Education and Outreach

EIT Workshop

Construction and Field Evaluation of an Electrically Isolated Tendon System in the Coplay Bridge - Long-Term Monitoring

October 24, 2018
Lehigh University, Bethlehem, PA

By Clay Naito
Workshop Schedule

- 820-840 Introductions and Overview
- 840-900 EIT Overview by Reggie Holt – FHWA
- 900-920 Fabricator Experience by Troy Jenkins – Northeast Prestressed Products
- 920-940 Coplay Bridge Project Overview by Larry Franko – Pennoni
- 940-1000 Break
- 1000-1030 Post Tension Supplier Experience by Shahid Islam – DSI
- 1030-1045 EIT Specification Development by Leon Fourney – TxDOT
- 1045-1110 Long-Term Monitoring by Clay Naito – Lehigh U.
- 1110-1200 Tour of ATLSS Research Center and Lunch
- 1200-230 Site Visit of Coplay Bridge
LCR Meter Availability

880 B&K Purchased on Amazon

Full-Featured Handheld LCR Meters

The E8780, E8790, and E880, 40,000-count handheld LCR meter, measure inductance, capacitance, and resistance values with precision. The E8790 and E880 also measure capacitance, inductance, and resistance. Additionally, the E880 offers capabilities, typically only found in bench LCR meters such as a terminal configuration, basic measurement accuracy up to 0.03%, test frequencies as high as 100 kHz, selectable test signal levels, and measurement rates.

Fast auto ranging and quick measurement configuration such as measurement parameter and test frequency selection make these meters very simple to operate. The meters also include handy functions such as data hold, Min/Max/ Average recording, hysteresis setting, and relative mode.

Measurement data can be transferred to a PC via the meter’s built-in USB interface, using either the provided data logging software or SCPI commands sent from a custom program.
LCR Meter Availability

880 B&K Purchased on Amazon

Post-tension / Pre-grout AC Resistance Measurement @ 1KHz
60 to 160kOhm

Post-tension / Pre-grout AC Resistance Measurement @ 1KHz
44 to 189kOhm
Post-Tensioning / Pre-Grout Measurement

• Goal Detect Major Damage to PT Duct
  – Potential for strand to gouge duct and result in metallic contact to reinforcement cage.
  – In this case Resistance < 20 Ohms

• Note Measurements in EIT on 10/22: 160, 80, 60, 120, 70 kOhm

• Measurement between Strand Extension and Steel Trumpet: 400 Ohm to 1 kOhm
Upcoming Measurements

• Post Grout – At Site Visit Today!
• 28-Day
• Tentative Plan – At Box Installation, 6 mo., 1 year
Post Grouting Measurements

- Measure AC Resistance @ 1KHz, R
  - Acceptance: \( R \times L > 50 \text{ kOhm-m} \) [164 kOhm-ft]
- Tendon Length \(~540\text{ft} [164.6\text{m}]\)
- Duct 3.75 in. [95 mm] corrugated PP

### Table 2. Threshold values for EIT, applicable 28 days after grouting (according to the Swiss guidelines [3, 4]).

<table>
<thead>
<tr>
<th>Duct Ø</th>
<th>Specific resistance ( R_f = R \cdot L )</th>
<th>Fatigue Resistance ( R )</th>
<th>Stray current (^1) Specific resistance ( R_f = R \cdot L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 mm</td>
<td>&gt;50 kOhm-m</td>
<td>&gt;20 Ω</td>
<td>&gt;250 kOhm</td>
</tr>
<tr>
<td>75 mm</td>
<td>&gt;50 kOhm-m</td>
<td>&gt;20 Ω</td>
<td>&gt;200 kOhm</td>
</tr>
<tr>
<td>100 mm</td>
<td>&gt;50 kOhm-m</td>
<td>&gt;20 Ω</td>
<td>&gt;150 kOhm</td>
</tr>
<tr>
<td>130 mm</td>
<td>&gt;50 kOhm-m</td>
<td>&gt;20 Ω</td>
<td>&gt;125 kOhm</td>
</tr>
</tbody>
</table>

**Max. tolerable failure rate**
- 10% for Monitoring
- 0% \(^3\) for Fatigue
- 20% for Stray current

\(^1\) To convert the measured resistance \( R \) to \( R_f \), \( R \) needs to be multiplied with the tendon length \( L \), where the value used for \( L \) must be at least 25 m.

\(^2\) In the case of a risk of stray current induced corrosion, in addition a National guideline issued by the Swiss Society for Corrosion Protection [11] needs to be considered.

\(^3\) At sections where the fatigue loading is critical, the acceptable failure rate is zero.

Acceptance > 50 / 164.6 = 0.30 kOhm
Post Grouting Measurements

- Measure AC Resistance @ 1KHz, R
  - Acceptance: \( R \times L > 50 \text{ kOhm-m} \ [164 \text{ kOhm-ft}] \)
- Tendon Length \( \sim 540\text{ft} \ [164.6\text{m}] \)
- Duct 3.75 in. [95 mm] corrugated PP

Acceptance > 50 / 164.6 = 0.30 kOhm
Post Grouting Measurements

- DSI Submittal!

4 Electrical Resistance Test Procedure

Electrical measurements shall be performed by a qualified electrician using a suitable LCR-meter, i.e. CMT-437 or equivalent. Measurements shall be done at both anchorages as shown in drawing PT-4.

Table 1: expected minimum values of electrical resistance based on tendon length

<table>
<thead>
<tr>
<th>Beam No.</th>
<th>Length, L (ft)</th>
<th>Length, L (m)</th>
<th>R_L (kOhm)</th>
<th>Minimum R (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>547.34</td>
<td>166.83</td>
<td>50</td>
<td>300</td>
</tr>
<tr>
<td>17</td>
<td>544.63</td>
<td>166.00</td>
<td>50</td>
<td>301</td>
</tr>
<tr>
<td>18</td>
<td>542.36</td>
<td>165.31</td>
<td>50</td>
<td>302</td>
</tr>
<tr>
<td>19</td>
<td>540.08</td>
<td>164.62</td>
<td>50</td>
<td>304</td>
</tr>
<tr>
<td>20</td>
<td>537.79</td>
<td>163.92</td>
<td>50</td>
<td>305</td>
</tr>
</tbody>
</table>

R_L is the min. value of the length normalized electrical resistance.

R = R_L/L

- Connect the positive electrical wire to the tendon through the anchorage, and the negative cable to the protruding prestressed strand.
- Measure the electrical resistance R using standard LCR-meter.
- The field Measured minimum electrical resistance R shall be as shown in table above.

Acceptance > 50 / 164.6 = 0.30 kOhm
Post Grouting Measurements

- Failure rate 10%
- IF ALL Tendons were EIT
  - 5 beams x 4 tendons = 20
  - 10% of 20 = 2 Tendons

---

Table 2. Threshold values for EIT, applicable 28 days after grouting (according to the Swiss guidelines [3, 4]).

<table>
<thead>
<tr>
<th>Duct Ø</th>
<th>Specific resistance$^1$ $R_t = R \cdot L$</th>
<th>Resistance $R$</th>
<th>Specific resistance$^1$ $R_t = R \cdot L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 mm</td>
<td>&gt;50 kΩm</td>
<td>&gt;20 Ω</td>
<td>&gt;250 kΩm</td>
</tr>
<tr>
<td>75 mm</td>
<td>&gt;50 kΩm</td>
<td>&gt;20 Ω</td>
<td>&gt;200 kΩm</td>
</tr>
<tr>
<td>100 mm</td>
<td>&gt;50 kΩm</td>
<td>&gt;20 Ω</td>
<td>&gt;150 kΩm</td>
</tr>
<tr>
<td>130 mm</td>
<td>&gt;50 kΩm</td>
<td>&gt;20 Ω</td>
<td>&gt;125 kΩm</td>
</tr>
</tbody>
</table>

Max. tolerable failure rate
- 10% 0% 3 20%

1 To convert the measured resistance $R$ to $R_t$, $R$ needs to be multiplied with the tendon length $L$, where the value used for $L$ must be at least 25 m.

2 In the case of a risk of stray current induced corrosion, in addition a National guideline issued by the Swiss Society for Corrosion Protection [11] needs to be considered.

3 At sections where the fatigue loading is critical, the acceptable failure rate is zero.

Acceptance $> 50 / 164.6 = 0.30$ kOhm
Post Grouting Measurements

• Capacitance and Loss Factor

**Capacitance C**

Capacitance C is understood as the capacitance of the plastic duct. The capacitance is significantly affected by dielectric properties, diameter, and wall thickness of the duct. For a duct of length L, the capacitance may be computed as follows:

\[
C = \frac{2\pi L \varepsilon_0 \varepsilon}{\ln(r_o/r_i)}
\]  

(1)

Here, \( \varepsilon_0 \) is the permittivity of free space, \( \varepsilon \) is the dielectric constant of the duct material, and \( r_o \) and \( r_i \) are the outer and inner duct radii, respectively. Thus, \( C \) decreases with increasing wall thickness, and for a given wall thickness, \( C \) increases with increasing duct diameter.
Post Grouting Measurements

• Loss Factor

**Loss factor D**

Loss factor D is defined as the ratio of the real and imaginary component of the impedance:

\[
D = \frac{\text{Re}(Z)}{\text{Im}(Z)} = \frac{|Z| \cos \varphi}{|Z| \sin \varphi} = \frac{1}{\tan \varphi}
\]

Here, \( \varphi \) is the phase angle between the voltage and the current signal, and \(|Z|\) is the magnitude of the impedance (\(\Omega\)). In a parallel equivalent circuit of \(R\) and \(C\), the real and imaginary parts of the impedance are:

\[
\text{Re}(Z) = \frac{R}{1+(\omega RC)^2}
\]

\[
\text{Im}(Z) = -\frac{\omega RC}{1+(\omega RC)^2}
\]

Here, \( \omega \) is the angular frequency. Thus, the loss factor can be written as:

\[
D = \frac{\text{Re}(Z)}{\text{Im}(Z)} = -\frac{1}{\omega RC}
\]
Post Grouting Measurements

• Capacitance and Loss Factor

Note that only threshold values for the resistance $R$ are given in [3, 4], but that no values were given for $C$ (capacitance) and $D$ (loss factor). The reason for this is that $C$ and $D$ are influenced by the type of the duct (different for different products from different suppliers). However, if the requirements of $R$ are not met, parameters $C$ and $D$ may give useful information for the interpretation of the measurements and indicate possible measures. It is Swiss practice to declare the actual values of $C$ and $D$ of a specific polymer duct system in the PT system documentation.
Monitoring Box – PennDOT Draft

Recommended by SGK Report

Anchorage

Measurement Cable (2.5mm$^2$) double connection lines and separately connected

Tendon Cat. C

Junction Box

Measuring Instrument (LCR-Meter)

Reinforcement
DSI Submittal

ENLARGED DETAIL 1

AWG #12 COPPER WIRE DOUBLE SHEATHED, EARTHING COLOR WITH 3/8" TERMINAL CONNECTOR

3/8" HEX-HEAD SCREW ANS WITH WASHERS ANS

ENLARGED DETAIL 2

AWG #12 COPPER WIRE DOUBLE SHEATHED, EARTHING COLOR WITH 3/8" TERMINAL CONNECTOR

GROUT CAP DRILL 3/8" NPT THREADS

CORE Drip SEAL WITH SILICONE

NOTE: DRILL 3/8" NPT HOLE IN GROUT CAP BEFORE INSTALLING THE 3/8" CORE Drip

ANCHORAGE ELECTRICAL CONNECTIONS AND TEST

1. EIT TESTS TO BE PERFORMED AFTER STRESSING AND GROUTING THE TENDON
2. EIT MEASUREMENTS SHALL BE PERFORMED AT BOTH ANCHORAGES
3. FIELD MEASURED ELECTRICAL RESISTANCE R SHALL BE 500Ω, 301Ω, 302Ω, 304Ω AND 305Ω MINIMUM FOR THE EIT TENDON IN BEAM B16, B17, B18, B19 AND B20 RESPECTIVELY

AWG #12 COPPER WIRE DOUBLE SHEATHED, BLACK (LENGTH AS NEEDED) (NEGATIVE WIRE)
New Plan for Box

- Connection to Diaphragm Cage, Both Strands and EIT
Part List
(McMaster Carr)

Coplay Bridge Parts
Long Term Monitoring Trends

Possible Chloride Intrusion