Sand Pit site (sand dune) using Cone Penetration test (CPT) and standard Penetration test (SPT) are presented. In addition, the pile instrumentation, test site layout and testing procedure are briefly discussed.

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