CASE STUDY: LOAD TRANSFER ANALYSIS ON AN INSTRUMENTED AUGERCAST PILE USING EDC STRAIN GAUGES AND GEOKON REBAR STRAINMETERS

Swamy Avasarala¹, Santosh Mummaneni², Vamshi Vemula³, Dr. Sastry Putcha⁴

¹ President, Aver Technologies, Inc., Virginia USA, +1-703-580-8907, swamy@avertechnologies.com
² Project Manager, Aver Technologies, Inc., Virginia USA, +1-703-580-8907, santosh@avertechnologies.com
³ Project Engineer, Radise International, Florida, USA, +1-561-841-0103, vamshi.vemula@radise.net
⁴ Chief Engineer, Smart Structures, Florida, USA, +1-561 841-0103, sputcha@smartstructures.com

ABSTRACT

This paper presents the results from a case study on the comparison of two strain acquisition instrumentation technologies, Geokon rebar strainmeters and Embedded Data Collectors (EDC) for the DC Water Main Pump Station project, in Washington D.C. These two instrumentation systems were installed by AVER in a single 18-inch (0.45 m) diameter augercast pile (with one-1.25 inch (3.175 cm) dywidag bar) at critical locations to determine the load transfer mechanism and establish a comparison between strain/load measured with these two systems along the pile. A quick static load test was performed on the test pile as per ASTM D1143 standard.

Prior to the installation of the pile, a 24-inch (0.6 m) diameter outer casing was installed to the proposed cutoff elevation of -22.5 feet (-6.85 m) to discount the frictional resistance within the upper overburden zone. The pile was then drilled through the outer casing to the tip elevation of -65.02 feet (-19.8 m) with inner casing within the overburden zone. Strainmeters along with EDC were installed on dywidag bar at various locations and then wet set into the concrete following auger retrieval. The loads measured with EDC and Geokon sensors were within 15% percent of each other.

Keywords: rebar strain meters, EDC strain gauges, augercast pile, loads, load tests

PROJECT BACKGROUND

Project Background & Requirements:

Like any other foundation piles, augercast piles are extensively used in the public and private sector structures in the United States for many years. It is a common practice to perform static compression (ASTM D1143), tension (ASTM D3689), and lateral load tests (ASTM D3966) depending on the project requirements. In recent years, embedded strain sensors, manufactured by Smart Structures, USA has gained prominence for its use to collect both static and dynamic measurements for driven piles. In addition, AVER has successfully used EDC for collecting long term static measurements for an abutment drilled shafts for I-95 Hotlanes project in Virginia, USA.

Geokon sisterbar strain gages are widely used in the foundation industry to monitor the load transfer mechanism within pile foundations throughout the world. As the Geokon strainmeters are vibrating wire and are welded to a sister bar, there is often a debate within the engineering community with regards to what modulus to use when converting measured strains to loads. EDC sensors, unlike Geokon strain gages are embedded directly into the concrete and therefore do not have the same concern.
For the first time, the EDC strain gages were used in augercast pile foundation at the DC Clean Rivers Project in Washington DC, USA. The project consisted of new Combined Sewer Outflows (C.S.O’s), surge tanks, and connecting channels supported by over 150 augercast piles. Each pile was 18 inches (0.45 m) in diameter with one 1.25 inches (31.75 mm) dywidag bar and lengths ranging between 70 to 80 feet (21.3 to 24.3 meters). The axial compression loads ranged from 440 to 480 kips (1957 to 2135 KN). The project specifications required axial compression and tension load tests for the proposed piles. This paper presents only the results from axial compression load test and load transfer measured along the pile with Geokon and EDC strain sensors.

**Augercast Test Pile Information:**

- Pile Length = 77.6 feet (23.67 m) long
- Pile Reinforcement = 1.25-inch (3.17 cm) diameter dywidag bar, Grade 150 ksi (1034 MPa)
- Achieved Grout Strength \( (f_{cp}) = 4720 \text{ psi (32.54 N/mm}^2) \)
- Elastic Modulus of Concrete \( (E_c=5700*\sqrt{(fc')}) = 3916 \text{ ksi (27000 MPa) \)
- Required Test Load = 240 Tons (2135 kN)
- Ground Elevation at the time of test = +10.58 feet (3.22 m)
- Proposed test pile cutoff Elevation = -22.5 feet (-6.85 m)
- Plan Tip Elevation = -65.02 feet (-19.8 m)

**Soil Profile Information:**

The soil profile at this project site location was summarized in the Table 1 below.

<table>
<thead>
<tr>
<th>Elevation (feet)</th>
<th>Elevation (meter)</th>
<th>Soil Classification (USCS)</th>
<th>SPT “N” Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.43 to -0.5</td>
<td>3.7 to -0.15</td>
<td>SM</td>
<td>7</td>
</tr>
<tr>
<td>-0.5 to -12.5</td>
<td>-0.15 to -3.81</td>
<td>CL</td>
<td>9</td>
</tr>
<tr>
<td>-12.5 to -18</td>
<td>-3.81 to -5.48</td>
<td>MH</td>
<td>8</td>
</tr>
<tr>
<td>-18 to -25</td>
<td>-5.48 to -7.62</td>
<td>CL</td>
<td>5</td>
</tr>
<tr>
<td>-25 to -29</td>
<td>-7.62 to -8.84</td>
<td>MH</td>
<td>5</td>
</tr>
<tr>
<td>-29 to -41</td>
<td>-8.84 to -12.49</td>
<td>SP-SM</td>
<td>33</td>
</tr>
<tr>
<td>-41 to -45</td>
<td>-12.49 to -13.72</td>
<td>SM</td>
<td>66</td>
</tr>
<tr>
<td>-45 to -56</td>
<td>-13.72 to -17.07</td>
<td>SC</td>
<td>60</td>
</tr>
<tr>
<td>-56 to -60</td>
<td>-17.07 to -18.29</td>
<td>ML</td>
<td>68</td>
</tr>
<tr>
<td>-60 to -67.5</td>
<td>-18.29 to -20.54</td>
<td>SC</td>
<td>50/3”</td>
</tr>
</tbody>
</table>

**INSTRUMENTATION AND TEST PROCEDURE:**

**Background Information of Geokon and EDC sensors:**

The test pile was instrumented with Geokon rebar strainmeters model 4911A at 7 locations and with 2 sets of EDC sister-strain gauges (each set has two strain gauges connected with a 12-feet (3.66 m) wire) at critical load transfer locations.
Geokon Rebar Strainmeters Model 4911 has a vibrating wire strain gauge and a thermistor attached to a No. 4 sister bar to record strains and temperature readings at the installed sensor location.

![Illustration of Model 4911 A rebar strainmeter](image1)

Figure 1: Illustration of Model 4911 A rebar strainmeter

Embedded Data Collectors are heat and corrosion resistant half bridge strain sensors with temperature and signal processing unit that can be utilized to measure strains under static and dynamic load conditions.

![EDC-Wireless monitoring system in action during baseline readings at DC water project.](image2)

Figure 2: EDC-Wireless monitoring system in action during baseline readings at DC water project.

**Instrumentation Plan and Installation**

For the feasibility of performing static load test and construction sequence considerations, the project contractor chose to install the proposed foundation from the existing ground elevation instead of from the proposed cutoff elevation. To properly simulate the actual pile behavior under the static loads, prior to the installation of the pile, a 24-inch (0.61 m) diameter outer casing was first installed to the proposed cutoff elevation of -22.5 feet (-6.85 m) to prevent frictional resistance within the upper overburden zone. The pile was then drilled through the outer casing to the pile tip elevation of -65.02 feet (-19.8 m) by setting an inner casing within the overburden zone.

Since there was no frictional resistance within the cased overburden zone (between elevation +10.58 feet (+3.22 m) to the cutoff elevation of -22.5 feet (-6.85 m)), Geokon rebar strainmeters G1 and G2 were installed at elevation +7.3 feet (+2.22 m) and pile cutoff elevation of -22.5 feet (-6.85 m), respectively, to measure strain readings that would represent the applied loads. The remaining six Geokon rebar strainmeters were installed between the pile cutoff and pile tip elevation at the locations indicated in Table 2.
Table 2: Geokon Rebar Strainmeter locations

<table>
<thead>
<tr>
<th>Geokon Sensor Number</th>
<th>Rebar Strainmeter Depth (From Ground EL.) feet (meter)</th>
<th>Approx. EL. at Strainmeter Location feet (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>3.25 (0.99)</td>
<td>7.33 (2.23)</td>
</tr>
<tr>
<td>G2</td>
<td>31.25 (9.52)</td>
<td>-20.67 (-6.30)</td>
</tr>
<tr>
<td>G3</td>
<td>38.25 (11.65)</td>
<td>-27.67 (-8.43)</td>
</tr>
<tr>
<td>G4</td>
<td>45.25 (13.79)</td>
<td>-34.67 (-10.56)</td>
</tr>
<tr>
<td>G5</td>
<td>52.25 (15.92)</td>
<td>-41.67 (-12.70)</td>
</tr>
<tr>
<td>G6</td>
<td>59.25 (18.05)</td>
<td>-48.67 (-14.83)</td>
</tr>
<tr>
<td>G7</td>
<td>66.25 (20.12)</td>
<td>-55.67 (-16.96)</td>
</tr>
</tbody>
</table>

In addition, two sets of EDC strain gauges were also installed on to the dywidag bar to measure strain readings at critical load transfer locations as indicated in Table 3. Each EDC strain gauge set has two strain gauges connected with 12 feet (3.6 m) wire in between the gauges.

**Table 3: EDC strain gauge locations**

<table>
<thead>
<tr>
<th>EDC Sensor Number</th>
<th>EDC strain gauge Depth from Ground Elevation feet (meter)</th>
<th>Approximate Elevation at EDC strain gauge location feet (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>65.78 (20.05)</td>
<td>-55.2 (-16.82)</td>
</tr>
<tr>
<td>S2</td>
<td>52.78 (16.08)</td>
<td>-42.2 (-12.86)</td>
</tr>
<tr>
<td>S3</td>
<td>49.08 (14.95)</td>
<td>-38.5 (-11.7)</td>
</tr>
<tr>
<td>S4</td>
<td>35.08 (10.69)</td>
<td>-24.5 (-7.47)</td>
</tr>
</tbody>
</table>

The Geokon strainmeter sisterbars along with EDC sensors with cables were fastened to dywidag bar with zip ties. The EDC sensors were installed by suspending each sensor (with clear space) with metal straps.
protruding from wire cage that was wrapped around the dywidag bar to provide sturdiness and prevent the sensor from collapsing onto the bar during placement into the concrete.

![Geokon rebar strainmeters and EDC strain gauges attached to dywidag bar.](image1)

**Figure 3:** Geokon rebar strainmeters and EDC strain gauges attached to dywidag bar.

In addition, to save the instrumentation below the pile cutoff elevation for long term monitoring during service loads, excess wiring was planned for each sensor and was pushed inside a 2-inch (5 cm) diameter and 10 feet (3 m) long PVC pipe. The PVC pipe was strapped to the dywidag bar with zip ties just above the proposed cutoff Elevation of -22.5 feet (-6.85 m). The PVC pipe was sealed at both ends to prevent grout flow through the pipe so that the wires from strainmeters (G2 through G7 and S1 to S4) can be spliced and used for long term monitoring purposes at a later date.

![Sealed PVC tube attached to dywidag bar (with extra EDC & Geokon cables inserted for long term monitoring).](image2)

**Figure 4:** Sealed PVC tube attached to dywidag bar (with extra EDC & Geokon cables inserted for long term monitoring)

**Augercast Test Pile Installation:**

Prior to the installation of the augercast pile, a 24-inch (0.6 m) outer casing was installed to the proposed cutoff elevation of -22.5 feet (-6.85 m) to discount the frictional resistance within the upper overburden zone. The pile was then drilled through the outer casing to the tip elevation of -65.02 feet (-19.8 m) with the inner casing within the overburden zone.

The pile hole inside the inner casing was grouted with concrete as the auger was retrieved. The dywidag bar with instruments and centralizer bars was then lowered into the wet concrete. Subsequently, a one inch (2.54 cm) telltale steel tube was also wet set into the concrete. Upon installation of dywidag bar into the grout, baseline readings were taken from both Geokon strainmeters and EDC strain gauges to confirm that all the sensors were functioning. A 0.5 inch (1.25 cm) telltale rod was used to measure the pile tip displacement.
Quick Static Axial Compression Load Test Procedure:

Axial compression static load test setup was carried out by general contractor, in accordance with project submittals and ASTM D1143 standard. A total of four, 18-inch (0.45 m) reaction augercast piles were installed as part of the load test setup. The following is a general description of the test procedure and results obtained.

- The test pile was instrumented with Geokon strainmeters (G1 through G7), EDC strain gauges (S1 through S4), two dial gauges (Pile Top), two piano wires and one telltale rod for measurement of strain and pile displacement during the load applications.
- During the loading cycle, the test load was applied through a 500-ton load cell in increments of approximately 10% of the maximum test load of 480 kips (2135 kN).
- Each load application during the loading cycle was held for 5-minute period and corresponding strain measurements, dial gauge readings, tell-tale readings, piano wire readings and survey levels of all 4 reaction piles (R1, R2, R3 and R4) were recorded.

During the 7th load increment, at an applied load of 150 tons (1334 kN), the supporting beams (R2 and R3) slightly swayed out of alignment and therefore the load test was aborted and the load was released.

- Two additional cross beams were welded to the transfer beams to provide additional support.
- The static load test was restarted and loads were again applied initially in increments of 20% until 300 kips (1335 kN) and followed by 10% standard increments to the maximum test load of 480 kips (2135 kN).
- The maximum test load of 480 kips (2135 kN) was retained for one hour and all the measurements were taken.
- During the unloading cycle, loads were reduced in decrements of approximately 25% of the maximum test load of 480 kips (2135 kN).
- Each load application during the unloading cycle was held for 5-min period and corresponding measurements were recorded.
Axial Compression Static Load Test Data Analysis & Results:

The following is a summary of our test results from axial compression load test on the augercast test pile:

- The raw Geokon field recorded readings were converted from micro seconds to micro strains and corresponding loads ($\varepsilon \times A \times E$) at each strainmeter location were obtained by multiplying the strain with pile cross sectional area and the elastic modulus of concrete.
- Baseline Geokon and EDC Readings were recorded prior to the test to determine relative strain increase due to loading during the test.
- The elastic modulus of concrete was determined based on the empirical relationship of 57000 times the square root of the compressive strength (ACI 318-08, 2008) (4720 psi or 32.54 MPa).
- The loads measured at G1, G2 and S4 (at the cutoff elevation of -22.5 feet (-6.85 m)) locations should be similar as soil friction within the overburden (casing zone) was zero.
- The loads measured by EDC strain gauges and Geokon rebar strainmeters at corresponding sensor locations were observed, in general, to be within 15%, with EDC load measurements slightly on the higher side.

Figure 7a: Geokon Loads vs. EDC loads at cut off EL.  
Figure 7b: Geokon loads @-34.67’ vs. EDC loads@ -38.5’
The average unit skin friction was computed between two consecutive levels of strainmeters by subtracting the load transfer computed from corresponding strain gages and a summary was presented in Table 4.

Table 4: Unit Skin Friction (ksf) calculated from loads measured by Geokon and EDC sensors

<table>
<thead>
<tr>
<th>Actual Applied Load (480 kips/2135 kN)</th>
<th>Unit Skin Friction from Geokon and EDC Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geokon</td>
</tr>
<tr>
<td></td>
<td>Midpoint Between Sensor Elevations feet (meter)</td>
</tr>
<tr>
<td>Overburden</td>
<td>~0.0 (0.0)</td>
</tr>
<tr>
<td>-24.17 (-7.37)</td>
<td>1.99 (95.2)</td>
</tr>
<tr>
<td>-31.17 (-9.48)</td>
<td>1.88 (90.01)</td>
</tr>
<tr>
<td>-38.17 (-11.63)</td>
<td>1.05 (48.35)</td>
</tr>
<tr>
<td>-45.17 (-13.76)</td>
<td>1.79 (85.7)</td>
</tr>
<tr>
<td>-52.17 (-15.90)</td>
<td>2.02 (96.72)</td>
</tr>
</tbody>
</table>

- Geokon sensors predicted slightly lower skin friction values than EDC sensors at several sensor locations as identified in Table 4.
At 480 kips (2135 kN) load increment, the unit skin friction measured from Geokon and EDC sensors were 2.02 ksf (96.7 kPa) and 1.79 ksf (85.7 kPa), respectively. The load measured at S1 and G7 sensor locations include the combination of end bearing and skin friction between these sensor locations and pile tip.

Therefore, the skin friction from these sensor locations was projected to the pile tip elevation by assuming the same unit friction.

The net load transfer/end bearing to the pile bottom based on Geokon strainmeter readings was 90 kips (400 kN) (185.5 kips in load at G7 – (3.14 * 1.5 feet *2.02 ksf *10 feet) = 90 kips).

The end bearing calculated based on unit skin friction of 1.79 ksf from EDC strain gauges was 88 kips (391 kN) (172.2 kips – (3.14*1.5 feet*1.79 ksf*10) = 88 kips).

Therefore, the end bearing values predicted based on unit skin friction from EDC/Geokon strainmeters matched well.

The load displacement for pile top (dial gauge) and bottom (telltales reading) along with Davisson failure line were plotted below in Figure 7.

![Load vs. Displacement graph](image)

**Figure 7: Load Displacement graph along with Davison Failure line for the load test.**

- For the applied maximum load of 480 kips (2135 kN), the total movement of the pile was 0.645 inches (16.3 mm), with net permanent pile displacement of 0.23 inches (5.8 mm).
- The telltale reading for the pile bottom showed approximately 0.15 inches (3.81 mm) at the end of the test which was comparable to final pile set of 0.23 inches (5.8 mm).
- Davisson (1972) failure displacement for a maximum load of 480 kips (2135 kN) was 0.65 inches (16.51 mm) which was slightly higher than 0.645 inches (16.38 mm) measured at this load. The fact that the load was transferred to the bottom segment of the augercast pile clearly
demonstrates that the skin friction on the upper segments of the pile was completely mobilized during the test.

CONCLUSIONS

Based on axial compression load test results and strain measurements from Geokon and EDC gauges, the following were our conclusions:

- The loads calculated from strains measured with EDC and Geokon sensors at each location and the estimated concrete elastic modulus from empirical formula of $E_c = 57000 \sqrt{(f'c)}$ (ACI 318-08, 2008) yielded consistent results.
- As expected, load measurements from Geokon rebar strainmeters (G1 and G2) and EDC strain gauge (S4) measurements at cut off elevation of EL. -22.5 feet (-6.85 m) matched well with applied jack load (within casing no loss of load was anticipated from skin friction).
- Loads measured by Geokon and EDC gauges at approximately similar sensor elevations matched well in general, with variations between 5 to 15 percent. The measured load difference between EDC and Geokon sensors reduced to 5 percent as the load increments increased to 480 kips (2135 kN) (highest load application).
- The estimated end bearing capacity by projecting the unit friction computed from EDC (S1) and Geokon (G7) sensors matched well and were within 5 percent (90 kips (400kN) from Geokon vs. 88 kips (391kN) from EDC gauges).
- It was found that EDC sensors had an advantage over traditional vibrating wire rebar strainmeters for their ability to measure both static and dynamic strains and their ease of use in wireless data collection.
- The difference in transferred loads measured using both the systems (Geokon and EDC sensors) can possibly be attributed to slight variation in their corresponding locations and concrete modulus from empirical formula used for converting the strains measured from EDC sensors embedded in concrete as well as Geokon strainmeters welded to rebar.
- The use of EDC sensors supplants the static load test as these sensors can also be embedded in production piles and their capacity can be ascertained utilizing dynamic testing methods and further determine the applicability of static load test results across the project site at a small cost.
- Overall, static strain measurements using EDC strain gauges were in-line with traditionally used Geokon strainmeters and therefore, can be a viable alternative for future projects.
REFERENCES


American Concrete Institute (A.C.I) Committee (2008), Structural Building Code: American Concrete Institute (A.C.I 318-08), Code Section 8.5.1 Modulus of Elasticity, PP107.
