Osterberg Cell Pile Load Test in Calgary, Alberta – A Case Study

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ABSTRACT
The local geology of the northwest area of Calgary within the outer Bow River Valley generally includes the presence of lacustrine soils overlying glacial till. The consistency of the lacustrine soil in this area is frequently soft to firm and is accompanied by shallow groundwater at some locations. The thickness of the lacustrine soils varies in this area and poses foundation challenges, particularly where high structural loads are anticipated. Accurate estimates of foundation design parameters in these soils can have significant impact on the construction cost and performance of foundations. With these considerations, a pile load test on a bored cast-in-place belled pile, drilled through the lacustrine soils and based in glacial till was conducted, utilizing an Osterberg Cell (O-Cell) method. The test was conducted for Trades and Technology Complex development of Southern Alberta Institute of Technology, located in northwest Calgary, Alberta. This paper presents a case history of the pile load test and discussion of the findings of the pile load test.

1 INTRODUCTION
Pile load tests are generally conducted to better estimate the pile design parameters, optimize the project cost, or to be able to use higher resistance factors in the limit states design methodology. The Canadian Foundation Engineering Manual allows the use of a higher resistance factor when design parameters are estimated using load test results.

With an Osterberg cell (O-Cell), pile load test on deep piles can be conducted economically, compared to the conventional testing method. The conventional method generally requires the use of reaction piles, which are not needed when using an O-Cell method. Given that the O-Cell utilizes reaction from shaft friction above the O-Cell and from end bearing and shaft resistances below the O-Cell, testing a shorter pile using O-Cell might not provide all the desired design parameters.

This paper presents a case study of a pile load test that was conducted using an O-Cell at Southern Alberta Institute of Technology (SAIT) in Calgary, Alberta. Pile design parameters estimated from the load test have also been compared with those estimated from analytical or empirical methods.

2 BACKGROUND
This load test was conducted during the foundation design of the Trades and Technology Complex within SAIT campus in northwest Calgary, Alberta (Figure 1). The entire project involved construction of three new building structures with partial to full basements. Columns with factored loads of up to 13,200 kN were to be supported on pile foundations. In total, the project involved installation of more than 400 bored cast-in-place concrete piles. Considering the number of piles and their design loads, one pile load test was conducted to obtain a more accurate estimate of pile design parameters as well as to be able to utilize a higher resistance factor for pile design.
3 GEOLOGY AND SUBSURFACE CONDITIONS

Surficial geology (Moran) indicates the presence of lacustrine offshore sediment consisting of silt in the project area. The lacustrine deposits at the site are anticipated to be generally consisting of clay, silt, and sand formed in preglacial lakes, with beds of glacial till overlying bedrock.

Subsurface conditions across the project site were fairly uniform excepting the thicknesses of the fill soil. Subsurface conditions were interpreted from a total of eight boreholes, drilled (augered or cored where practical) at the project site to depths varying from 22.6 m to 41.2 m below grade. In general, lacustrine soil consisting of interbedded layers of silt, sand, and clay, of thickness varying from 16.3 m to 20.6 m, were found overlying glacial till, which was underlain by bedrock. The glacial clay till was encountered at depths varying 16.8 m to 21.3 m below grade. Bedrock consisting of clay shale or siltstone was encountered at depths varying from 30.8 m to 34.7 m below grade. The surface elevations of the boreholes varied by 1.9 m across the site.

The lacustrine soil had varied consistency with Standard Penetration Test (SPT) blow counts in the range of 4 to 27. The clay till below the lacustrine soil was hard with SPT blow counts generally greater than 30.

The subsurface conditions near the testpile location are summarized in Figure 2. Core samples of clay till were obtained from the borehole drilled near the test pile, for conducting Unconfined Compressive Strength (UCS) tests. UCS of approximately 500 kPa and 800 kPa were measured on core samples of clay till recovered from depths of 23.8 m and 21.5 m, respectively.

Figure 2. Subsurface Conditions near Test Pile Location
The groundwater level was recorded at a depth of 7.5 m below grade in a three-month monitoring period following the drilling program, near the test pile location.

4 TESTPILE CONSTRUCTION AND INSTRUMENTATION DETAILS

The testpile was founded in clay till at a depth of 22.0 m below the existing ground surface. Due to sloughing of the lacustrine soils, two casings were utilized to construct the testpile. The upper casing was 1,270 mm in diameter and extended to a depth of 10.2 m. The lower casing was 1,070 mm in diameter and extended from the bottom of the upper casing to a depth of 20.0 m (i.e., 2.0 m above the base of the pile). A 1,600 mm diameter bell was constructed at the base of the pile using a conventional belling tool. The geometry of the testpile is presented in Figure 2.

A 3.9 MN O-Cell, attached to a steel frame, was installed at a depth of 20.9 m in the testpile at the top of the pile bell. The load cell had three Linear Vibrating Wire Displacement Transducers (LVWDTs – Geokon Model 4450 series) between the upper and the lower plates of the O-Cell to measure vertical movements during loading. Two diametrically opposed sister bar strain gages (Geokon 4911 Series) were installed at four different elevations above the O-Cell (shown in Figure 2), to assess the side shear resistance of the pile. Two telltale casings (12.5 mm diameter) were attached to the carrying frame, extending from the top of the O-Cell assembly to beyond the top of the pile. Two steel pipes extending from the bottom of the o-cell to the top of the pile were installed to vent the break in the pile formed by the expansion of the O-Cell. Two automated digital survey levels (Leica NA 3000 Series) were utilized to monitor the pile top movements from a distance of approximately 8.0 m.

5 DATA ACQUISITION AND TESTING PROCEDURE

All instrumentation was connected through a data logger (Data Electronics – DT615 Series Geologger) to a laptop computer. The data logger recorded instrument readings every 30 seconds during the test.

The test was initiated by pressurizing the O-Cell to break the tack welds that hold the upper and the lower plates of the O-Cell and to form a fracture plane in the concrete surrounding the O-Cell. After the break occurred, the pressure was released and instrumentation readings were set to zero.

The pile was then loaded using the O-Cell in a total of 22 equal loading increments up to a load of 4.25 MN, holding each load for 8 minutes. Further loading could not be conducted as the O-Cell reached its maximum stroke. Load increments were generally applied as per American Society for Testing Materials (ASTM) D1143’s “Quick Load Test Method for Individual Piles”.

6 RESULTS AND ANALYSES

For the purpose of calculating unit net side friction, only net load (i.e., gross load minus the buoyant pile load) applied by the O-Cell was considered. At the maximum load of 4.25 MN applied by the O-Cell, the upward and the downward movements of the plates of the O-Cell were 14 mm and 120 mm, respectively. The side friction was assessed using the strain gage data and the estimated pile stiffnesses. Considering the pile diameters, utilized steel frame, and the concrete strength, the pile stiffnesses were estimated to be 35,800 MN and 25,400 MN in 1.270 mm and 1.070 mm diameter zones, respectively, and were assumed to be constant for the calculations. At the time of the pile load test, the concrete was estimated to have a compressive strength of 34.6 MPa and its modulus was estimated using the American Concrete Institute (ACI) method.

The calculated values of the ultimate side friction, assuming constant stiffness and pile diameters, at the maximum load of the O-Cell, are summarized in Table 1.

<table>
<thead>
<tr>
<th>Elevation</th>
<th>Ultimate Shaft Friction (kPa)</th>
<th>Typical Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-Cell to Strain Gage Level 1</td>
<td>123</td>
<td>Hard clay till/lacustrine clay</td>
</tr>
<tr>
<td>Strain Gage Level 1 to</td>
<td>39</td>
<td>Lacustrine silt</td>
</tr>
<tr>
<td>Strain Gage Level 2 to</td>
<td>19</td>
<td>Lacustrine clay</td>
</tr>
<tr>
<td>Strain Gage Level 3 to</td>
<td>51</td>
<td>Lacustrine sand</td>
</tr>
<tr>
<td>Strain Gage Level 4 to Top of the Pile</td>
<td>28</td>
<td>Lacustrine silt/clay</td>
</tr>
</tbody>
</table>

The mobilized base resistance at the maximum O-Cell load of 4.25 MN was calculated to be 2,113 kPa assuming the transfer of the entire load to the pile base. Figure 3 shows the plot of calculated base resistance and measured movement of the pile base.

Figure 3. Mobilized Base Resistance vs. Base Settlement
For the design of the production piles, elastic modulus values for estimation of pile base settlement can be estimated from the plot of Figure 3. The elastic settlement at the pile base can be estimated from the expression:

\[ S = qB(I - v^2)/E \]  

Where,
- \( S \) = Settlement
- \( B \) = Diameter of the pile base
- \( I \) = Dimensionless shape and rigidity factor
- \( v \) = Poisson's ratio
- \( E \) = Modulus of Elasticity

Assuming \( v = 0.3 \) and \( I = 0.79 \) (for rigid circular loaded area), the above expression can be simplified to:

\[ S = 0.72qB/E \]

The values of \( E \) at different base resistances can be back calculated using the above expression and the data presented in Figure 3. For example, the values of \( E \) were estimated to be 124.9 MPa, 76.7 MPa, and 65.9 MPa at respective base settlements of 10 mm, 20 mm, and 25 mm for the test pile.

7 CREEP CONSIDERATION

The pile base, when subjected to a constant stress, is anticipated to exhibit some creep movements. In general, the creep behaviour is anticipated to increase at higher stress level. Pile design should ensure that the stress at the pile base does not exhibit undesirable or excessive creep movement. For this purpose, a 'creep limit' value was determined, which generally indicates a stress level beyond which creep movement might be excessive to tolerate. Creep limit for base resistance was determined using a method similar to that of ASTM D4719. Plots of creep movements at different loading steps are presented on Figure 4. The 'creep limit' for the base resistance was determined to be 2.51 MN. Considering the base area of the pile, the base resistance of 2.51 MN at the 'creep limit' corresponds to a base pressure of 1,248 kPa.

8 DISCUSSION

Relatively higher shaft resistance was observed in lacustrine silt and sand compared to clay with similar SPT blow counts.

Ultimate base resistance of the pile was in general agreement with the result of UCS, conducted on a sample recovered from a depth near the base of the pile. The theoretical ultimate base resistance for piles can be estimated as \( 9S_u \) (Bowels, 5th Edition), yielding a value of 2,250 kPa by using laboratory measured \( S_u \) of 250 kPa.

Relatively more displacement is required to mobilize base resistance than to mobilize shaft resistance. This is evidenced by the fact that the upward and the downward movements of the plates of the O-Cell were 14 mm and 120 mm, respectively at the maximum O-Cell load of 4.25 MN.

The calculated parameters are based on an assumption of a constant shaft area of the pile in longitudinal direction, which might not be true for the actual pile. Accordingly, the calculated parameters should be utilized with care. For accurate measurement of shaft area, advance method such as sonic or sonar caliper method may be used to determine the variations of pile shaft diameter in longitudinal direction.

Calculation of base resistance is based on the assumption that the entire load below the O-Cell is transferred to the pile base without any dissipation to the sidewall of the bell.

The value of \( E \) was found to vary with the level of loading or stress. Appropriate value of \( E \) should be used to estimate the settlement of the pile base for the anticipated pile load at its base.

Pile design should ensure that the stress at the base of the pile due to service load does not exceed the base pressure obtained from the 'creep limit' value.

9 ACKNOWLEDGEMENTS

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10 REFERENCES

