Federal Highway Administration Project
DTFH61-11-H-0027
Advancing Steel and Concrete Bridge Technology to Improve Infrastructure Performance

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

Data Sheet

880 B&K Purchased on Amazon

40,000-Count Dual-Display Handheld LCR Meters
Models 878B, 879B, and 880

Full Featured Handheld LCR Meters

The 878B, 879B, and 880 40,000-count handheld LCR meters measure inductance, capacitance, and resistance quickly and precisely. The 879B and 880 also measure impedance, Theta, and ESR. Additionally, the 880 offers capabilities typically only found in bench LCR meters such as a 4-terminal configuration, basic measurement accuracy up to 0.1 %, test frequencies up to 100 kHz, selectable test signal levels and measurement rate.

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, tolerance sorting, and relative mode.

Measurement data can continuously transfer to a PC via the meter's mini USB interface, using either the provided data logging software or SCPI commands sent from a custom program.

ESR Measurements

Models 879B and 880 have the ability to measure the ESR (Equivalent Series Resistance) of capacitors. ESR is the sum of in-phase AC resistance of a capacitor and used to rate a capacitor's quality. An ideal capacitor would be lossless and have an ESR of zero. A capacitor could measure the correct capacitance value, yet still be defective, due to the component's excessive in-phase AC resistance. The 879B and 880 would be able to detect this faulty component.

Features & Benefits

- 40,000 counts resolution on primary and 10,000 counts resolution on secondary display
- L, C, R and Z (879B & 880 only) primary measurements
- Automatic calculation of secondary parameters D, Q, θ, ESR (θ/ESR for 879B & 880 only), DCR (880 only)
- Accuracy up to 0.1% and selectable test frequencies up to 100 kHz (880 only)
- Fast auto range design for rapid, easy component measurements
- Auto detect mode for automatic component type identification and measurement type selection (880 only)
- Relative mode
- Visible and audible tolerance mode
- Data Hold and Min/Max/Average recording
- USB (Virtual COM) interface
- SCPI compliant commands for remote communication
- Software for datalogging and front panel emulation available as free download
- Configurable power-up-states
- 3 year warranty

Applications

- Passive component troubleshooting
- Electronic assembly
- Quality control (component sorting)

Specifications	878B	879B	880
Measurements	L, C, R, D, Q	L, C, R, Z, D, Q, θ, ESR	L, C, R, Z, D, Q, θ, ESR & DCR
Basic Accuracy	0.5%	0.5%	0.1%
Test Frequency	120 Hz, 1 kHz	100 Hz, 120 Hz, 1 kHz, 10 kHz	100 Hz, 120 Hz, 1 kHz, 10 kHz, 100 kHz
Test Signal	0.6 Vrms	0.6 Vrms	0.3 Vrms, 0.6 Vrms, 1 Vrms DCR: 1 Vdc
Backlit Display	-	√	√
Auto Detect Mode	-	-	√
Tolerance Mode	1%, 5%, 10%	1%, 5%, 10%, 20%	1%, 5%, 10%, 20%
Measurement Rate	1.5 readings/sec	1.5 readings/sec	4 readings/sec (fast), 1.5 readings/sec (slow)

COSINUS® MESSTECHNIK GMBH

CMT-437
Digitales LCR Messgerät

Eigenschaften und Funktionen:

- 20000/2000 Digit Dualdisplay
- 46-Segment Analoganzeige
- Automatische LCR Bereichswahl
- Display mit Hintergrundbeleutchtung
- Grundgenauigkeit 0.2%
- Parameter: L, C, R, D, Q, θ, EsR
- Messfrequenzen 100Hz/120Hz/1kHz/10kHz/100kHz
- Parallel/Seriell Testmodus
- Sortiermodus für QC
- Max/Min Funktion
- Data Hold
- Kalibrationsmodus
- Netzgerätanschluss
- Nullmodus
- Batterieanzeige
- Autiomatische Abschaltfunktion
- Optische USB Schnittstelle
- 2 Leiter Schnellmessung
- 5 Leiter Präzisionsmessung

Technische Spezifikationen: (bei 23°C±5°C<80%RH)

L: Messbereich 20µH~2000H
Genauigkeit ±(0.2%+5d)
Auflösung 0.001µH

C: Messbereich 20pF~20mF
Genauigkeit ±(0.2%+3d)
Auflösung 0.001pF

Ω: Messbereich 20Ω~200MΩ
Genauigkeit ±(0.2%+2d)
Auflösung 0.001Ω

DC Ω: Messbereich 200Ω~200MΩ
Genauigkeit ±(0.2%+2d)
Auflösung 0.01Ω

Q: Messbereich 0.000 to 999
Auflösung 0.001

D: Messbereich 0.000 to 999
Auflösung 0.001

θ: Messbereich +/-90°
Auflösung 1°

Available in the EU

Allgemeine Spezifikationen:

Betriebstemperatur: 0°C~50°C
Lagertemperatur: -20°C~60°C 0 to 80% RH
Temperaturkoeffizient: 0.15 x (spez. Genauigkeit)/ °C, <18°C, >28°C
Batteriedauer: bis zu 50 Stunden (Alkaline)
Versorgung: Typ AA 1.5V x 4 Batterien (IEC LR6)
Abmessungen: 96mm (B) x 200mm (L) x 51.20mm (H) mit Holster
Gewicht: ca. 605g mit Holster

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 x L > 50 kOhm-m [164 kOhm-ft]
- Tendon Length ~540ft [164.6m]
- 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]).

	Main criterion		
	Monitoring	**Fatigue**	**Stray current**[2]
Duct Ø	**Specific resistance**[1] $R_l = R \cdot L$	**Resistance** R	**Specific resistance**[1] $R_l = R \cdot L$
60 mm	>50 kΩm	>20 Ω	>250 kΩm
75 mm	>50 kΩm	>20 Ω	>200 kΩm
100 mm	>50 kΩm	>20 Ω	>150 kΩm
130 mm	>50 kΩm	>20 Ω	>125 kΩm
Max. tolerable failure rate	10%	0% [3]	20%

[1] To convert the measured resistance R to R_l, 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.

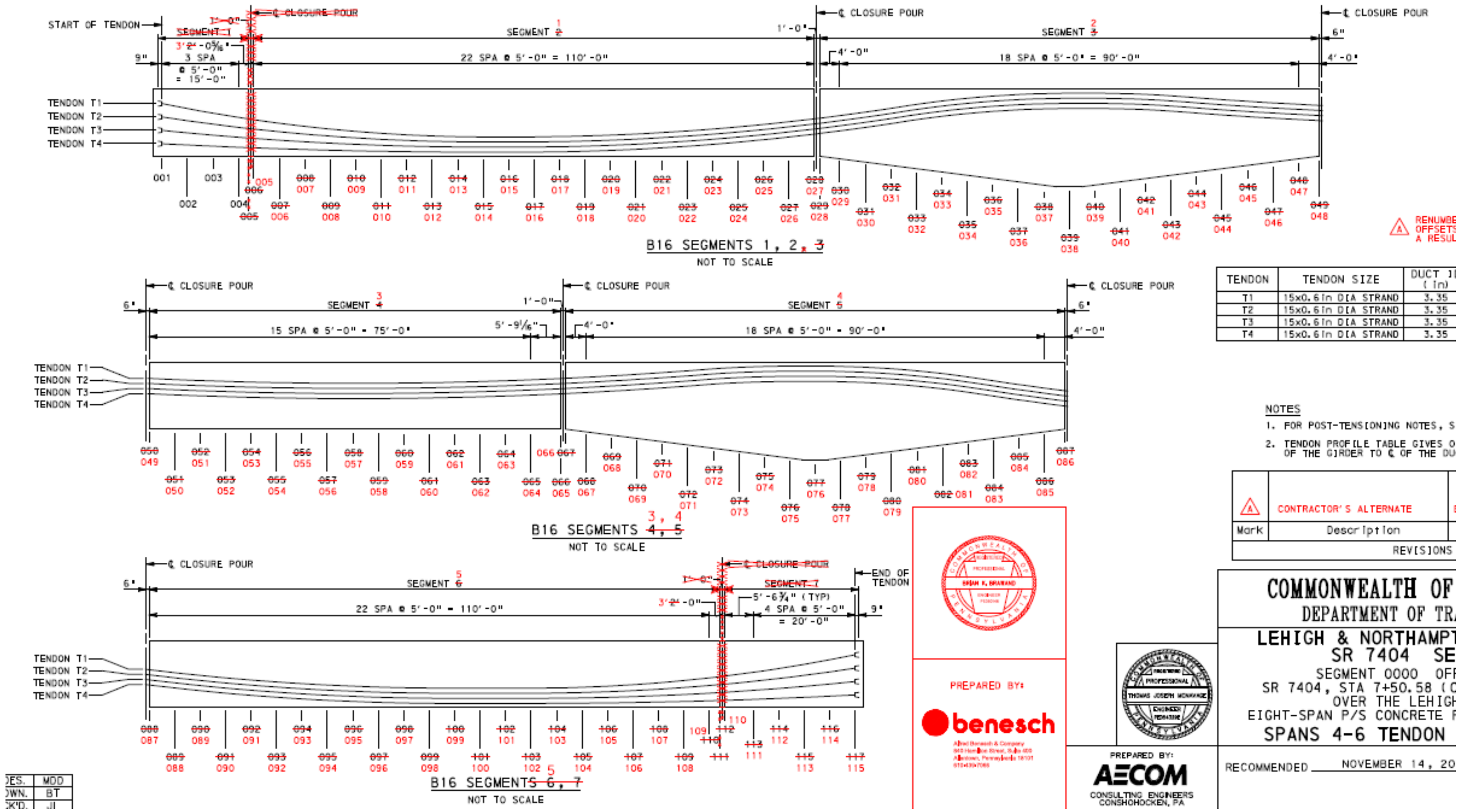
[3] At sections where the fatigue loading is critical, the acceptable failure rate is zero.

Acceptance > 50 / 164.6 = 0.30 kOhm

Post Grouting Measurements

Question? Actual Length or Projected

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



Acceptance > 50 / 164.6 = 0.30 kOhm

Post Grouting Measurements

Question? Actual Length or Projected

- 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

Beam No.	Length, L (ft)	Length, L (m)	R_L (kΩm)	Minimum R (Ω)
16	547.34	166.83	50	300
17	544.63	166.00	50	301
18	542.36	165.31	50	302
19	540.08	164.62	50	304
20	537.79	163.92	50	305

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]).**

	Main criterion		
	Monitoring	**Fatigue**	**Stray current**[2]
Duct Ø	**Specific resistance**[1] $R_l = R \cdot L$	**Resistance** R	**Specific resistance**[1] $R_l = R \cdot L$
60 mm	>50 kΩm	>20 Ω	>250 kΩm
75 mm	>50 kΩm	>20 Ω	>200 kΩm
100 mm	>50 kΩm	>20 Ω	>150 kΩm
130 mm	>50 kΩm	>20 Ω	>125 kΩm
Max. tolerable failure rate	10%	0% [3]	20%

[1] To convert the measured resistance R to R_l, 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:

$$C = 2\pi L\varepsilon_o\varepsilon/\ln(r_o/r_i) \tag{1}$$

Here, ε_o is the permittivity of free space, ε 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:

$$D = \frac{Re(Z)}{Im(Z)} = \frac{|Z|cos\varphi}{|Z|sin\varphi} = \frac{1}{tan\varphi} \qquad (2)$$

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

$$Re(Z) = \frac{R}{1+(\omega RC)^2} \qquad (3)$$

$$Im(Z) = -\frac{\omega RC}{1+(\omega RC)^2} \qquad (4)$$

Here, ω is the angular frequency. Thus, the loss factor can be written as:

$$D = \frac{Re(Z)}{Im(Z)} = -\frac{1}{\omega RC} \qquad (5)$$

Post Grouting Measurements

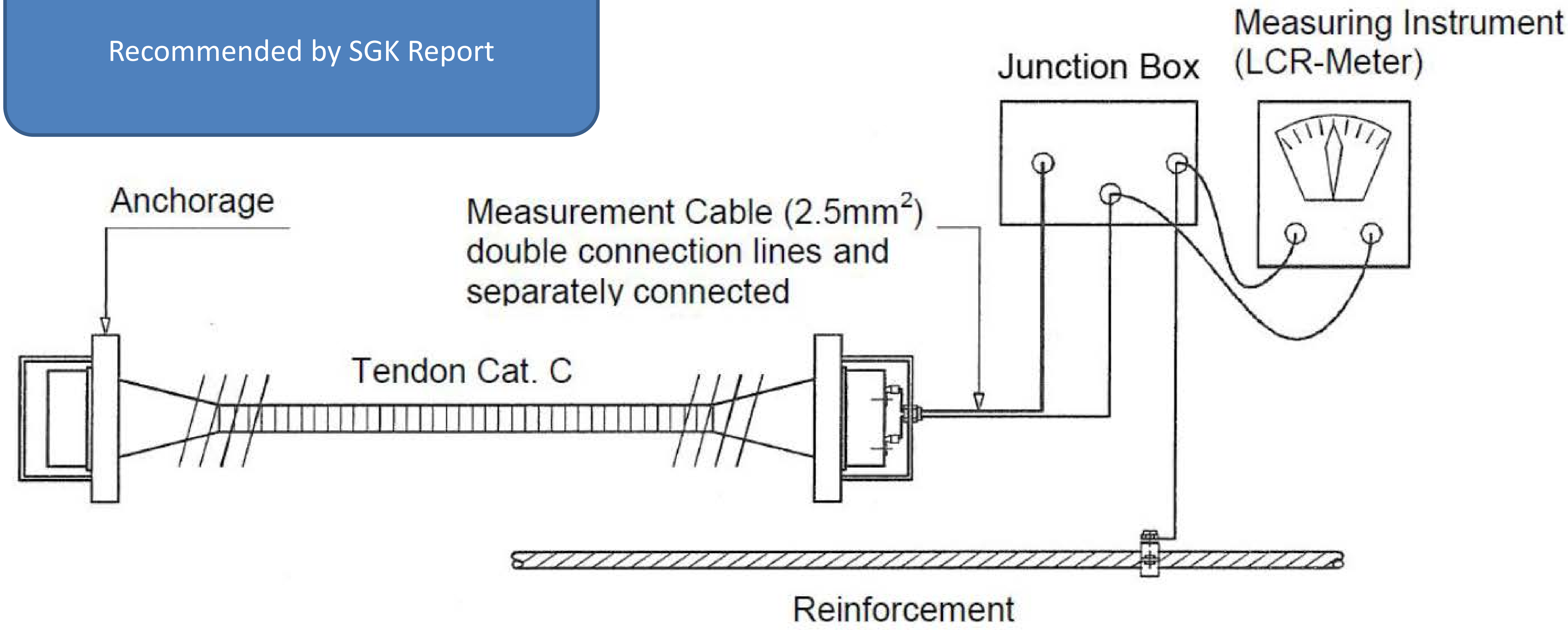
- Capacitance and Loss Factor

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.

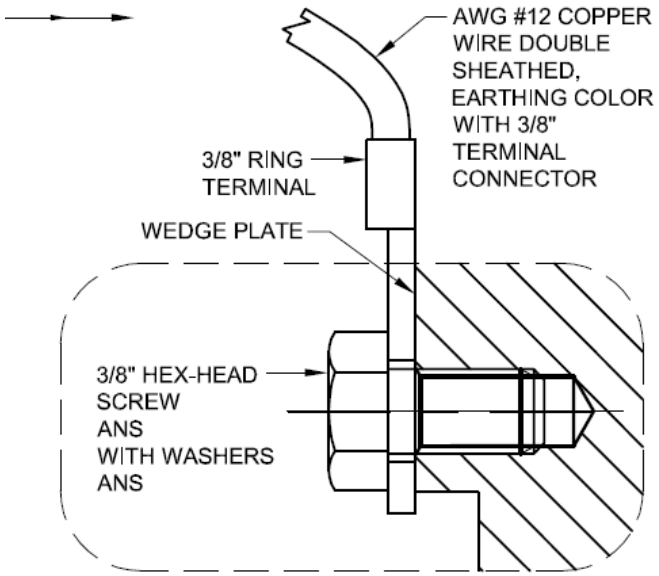
No Values Specified

Monitoring Box – PennDOT Draft

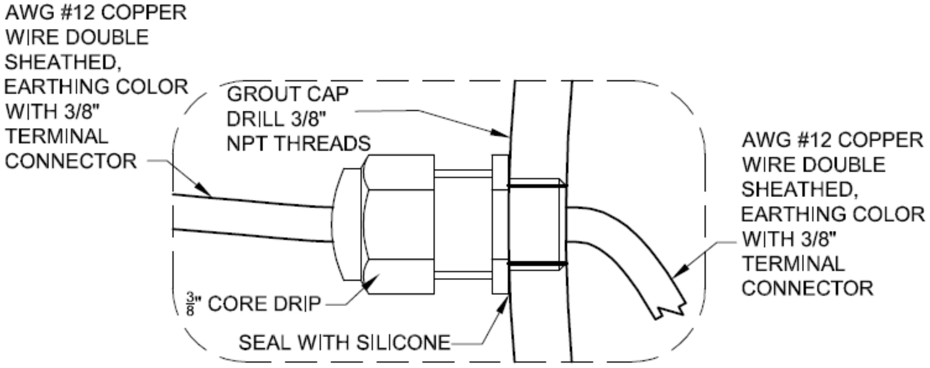
Recommended by SGK Report



DSI Submittal

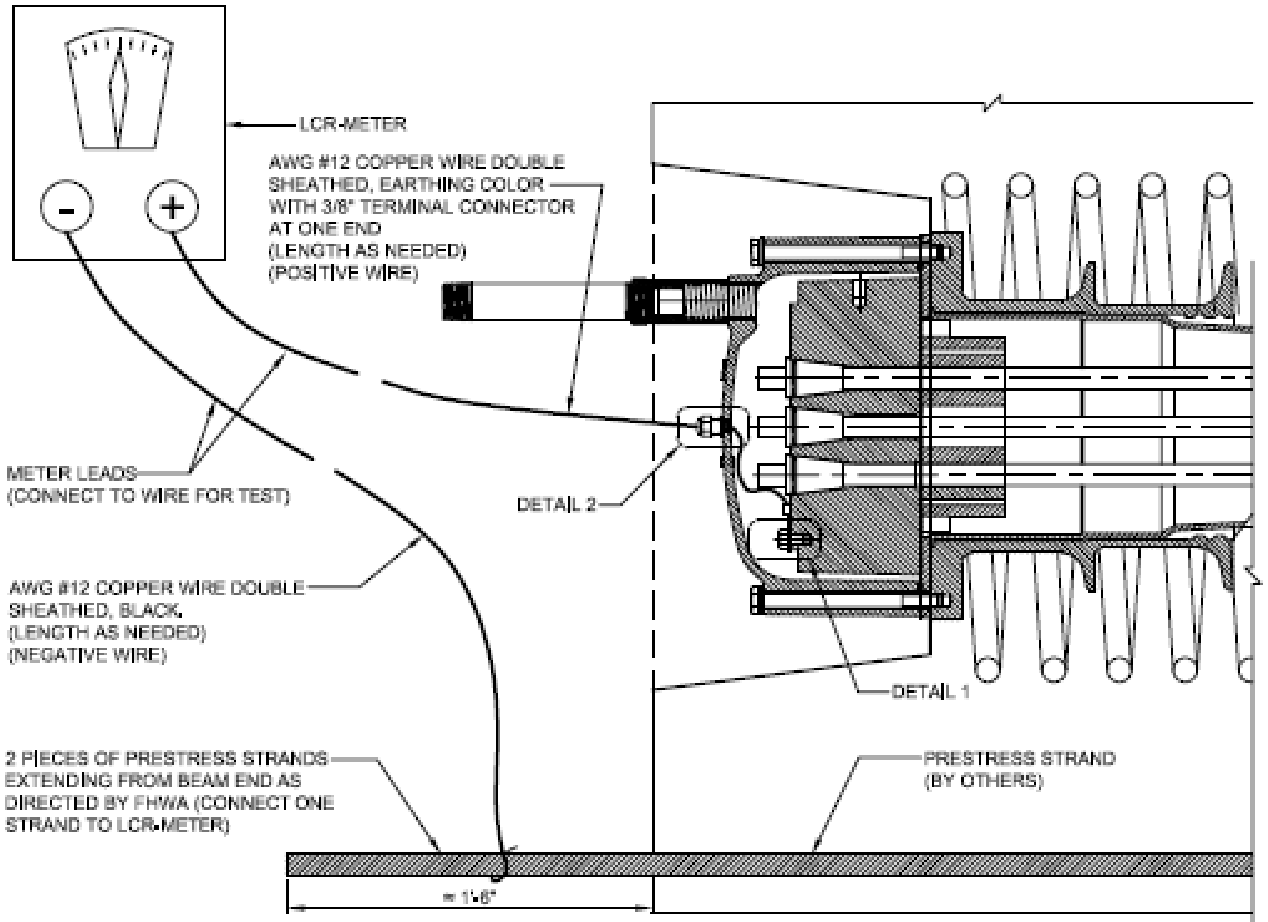


ENLARGED DETAIL 1



ENLARGED DETAIL 2

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



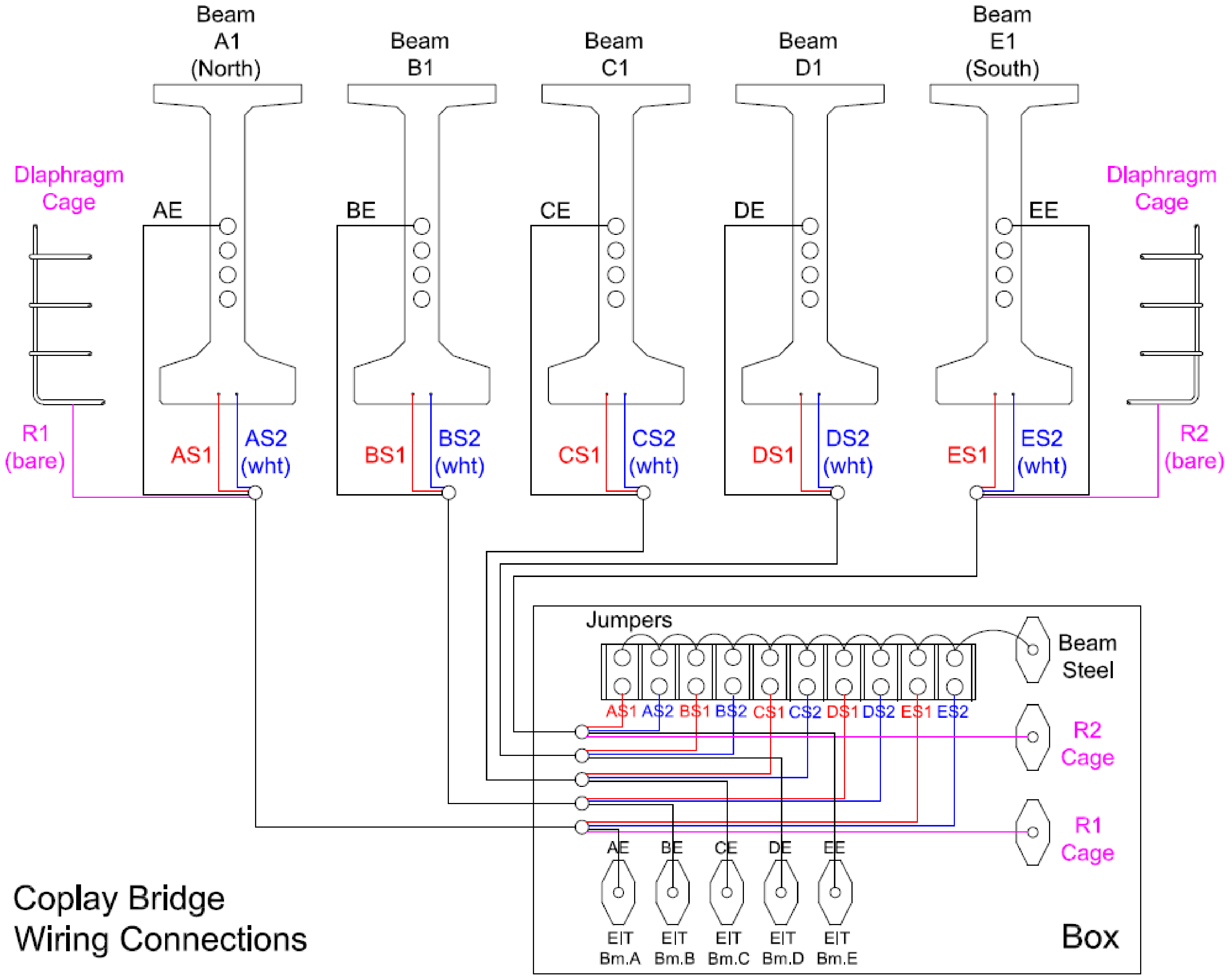
EIT NOTES:

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 300Ω, 301Ω, 302Ω, 304Ω AND 305Ω MINIMUM FOR THE EIT TENDON IN BEAM B16, B17, B18, B19 AND B20 RESPECTIVELY

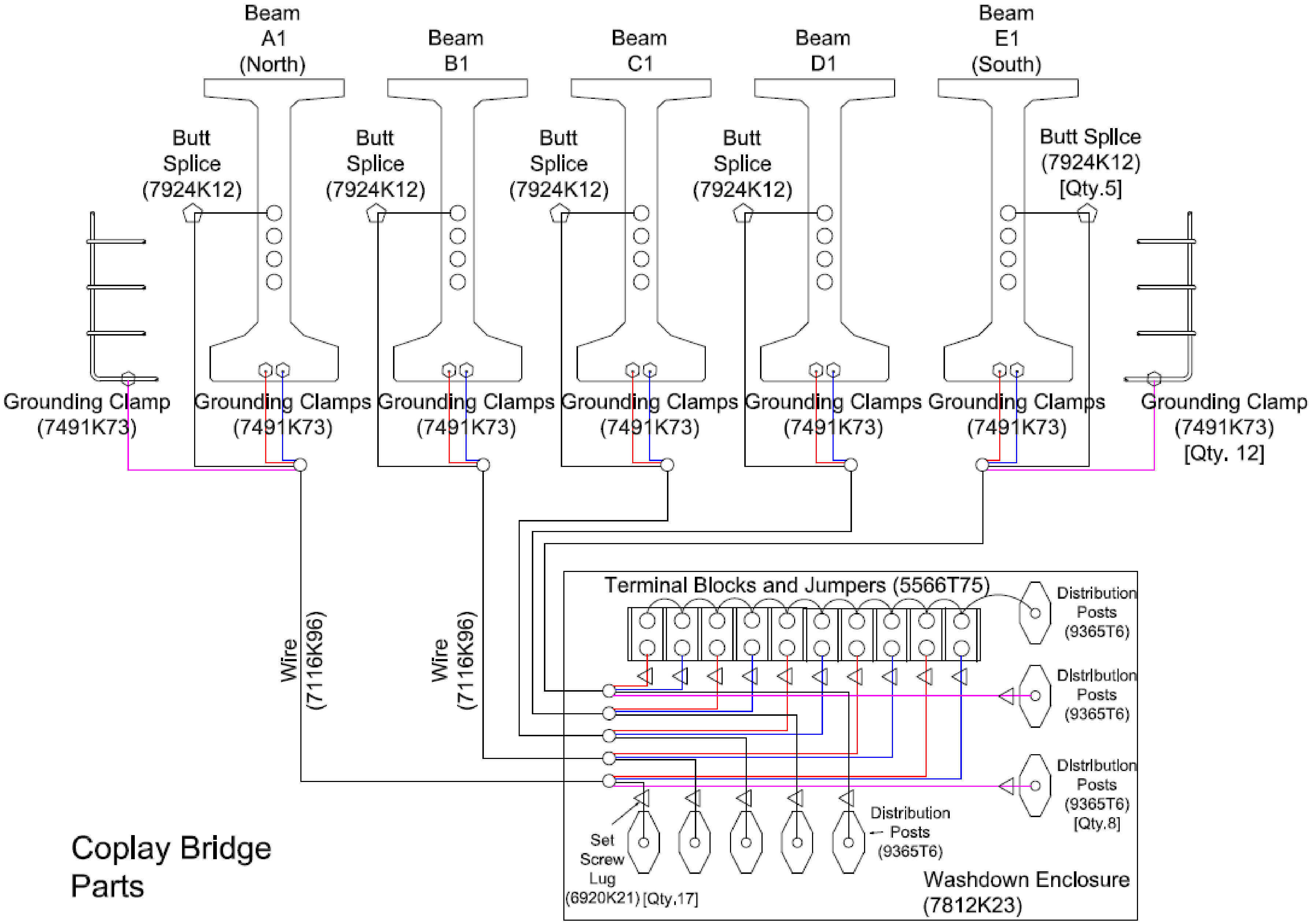
ANCHORAGE ELECTRICAL CONNECTIONS AND TEST

New Plan for Box

- Connection to Diaphragm Cage, Both Strands and EIT



Part List (McMaster Carr)



Long Term Monitoring Trends