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TECHNICAL MEMORANDUM

Project Name: **Funding for Engineering Support Services and Recommendations for Roadside Safety Issues/Problems for Member States, TTI Project No. 617781**

Sponsor: **Colorado Department of Transportation (WSDOT)**

Subject: **Final Technical Memorandum**

DATE: **September 19, 2024**

FROM: **William Williams, P.E.**, Associate Research Engineer
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PROBLEM STATEMENT AND BACKGROUND

Currently, there is a need for more instrumentation to measure stresses and strains in roadside safety structural components. Accurate measurement of this data would provide additional information in the design or roadside safety hardware for crash impact loading. Many pooled fund states need a professional assessment of their roadside safety hardware and barrier systems. The purpose of this project is to collect data on selected projects and to provide this data to the supporting member state Colorado Department of Transportation.

OBJECTIVE

There is a need, during the course of normal MASH compliance testing or component testing with respect to MASH Requirements, to utilize instrumentation to measure and record stress and strain data in components for use in further research. This instrumentation typically is in the form of strain gages installed at strategic locations on components to measure stresses and strain in members/components at key locations for critical loading. The purpose project was to establish a funding mechanism for adding instrumentation to a project for the collection/measurement of stresses and strains in test installation components. One project was selected for this project. A brief description of the testing and the instrumentation used on this project is provided as follows.

Overview of Selected Project (1) - MASH Testing of Luminaire Pole on Single Slope Traffic Rail, TTI Project 440863

The purpose of the test performed for this project was to assess the performance of a tall luminaire pole mounted on Single Slope Traffic Rail according to the safety-performance evaluation guidelines included in the second edition of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1*). The crash test was performed in accordance with *MASH* Test Level 4 (4-12):

1. ***MASH Test*** 4/5 12: A 10000S/36000V vehicle weighing 22,000 lb/79,300 lb impacting the longitudinal barrier while traveling at 56/50 mi/h and 15 degrees**.**

This report provides details on the Luminaire Pole on Single Slope Traffic Rail, the crash tests and results, and the performance assessment of the Luminaire Pole on Single Slope Traffic Rail for *MASH* 4-12 Longitudinal Barrier evaluation criteria.

The Luminaire Pole on Single Slope Traffic Rail met the performance criteria for *MASH* 4-12 Longitudinal Barrier. Instrumentation (strain gauges) were installed on several transverse reinforcing bars in the to of the deck and at the base of the pole. For additional information on the locations of the gages, please refer to the drawing and details in Figures 1 to 4 below. For information on the strain gages used for this project please refer to the information in Appendix A.

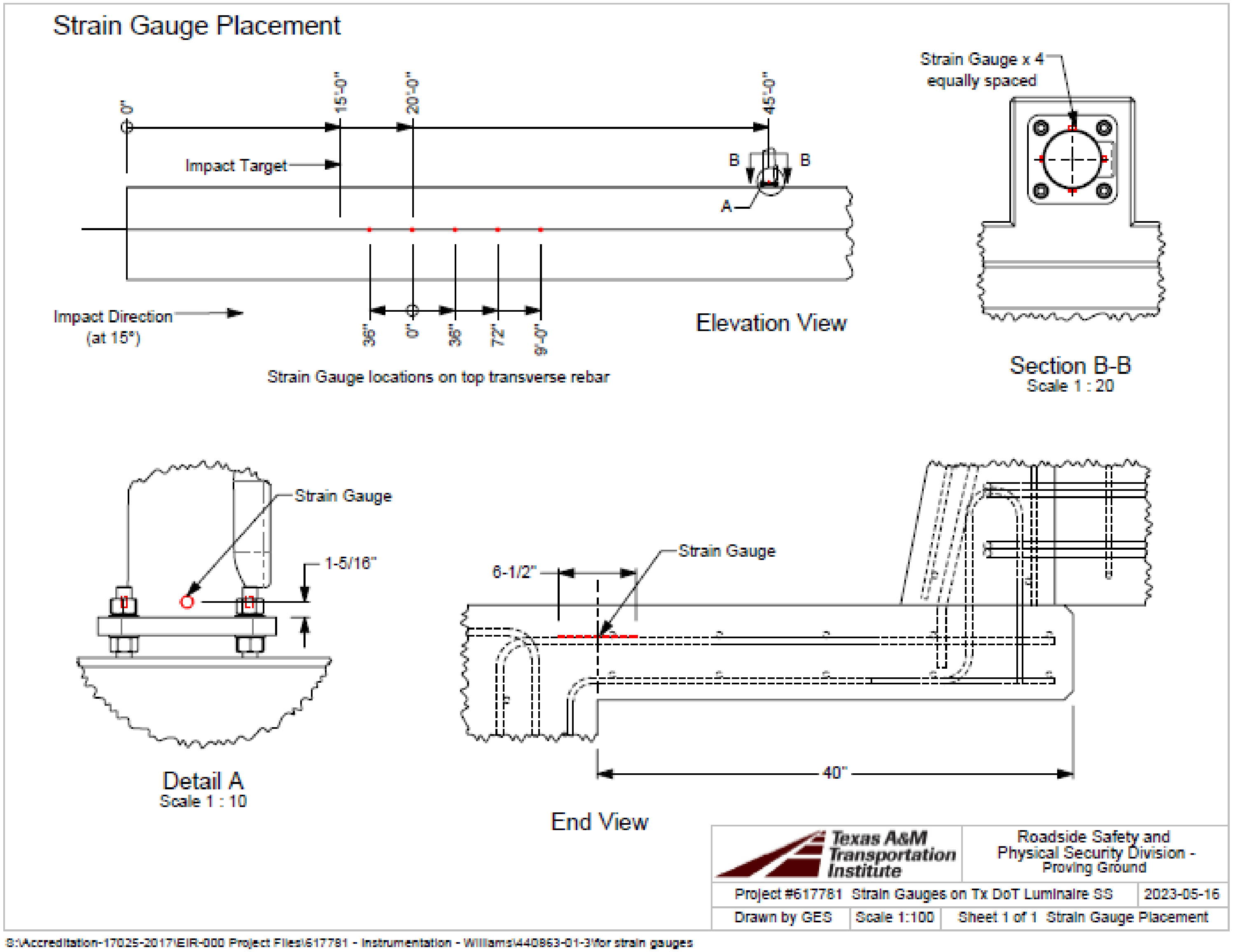

Figure 1 – Layout of Strain Gauges on Test Installation.

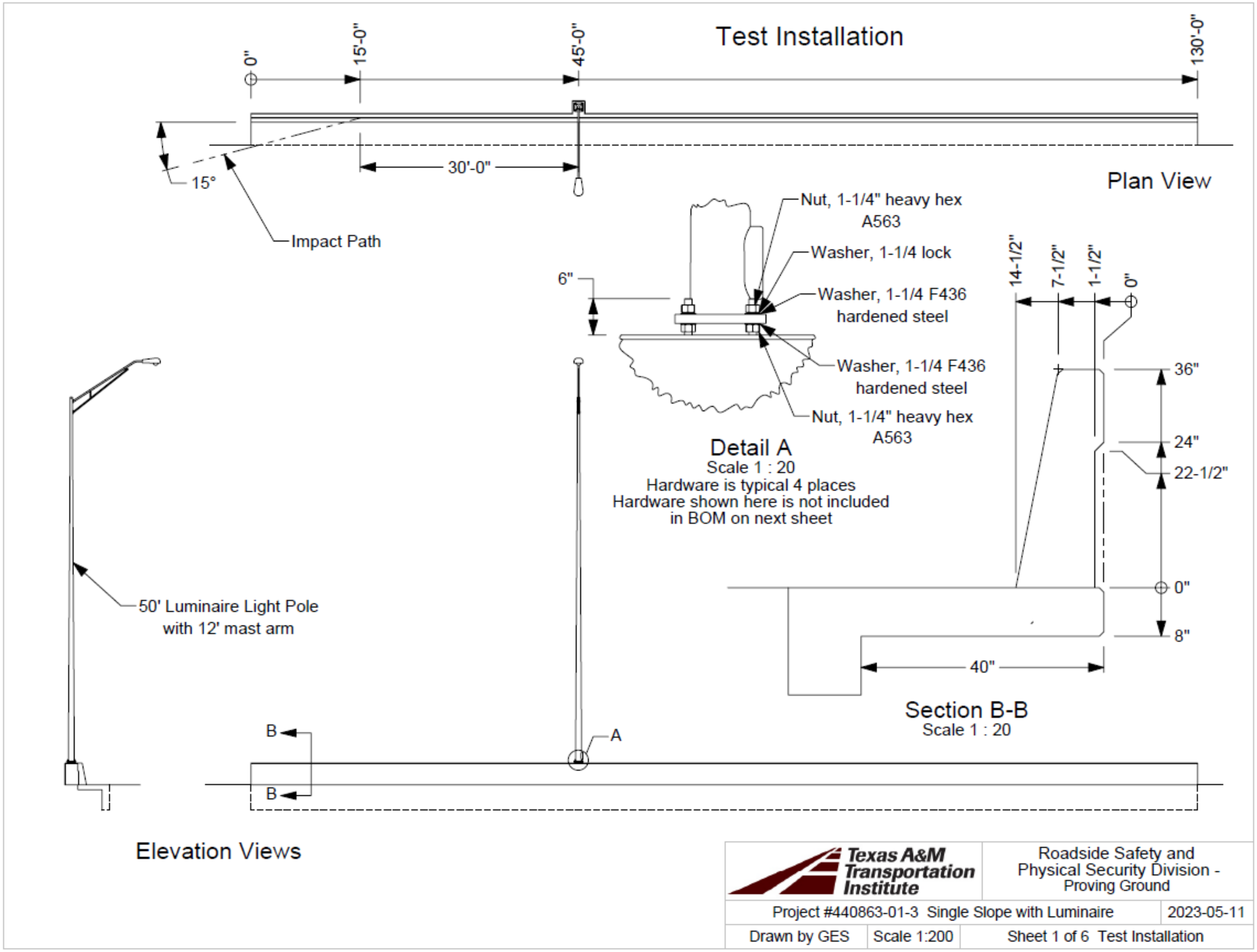

Figure 2 – Barrier Details.

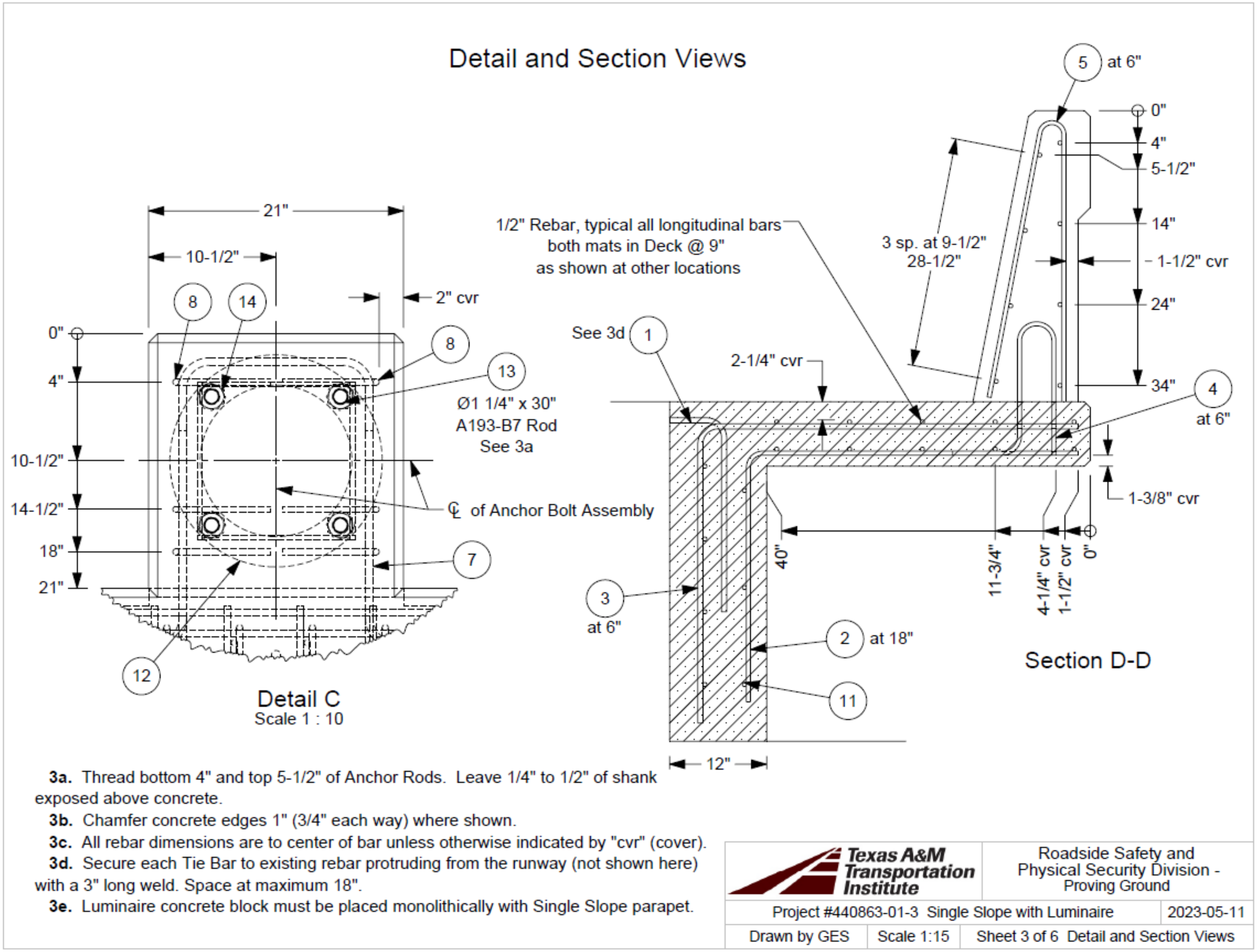

Figure 3 – Barrier and Reinforcement Details.

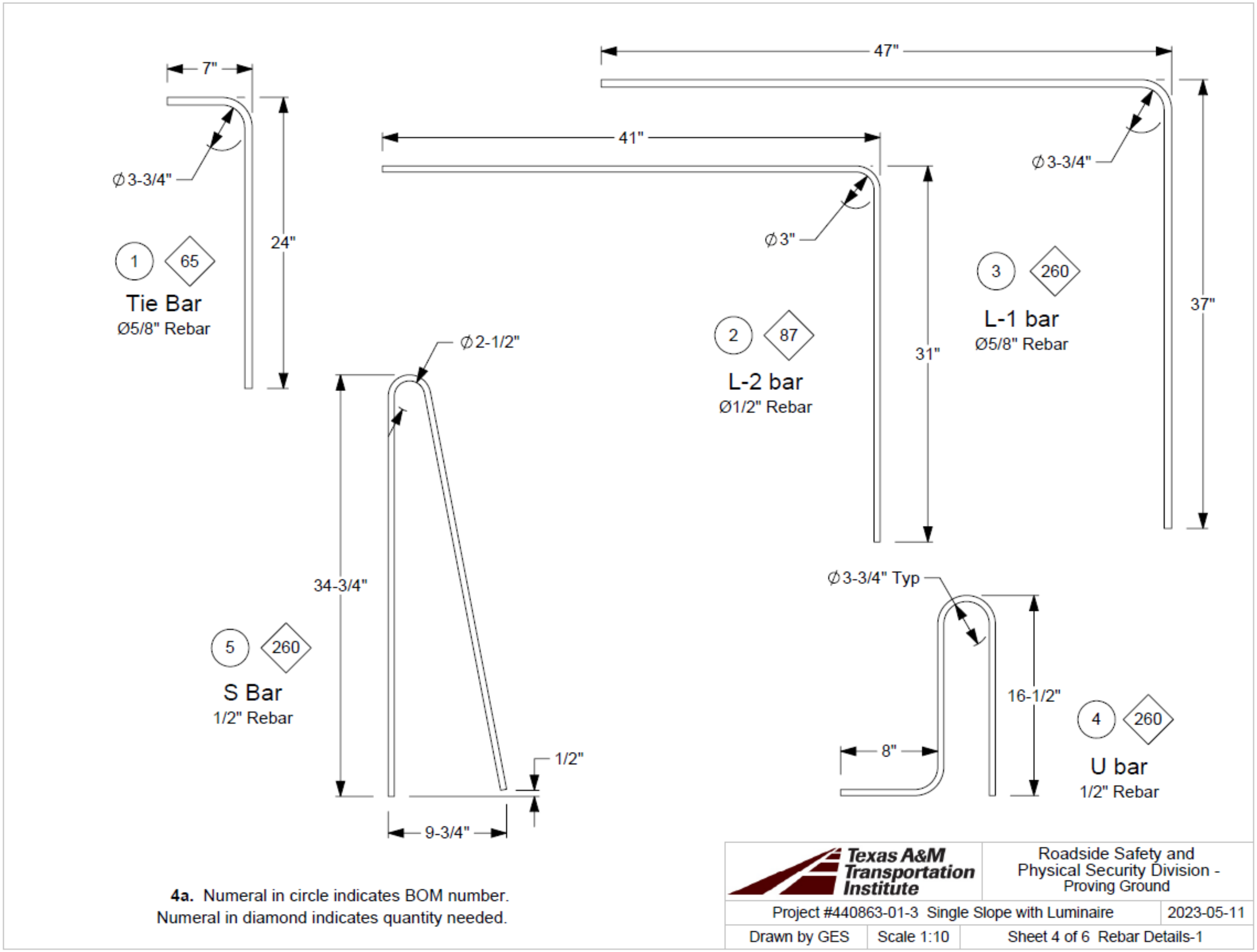

Figure 4 – Reinforcement Details.

Photo of the test installation with the strain gauges are shown in Figures 5 to 7 as follows.

Figure 5 – Photos of Strain Gauges on Light Pole

Figure 6 – Layout of Strain Gauges

Figure 7 – Layout of Strain Gauge

A full scale crash test was performed on the installation on June 22, 2023. All collected data from this project was collected and provided in excel format to Colorado DOT after the crash test. Analyzing the data was performed by Colorado DOT and was not a part of this project for TTI. This project was the only one selected for instrumentation.

APPENDIX A

GEOKON®

Resistance Strain Gauge Calibration Report

This Calibration has been Verified/ Validated as of: April 07, 2023

Serial Number: 2237839

Calibration Date: April 7, 2023

Temperature: 22.7

Calibration Instruction: CI-3900

Technician:

Average Displacement (inches)	Reading 1st Cycle (mV/V)	Reading 2nd Cycle (mV/V)	Average Reading (mV/V)	Calculated Linear Displacement (inches)	Error Linear (%FS)	Calculated Polynomial Displacement	Error Polynomial (%FS)
0.0000	1.0158	1.0160	1.0159	-0.00007	-0.29	-0.00001	-0.02
0.0052	1.1050	1.1053	1.1051	0.00522	0.08	0.00521	0.03
0.0104	1.1935	1.1935	1.1935	0.01047	0.25	0.01041	0.04
0.0156	1.2808	1.2808	1.2808	0.01564	0.16	0.01559	-0.04
0.0208	1.3678	1.3678	1.3678	0.02081	0.02	0.02079	-0.03
0.0260	1.4543	1.4543	1.4543	0.02594	-0.24	0.02601	0.03

Linear Gage Factor (G): 0.05934 (inches/ mV/ V) 2.5 G·R1-R0· ·14835

16.85 × 2.5

Polynomial Gage Factors: A: 0.0026563 B: 0.05278 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON®

Resistance Strain Gauge Calibration Report

This Calibration has been Verified/ Validated as of: April 07, 2023

Serial Number: 2237840

Calibration Date: April 7, 2023

Temperature: 22.7

Calibration Instruction: CI-3900

Technician:

Average Displacement (inches)	Reading 1st Cycle (mV/V)	Reading 2nd Cycle (mV/V)	Average Reading (mV/V)	Calculated Linear Displacement (inches)	Error Linear (%FS)	Calculated Polynomial Displacement	Error Polynomial (%FS)
0.0000	1.6328	1.6325	1.6326	-0.00003	-0.13	0.00001	0.04
0.0052	1.7198	1.7198	1.7198	0.00520	-0.02	0.00519	-0.05
0.0104	1.8068	1.8070	1.8069	0.01043	0.10	0.01039	-0.04
0.0156	1.8940	1.8938	1.8939	0.01565	0.18	0.01561	0.05
0.0208	1.9800	1.9800	1.9800	0.02082	0.06	0.02081	0.03
0.0260	2.0655	2.0655	2.0655	0.02595	-0.20	0.02599	-0.03

Linear Gage Factor (G): 0.06002 (inches/ mV/ V)

Polynomial Gage Factors: A: 0.0017319 B: 0.05362 C: ________

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement:

Linear, $D = G(R_1 - R_0)$

Polynomial, $D = AR_1^2 + BR_1 + C$

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON®

Resistance Strain Gauge Calibration Report

This Calibration has been Verified/ Validated as of: April 07, 2023

Serial Number: 2237841

Calibration Date: April 7, 2023

Temperature: 22.7

Calibration Instruction: CI-3900

Technician:

Average Displacement (inches)	Reading 1st Cycle (mV/V)	Reading 2nd Cycle (mV/V)	Average Reading (mV/V)	Calculated Linear Displacement (inches)	Error Linear (%FS)	Calculated Polynomial Displacement	Error Polynomial (%FS)
0.0000	2.0413	2.0415	2.0414	-0.00012	-0.46	0.00000	-0.02
0.0052	2.1253	2.1253	2.1253	0.00523	0.13	0.00521	0.03
0.0104	2.2078	2.2075	2.2076	0.01049	0.34	0.01040	-0.01
0.0156	2.2890	2.2893	2.2891	0.01569	0.34	0.01560	0.01
0.0208	2.3695	2.3693	2.3694	0.02081	0.04	0.02079	-0.03
0.0260	2.4490	2.4490	2.4490	0.02589	-0.42	0.02601	0.02

Linear Gage Factor (G): 0.06381 (inches/ mV/ V)

Polynomial Gage Factors: A: 0.0051049 B: 0.04089 C: ________

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement:

Linear, $D = G(R_1 - R_0)$

Polynomial, $D = AR_1^2 + BR_1 + C$

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON®

Resistance Strain Gauge Calibration Report

This Calibration has been Verified/ Validated as of: April 07, 2023

Serial Number: 2237842

Calibration Date: April 7, 2023

Temperature: 22.7

Calibration Instruction: CI-3900

Technician:

Average Displacement (inches)	Reading 1st Cycle (mV/V)	Reading 2nd Cycle (mV/V)	Average Reading (mV/V)	Calculated Linear Displacement (inches)	Error Linear (%FS)	Calculated Polynomial Displacement	Error Polynomial (%FS)
0.0000	1.5808	1.5818	1.5813	-0.00002	-0.06	0.00001	0.05
0.0052	1.6775	1.6783	1.6779	0.00518	-0.07	0.00518	-0.09
0.0104	1.7750	1.7755	1.7753	0.01042	0.08	0.01040	-0.01
0.0156	1.8720	1.8723	1.8721	0.01563	0.13	0.01561	0.04
0.0208	1.9685	1.9685	1.9685	0.02082	0.08	0.02081	0.05
0.0260	2.0640	2.0640	2.0640	0.02596	-0.16	0.02599	-0.04

Linear Gage Factor (G): 0.05381 (inches/ mV/ V)

Polynomial Gage Factors: A: 0.000991 B: 0.05019 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement:

Linear, $D = G(R_1 - R_0)$

Polynomial, $D = AR_1^2 + BR_1 + C$

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

4

GEOKON®

Resistance Strain Gauge Calibration Report

This Calibration has been Verified/ Validated as of: April 07, 2023

Serial Number: 2237843

Calibration Date: April 7, 2023

Temperature: 22.7

Calibration Instruction: CI-3900

Technician:

Average Displacement (inches)	Reading 1st Cycle (mV/V)	Reading 2nd Cycle (mV/V)	Average Reading (mV/V)	Calculated Linear Displacement (inches)	Error Linear (%FS)	Calculated Polynomial Displacement	Error Polynomial (%FS)
0.0000	1.0115	1.0120	1.0118	-0.00005	-0.18	0.00000	0.01
0.0052	1.1018	1.1025	1.1021	0.00520	0.02	0.00519	-0.02
0.0104	1.1920	1.1925	1.1923	0.01044	0.17	0.01040	0.01
0.0156	1.2813	1.2820	1.2816	0.01564	0.15	0.01560	0.00
0.0208	1.3703	1.3710	1.3706	0.02081	0.04	0.02080	0.01
0.0260	1.4588	1.4593	1.4590	0.02595	-0.20	0.02600	-0.01

Linear Gage Factor (G): 0.05813 (inches/ mV/ V)

Polynomial Gage Factors: A: 0.0018806 B: 0.05348 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

1. INTRODUCTION

The Model 3900 Embedment Strain Gauge is designed for the measurement of dynamic strains in concrete structures and soils. It comprises a full-bridge strain gauge proving ring element coupled in series with a tension spring which is stretched between two end flanges. An outer PVC tube sealed with O-rings provides a waterproof housing. The end flanges are embedded and move in accordance with the surrounding material. The voltage signals from the strain gauge are transmitted via cable to the readout location.

The strain gauge can be read out by means of the GEOKON Model 502 Readout Box or by a applying a 2 to 12 Volt excitation to the input leads and reading the corresponding millivolt output. The standard wiring for use with the GK-502 readout box is configured to compensate for the use of long cables by the remote sensing of the input voltage at the sensor. A Thermistor is included inside the sensor to measure temperature. This requires a cable with four shielded pairs of conductors.

2. INSTALLATION

The embedment gauge is delivered with the sensor set at an approximately midrange position ready for installment. The standard range is ± 2500 microstrains. (Other ranges are available). An initial test can be conducted by connecting the strain gauge to the GK-502 Readout Box or to a regulated voltage supply. Movement of the end flanges should produce a corresponding change in the gauge output. At no time should the end flanges be twisted or pulled beyond the range of the sensor as this could permanently damage the gauge.

The gauge should be installed directly in the concrete or soil by hand. Large aggregate should be removed from the area immediately surrounding the sensor. The use of vibrators immediately next to the gauge should be avoided. The standard cable has a thick PVC jacket and can be placed directly in the concrete.

3. TAKING READINGS

Connect the ten-pin connector to the GK-502 readout box or connect the bare wires to a voltage supply and millivoltmeter as follows:

Bendix Pin	Circuit Label	Description	GEOKON Purple Cable	
A	S-	Bridge Output -	White's Black	– 2
B	P+	Bridge Excitation +	Red	– 1
C	P-	Bridge Excitation -	Red's Black	– 3
D	S+	Bridge Output +	White	– 4
E	NC	No Connection	NC	
F	G	Ground for shield	Shield	– 5
G	T	Thermistor	Blue	
H	T	Thermistor	Blue's Black	
J	RS+	Remote Sense +	Green	– 9
K	RS-	Remote Sense -	Green's Black	– 8

Table 1 - Input Connections

3.1 Circuit Diagram

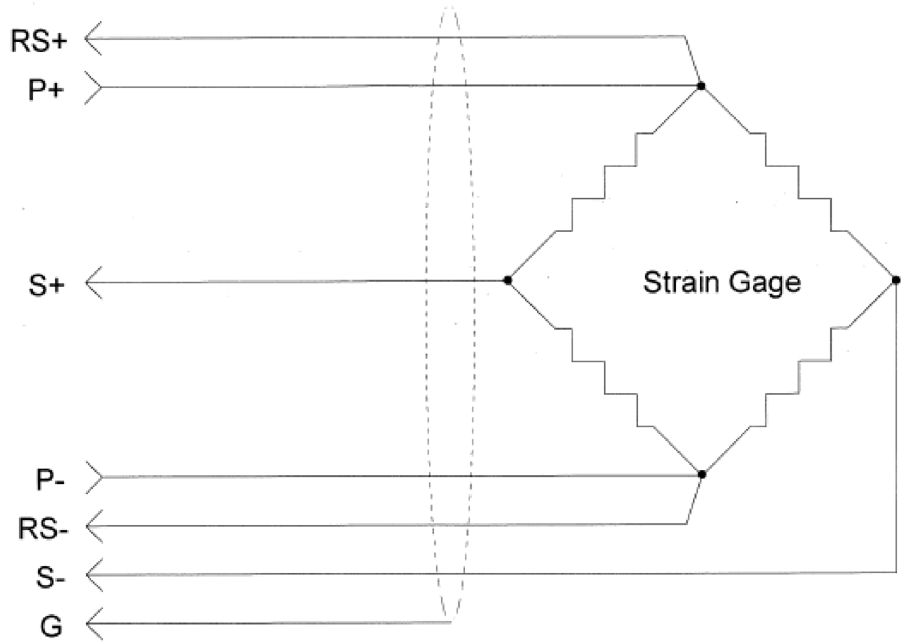

Figure 1 - Circuit Diagram

3.2 Using the GEOKON GK-502 Readout Box

The user is referred to the GK-502 Instruction Manual for additional information on the following instructions:

1) Connect the embedment gauge to the readout box by means of the 10-pin input connector.

2) Press the 'ON/OFF' button power switch to the "ON" position.

3) Press the 'UNITS' button until the UNITS displayed are mV/V.

4) Read the display and record.

5) See the GK-502 Instruction Manual for further instructions.

4. DATA REDUCTION

4.1 Displacement Calculation

The basic units utilized by GEOKON for measurement and reduction of data from Model 3900 Embedment Strain Gauges are mV/V.

If a GK-502 readout box is used, **mV/V** can be displayed directly.

The displacement **D** is given by the equation:

$$D = G(R_1 - R_0)$$

Equation 1 - Displacement

Where;
D is the displacement in the units given on the calibration report provided with the instrument.
R_0 is the initial GK-502 reading in mV/V.
R_1 is the current GK-502 reading in mV/V.
G is the calibration factor in inches/mV/V, as supplied on the Cal Sheet. (See Appendix C. for a sample calibration report.)

If a regulated power supply and a millivoltmeter are used, then calculate the mV/V by dividing the displayed millivolt output by the voltage input measured at the sensor using the remote signal leads, (Green and Green's Black).

4.2 Strain Calculation

To calculate the **strain ε,** divide the measured displacement **D** by the gauge length **L.**
The standard length for **L** is Eight inches (203 mm).

Example: Using a GK-502, R_0 = -0.8640 and R_1 = -0.5563, G = 0.05193 inches/mV/V.
Strain ε **= ((-0.5563-(-0.8640) x 0.05193/8 = +2000 microstrain (tension)**

Note that an increasing reading denotes a tensile strain.

4.3 Temperature Correction Factor

Tests have shown that the temperature effect is such that the embedment gauge reading goes up (extension) as the temperature goes up and the required temperature correction factor is plus 22.5 microstrains per °C.

So, for example, using the GK-502 (displaying mV/V) to take the readings, and a standard eight-inch-long gauge, where **G** is given in inches/mV/V, the calculation for strain **S**, corrected for temperature change ($\mathbf{T_1 - T_0}$) measured in degrees Centigrade, is:

$$S = (R_1 - R_0)(G)\left(\frac{1{,}000{,}000}{8}\right) - 22.5(T_1 - T_0) \text{ microstrain}$$

Equation 2 - Strain Calculation with Temperature Correction

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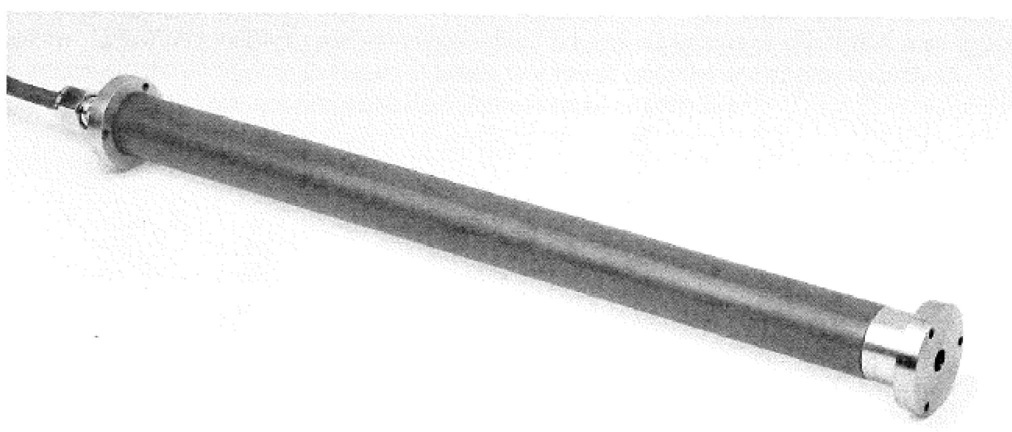
Instruction Manual

Model 3900

Embedment Strain Gauge



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