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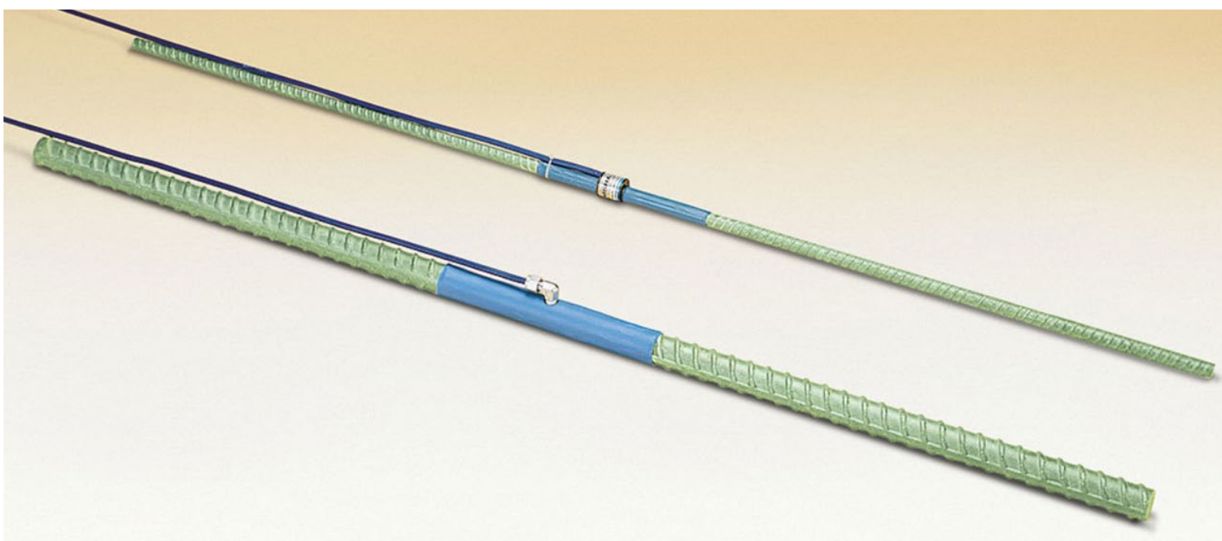
Installation Manual

Models 4911/4911A

Vibrating Wire Rebar Strain Meters



(Doc Rev S.1, 08/05/24)

Warranty Statement

Geokon warrants its products to be free of defects in materials and workmanship, under normal use and service for a period of 13 months from date of purchase. If the unit should malfunction, it must be returned to the factory for evaluation, freight prepaid. Upon examination by Geokon, if the unit is found to be defective, it will be repaired or replaced at no charge. However, the WARRANTY is VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion or current, heat, moisture or vibration, improper specification, misapplication, misuse or other operating conditions outside of Geokon's control. Components which wear or which are damaged by misuse are not warranted. This includes fuses and batteries.

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Every precaution for accuracy has been taken in the preparation of manuals and/or software, however, Geokon neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damages or losses that result from the use of the products in accordance with the information contained in the manual or software.

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EQUATIONS

1. INTRODUCTION

Geokon Vibrating Wire Rebar Strain Meters are designed primarily for monitoring the stress exerted upon reinforcing steel inside concrete structures, such as bridges, concrete piles, and diaphragm walls. The strain meter comprises a length of high strength steel, bored along its central axis to accommodate a miniature vibrating wire strain gauge. Both models of strain meters are robust, reliable, and easy to install and read. They are unaffected by moisture, cable length, or contact resistance. The long-term stability of these instruments has proven to be excellent.

Readout of the load or stress is achieved remotely using a portable readout or datalogging system available from Geokon. Each strain meter is supplied with a calibration report, which shows the relationship between readout digits and microstrain. The calibration report also shows the initial no load zero reading.

Model 4911 Vibrating Wire Rebar Strain Meter or “Sister Bar” (Figure 1) comprises a short length of high strength steel welded between two sections of reinforcing bar. It is designed to be wire tied in parallel with structural rebar. The small diameter of the 4911 minimizes its affect on the sectional modulus of the concrete. The cable exits the strain meter through a small block of protective epoxy.

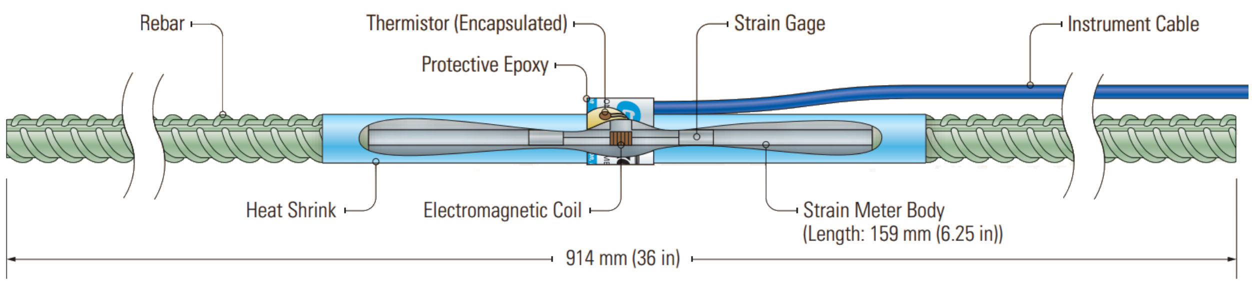

Figure 1 - Model 4911 Rebar Strain Meter

Model 4911A Vibrating Wire Rebar Strain Meter (Figure 2) comprises a short length of high strength steel welded between two sections of reinforcing bar. It is designed to be welded between sections of structural concrete reinforcing bar. The cable exits the strain meter via a compression fitting.

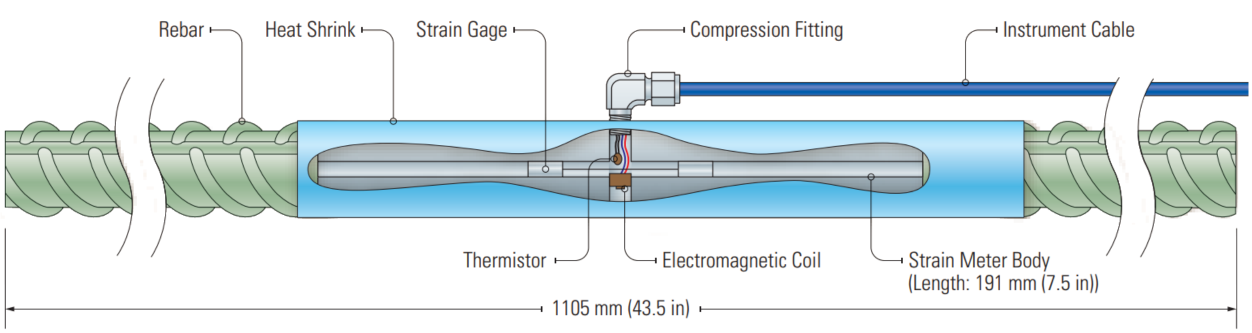

Figure 2 - Model 4911A Rebar Strain Meter

2. INSTALLATION

2.1 Preliminary Test

A preliminary check should be performed before installing gauges in the field. To perform the preliminary check, complete the following steps:

Warning! Do not lift the strain meter by the cable.

1) Connect the gauge to a readout box. (See readout instructions in Section 3.) Observe the displayed readout.

2) Compare the zero reading given on the calibration report to the current zero reading. Under normal circumstances the two readings should not differ by more than 25 digits (10 microstrains), however, shocks incurred during shipping may cause larger shifts. If the reading is within 100 digits (40 microstrains) of the factory zero, and is stable, it is safe to proceed with the installation.

3) Pull on the strain meter ends; confirm that digits on the readout rise as the tension increases.

Checks of electrical continuity can be made using an ohmmeter. The resistance between the two lead wires (usually red and black) should be around 50 ohms. Remember to add the cable resistance, approximately 14.7Ω for every 1000 ft. (48.5Ω per km) at 20 °C. Multiply these factors by two to account for both directions.

Resistance between the two thermistor wires (usually white and green) varies with temperature. Use Table 5 in Appendix B to convert the resistance to temperature and compare the result to the ambient temperature.

Resistance between any conductor and the shield should exceed two megohms.

If the strain meter fails any of the preliminary tests, see Section 5 for troubleshooting.

2.2 Installing Model 4911, "Sister Bar"

Sister Bars are usually installed using standard iron tie wire. Ties near the ends and at the one-third points are enough if the gauge is being wired to a larger section of rebar or to horizontal bars. Wiring at the one third points alone is enough if the gauge is being wired in parallel to the structural rebar. Route the instrument cable along the rebar system and tie it off every three to four feet (one-meter) using nylon cable ties. Avoid using the tie wire on the instrument cable as it could cut the cable. See Figure 3 and Figure 4 on the following page.

Be sure to note the location and serial numbers of all instruments during the installation process. This information is necessary to apply the proper calibration factors and determine strain characteristics when reducing data.

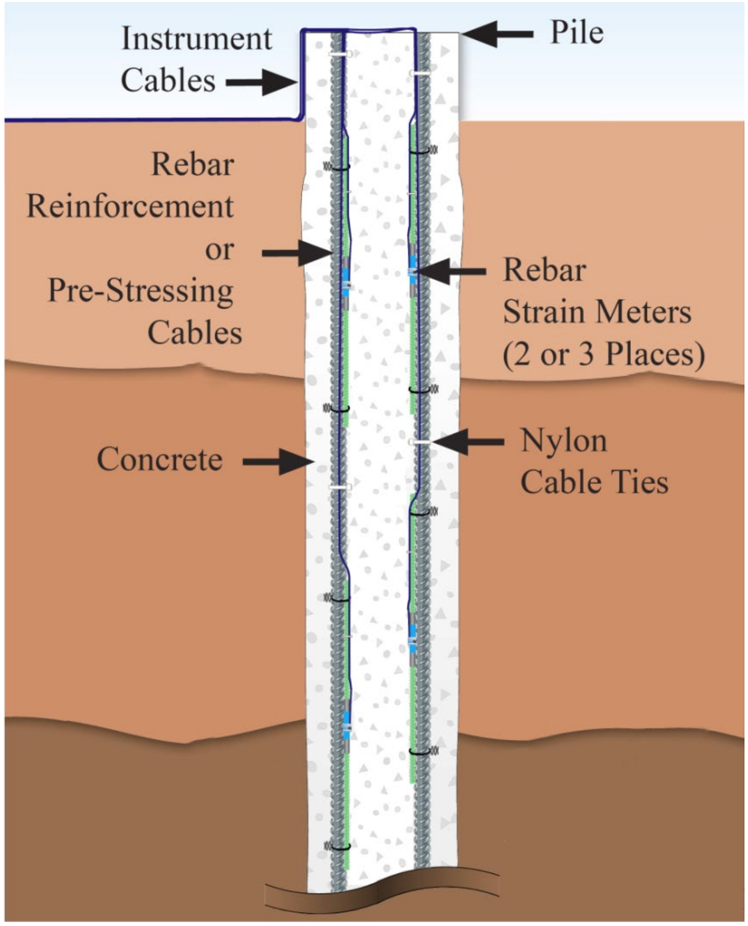

Figure 3 - Model 4911 "Sister Bar" Installation

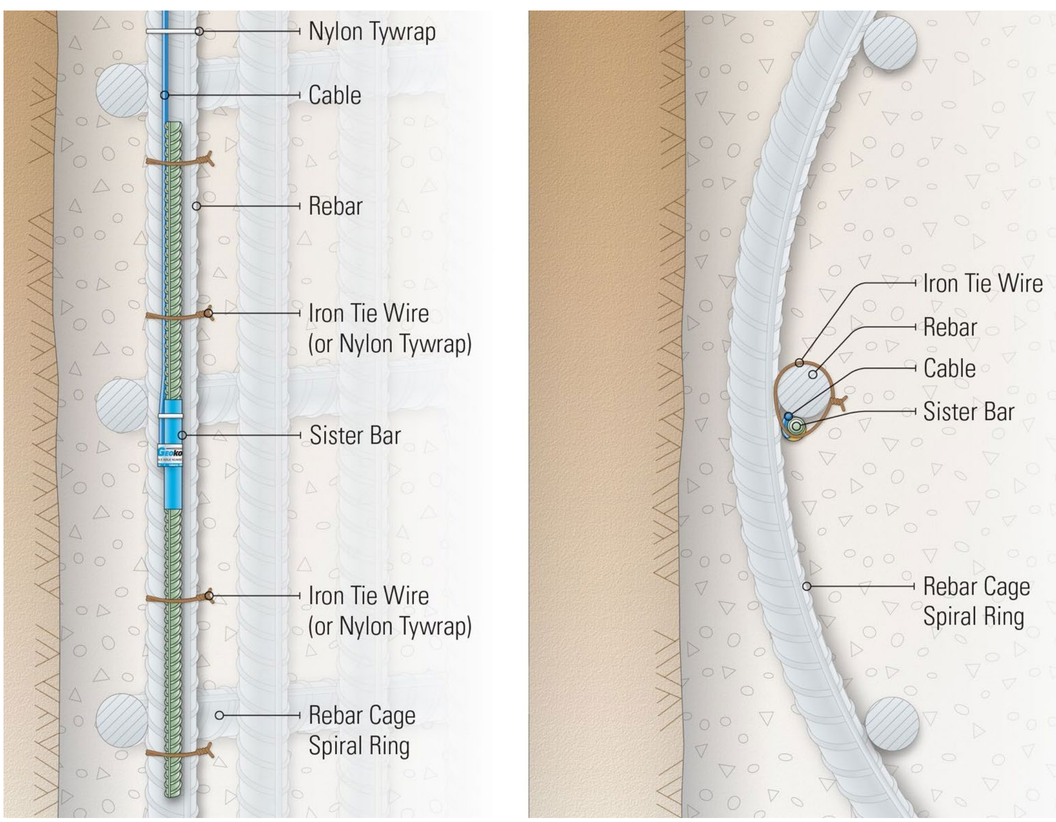

Figure 4 - Model 4911 "Sister Bar" Installation Detail

2.3 Installing Model 4911A

Normally the strain meter is welded in series with the reinforcing steel that is to be instrumented on site. The strain meter is of sufficient length that it may be welded in place without damaging the internal strain gauge element. However, care should still be taken to ensure that the central portion of the strain meter does not become too hot, as the plucking coil and protective epoxy could melt. In order to prevent this, it may be necessary to place wet rags between the weld area and the coil housing. Take care not to damage or burn the instrument cable during welding. After welding, route the instrument cable along the rebar system and tie it off every three to four feet (one-meter) using nylon cable ties. Avoid using iron tie wire to secure the cable as the cable could be cut. Figure 5 show a typical 4911 installation.

Be sure to note the location and serial numbers of all instruments during the installation process. This information is necessary for applying the proper calibration factors and determining strain characteristics when reducing data.

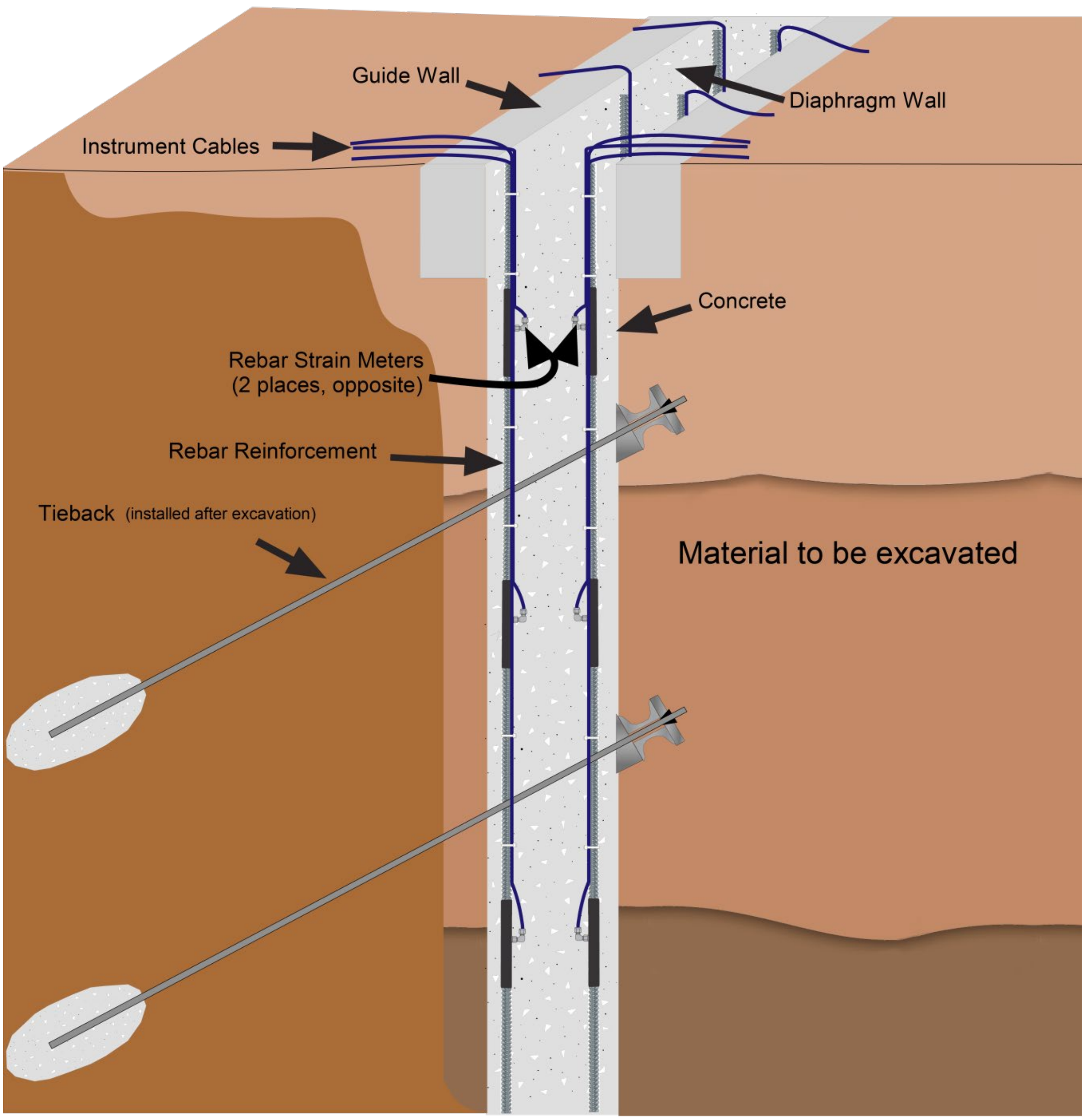

Figure 5 - Model 4911A Installation

2.4 Cable Installation

As noted in the in the previous sections, instrument cables should be routed along the structural rebar and secured with nylon cable ties every two to three feet (one-meter). Outside of the instrumented structure, the cable should be protected from accidental damage caused by moving equipment or other construction activity.

2.5 Cable Splicing and Termination

Terminal boxes with sealed cable entries are available from Geokon for all types of applications. These allow many gauges to be terminated at one location with complete protection of the lead wires. The interior panel of the terminal box can have built-in jacks or a single connection with a rotary position selector switch. Contact Geokon for specific application information.

Cables may be terminated by stripping and tinning the individual conductors and then connecting them to the patch cord of a readout box. Alternatively, a connector may be used which will plug directly into the readout box or to a receptacle on a special patch cord.

The cable from the strain meters can also be protected using flexible conduit, which can be supplied by Geokon.

Because the vibrating wire output signal is a frequency rather than a current or voltage, variations in cable resistance have little effect on gauge readings; therefore, splicing of cables has no ill effects, and in some cases may in fact be beneficial. The cable used for making splices should be a high-quality twisted pair type, with 100% shielding and an integral shield drain wire.

When splicing, it is very important that the shield drain wires be spliced together. Always maintain polarity by connecting color to color.

Splice kits recommended by Geokon incorporate casts that are placed around the splice and are then filled with epoxy to waterproof the connections. When properly made, this type of splice is equal or superior to the cable in strength and electrical properties. Contact Geokon for splicing materials and additional cable splicing instructions.

2.6 Lightning Protection

Unlike numerous other types of instrumentation available from Geokon, rebar strain meters do not have any integral lightning protection components, such as transorbs or plasma surge arrestors. Usually this is not a problem, as these types of gauges are installed within concrete and are somewhat isolated from potentially damaging electrical transients. However, there may be occasions where some sort of lightning protection is desirable, for example, where the instrument is in contact with rebar that is exposed to direct or indirect lightning strikes. In addition, if the instrument cable is exposed, it may be appropriate to install lightning protection components, as the transient could travel down the cable to the gauge and possibly destroy it.

Suggested Lightning Protection Options:

- If the instrument is connected to a terminal box or multiplexer, components such as plasma surge arrestors (spark gaps) may be installed in the terminal box/multiplexer to provide a measure of transient protection. Terminal boxes and multiplexers available from Geokon provide locations for the installation of these components.

- Lighting arrestor boards and enclosures are also available from Geokon. These units install where the instrument cable exits the structure being monitored. The enclosure has a removable top to allow the customer to service the components or replace the board if the unit is damaged by a lightning strike. A connection is made between the enclosure and earth ground to facilitate the passing of transients away from the strain meter. See Figure 6 below.

- Plasma surge arrestors can be epoxied into the instrument cable, close to the instrument. A ground strap then connects the surge arrestor to an earth ground, such as a grounding stake or the rebar itself.

  Consult the factory for additional information on available lightning protection.

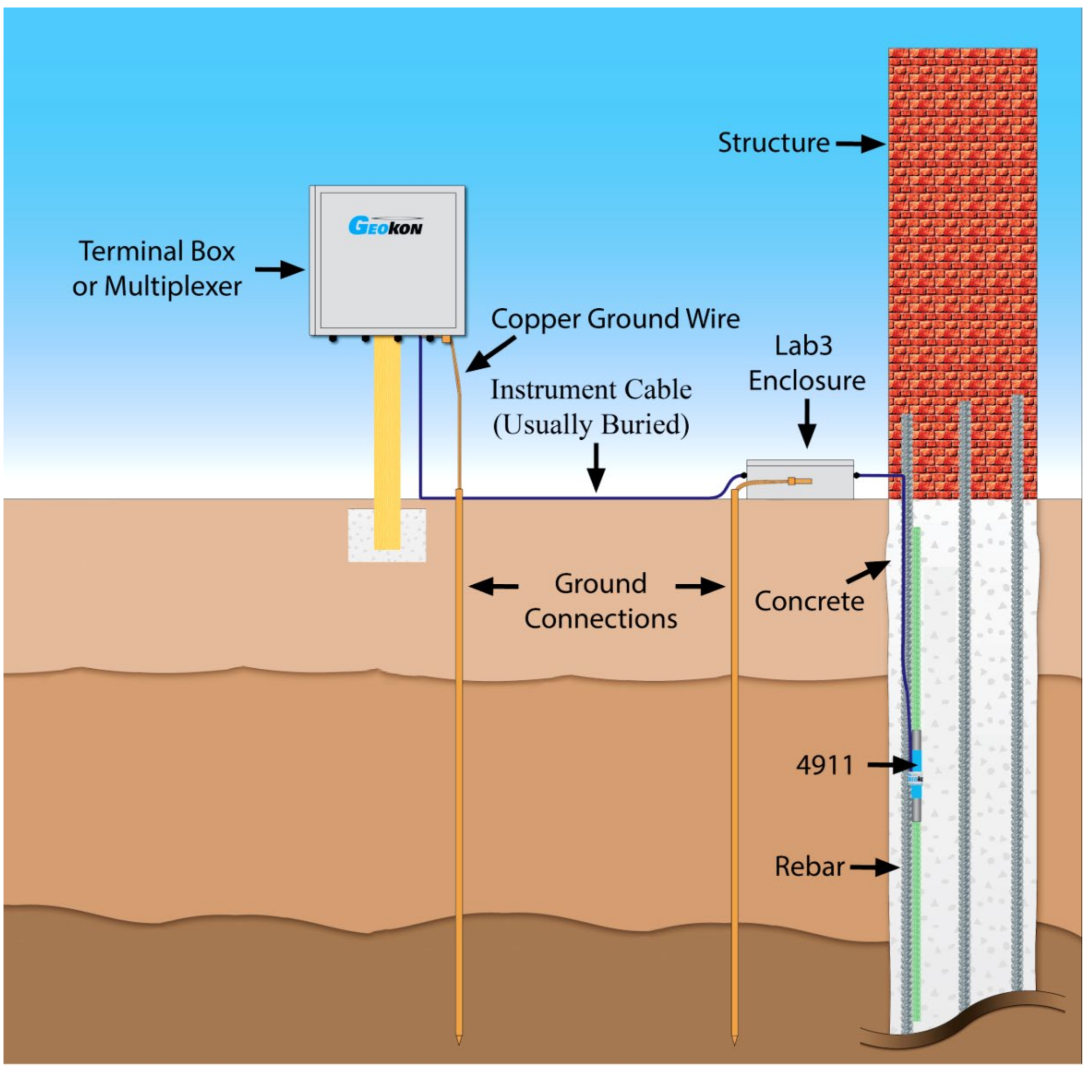

Figure 6 - Recommended Lightning Protection Scheme

3. TAKING READINGS

3.1 GK-404 Readout Box

The Model GK-404 Vibrating Wire Readout is a portable, low-power, handheld unit that can run continuously for more than 20 hours on two AA batteries. It is designed for the readout of all Geokon vibrating wire gauges, load cells, and transducers; and is capable of displaying the reading in either digits, frequency (Hz), period (μs), or microstrain (με). The GK-404 also displays the temperature of the load cell (embedded thermistor) with a resolution of 0.1 °C.

3.1.1 Operating the GK-404

Before use, attach the flying leads to the GK-404 by aligning the red circle on the silver "Lemo" connector of the flying leads with the red line on the top of the GK-404 (Figure 7). Insert the Lemo connector into the GK-404 until it locks into place.

Figure 7 - Lemo Connector to GK-404

Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

To turn the GK-404 on, press the "ON/OFF" button on the front panel of the unit. The initial startup screen will be displayed. After approximately one second, the GK-404 will start taking readings and display them based on the settings of the POS and MODE buttons.

The unit display (from left to right) is as follows:

- The current Position: Set by the **POS** button. Displayed as a letter A through F.
- The current Reading: Set by the **MODE** button. Displayed as a numeric value followed by the unit of measure.
- Temperature reading of the attached gauge in degrees Celsius.

Use the **POS** button to select position **B** and the **MODE** button to select **Dg** (digits). (Other functions can be selected as described in the GK-404 Manual.)

The GK-404 will continue to take measurements and display readings until the unit is turned off, either manually, or if enabled, by the Auto-Off timer. If the no reading displays or the reading is unstable, see Section 5 for troubleshooting suggestions.

For further details, please refer to the GK-404 manual.

3.2 GK-405 Readout Box

The GK-405 Vibrating Wire Readout is made up of two components: The Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout Application; and the GK-405 Remote Module, which is housed in a weatherproof enclosure and connects to the vibrating wire gauge to be measured. The two components communicate wirelessly. The Readout Unit can operate from the cradle of the Remote Module, or, if more convenient, can be removed and operated up to 20 meters from the Remote Module.

3.2.1 Connecting Sensors 10-pin Bulkhead Connectors Attached

Align the grooves on the sensor connector (male), with the appropriate connector on the readout (female connector labeled senor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

3.2.2 Connecting Sensors with Bare Leads

Attach the GK-403-2 flying leads to the bare leads of a Geokon vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.2.3 Operating the GK-405

Press the button labeled “POWER ON”. A blue light will begin blinking, signifying that the Remote Module is waiting to connect to the handheld unit. Launch the GK-405 VWRA program by tapping on “Start” from the handheld PC’s main window, then “Programs” then the GK-405 VWRA icon. After a few seconds, the blue light on the Remote Module should stop flashing and remain lit. The Live Readings Window will be displayed on the handheld PC. Figure 8 shows a typical vibrating wire output in digits and thermistor output in degrees Celsius. If the no reading displays or the reading is unstable, see Section 5 for troubleshooting suggestions.

For further information, consult the GK-405 Instruction Manual.

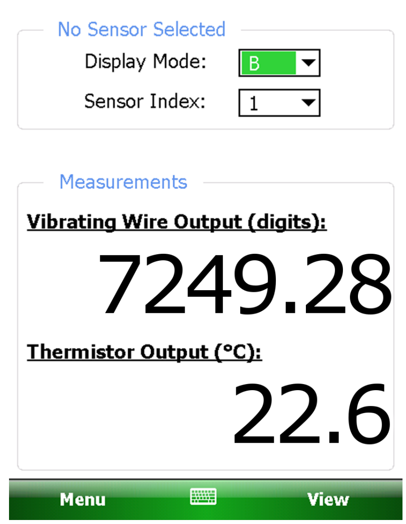

Figure 8 - Live Readings – Raw Readings

3.3 GK-403 Readout Box (Obsolete Model)

The GK-403 can store gauge readings and apply calibration factors to convert readings to engineering units. The following instructions explain taking gauge measurements using Modes “B”. Consult the GK-403 Instruction Manual for additional information.

3.3.1 Connecting Sensors with 10-pin Bulkhead Connectors Attached

Align the grooves on the sensor connector (male), with the appropriate connector on the readout (female connector labeled senor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

3.3.2 Connecting Sensors with Bare Leads

Attach the GK-403-2 flying leads to the bare leads of a Geokon vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.3.3 Operating the GK-403

1) Turn the display selector to position “B”.

2) Turn the unit on.

3) The readout will display the vibrating wire output in digits. The last digit may change one or two digits while reading.

4) The thermistor reading will be displayed above the gauge reading in degrees centigrade.

5) Press the “Store” button to record the value displayed.

If the no reading displays or the reading is unstable, see Section 5 for troubleshooting suggestions.

The unit will automatically turn off after approximately two minutes to conserve power.

3.4 Measuring Temperatures

All vibrating wire strain meters are equipped with a thermistor, which gives a varying resistance output as the temperature changes. The white and green leads of the instrument cable are normally connected to the internal thermistor.

The GK-403, GK-404, and GK-405 readout boxes will read the thermistor and display the temperature in degrees C.

To read temperatures using an ohmmeter:

1) Connect an ohmmeter to the green and white thermistor leads coming from the strain meter. (Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant. For long cables a correction can be applied, equal to approximately 14.7Ω per 1000 ft. (48.5Ω per km) at 20 °C. Multiply these factors by two to account for both directions.)

2) Look up the temperature for the measured resistance in Appendix B, Table 5**.**

4. DATA REDUCTION

4.1 Strain Calculation

The basic units utilized by Geokon for measurement and reduction of data are “digits”. Calculation of digits is based on the following equation:

$$\text{Digits} = \left(\frac{1}{T}\right)^2 \text{ x } 10^{-3} \text{ or Digits} = \frac{Hz^2}{1000}$$

Equation 1 - Digits Calculation

Where;
T is the period in seconds.
Hz is the frequency in cycles per second.

To convert digits to strain the following equation applies:

$$\varepsilon_{apparent} = (R_1 - R_0) \times C$$

Equation 2 - Apparent Strain

Where;
R_0 is the initial reading in digits, usually obtained at installation or at the commencement of a test.
R_1 is the current reading in digits.
C is the calibration factor from the supplied calibration report. (For an example of a typical strain meter calibration report see Figure 10 in Appendix D.)

For example: Assuming an initial reading (R_0) of 8000 digits, a current reading (R_1) of 7700, and a calibration factor (C) of 0.343 microstrains per digit; the strain calculation would be as follows:
$\varepsilon_{apparent} = (7700 - 8000) \times 0.343 = - 102.9\ \mu\varepsilon$ (compression)

4.2 Temperature Correction

The assumption with strain meters embedded in concrete is that ***the strain in the meter is equal to the strain in the concrete***. However, when the temperature changes the concrete expands and contracts at a rate slightly less than the rate of the steel of the vibrating wire. The coefficients of this expansion are shown in the table below.

Steel (K_{steel}):	12.2 ppm/°C	6.7 ppm/°F
Concrete ($K_{concrete}$):	≈10 ppm/°C	≈5.5 ppm/°F
Difference (K):	2.2 ppm/°C	1.2 ppm/°F

Table 1 - Thermal Coefficients

Because of the difference in these two coefficients, a correction is required to the apparent strains, equal to the difference of the two coefficients. The equation for this correction is as follows:

$$\varepsilon_{\text{load related}} = ((R_1 - R_0) \times C) + ((T_1 - T_0) \times K)$$

Equation 3 - Load Related Strain

Where;
T_0 is the initial temperature recorded at the time of installation.
T_1 is the current temperature.
K is the thermal coefficient from Table 1.

The strains thus calculated are due to load changes only.

Using the same theoretical example from Section 4.1, where R_0 = 8000 digits on channel B, and R_1 = 7700 digits on channel B, with the addition of temperature, T_0 = 20 °C and T_1 = 60 °C (during the concrete curing); the strain corrected for temperature (i.e. due to load changes only) can be calculated as follows:

$\varepsilon_{\text{load related}}$ = (7700 – 8000) 0.343 + (60 – 20) (12.2 – 10) = – 14.9 µstrain (compression)

Please note that the **actual** strain undergone by the concrete, (e.g., that which would be measured by a tape measure,) is given by the formula:

$$\varepsilon_{\text{actual}} = ((R_1 - R_0) \times C) + ((T_1 - T_0) \times K_{\text{steel}})$$

Equation 4 - Actual Strain

Apparent strain =
(7700 – 8000) x 0.343 = – 103 µstrain (compression)

Load related strain =
(7700 – 8000) x 0.343 + (60 – 20) x (12.2 – 10) = – 15 µstrain (compression)

Actual strain =
(7700 – 8000) x 0.343 + (60-20) x (12.2) = +385 µstrain (tension)

From the above example, it can be seen that while the concrete was actually expanding by 385 microstrains due to the temperature increase, the apparent strain was 103 microstrains in compression, and the actual change of strain due to increased stress in the concrete was only 15 microstrains compression.

4.3 Environmental Factors

Since the purpose of the strain meter installation is to monitor site conditions, factors which may affect these conditions should always be observed and recorded. Seemingly minor effects may have a real influence on the behavior of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to: blasting, rainfall, tidal levels, traffic, temperature and barometric changes, weather conditions, changes in personnel, nearby construction activities, excavation and fill level sequences, seasonal changes, etc.

4.4 Shrinkage Effects

A well know property of concrete is its propensity to shrink as the water content diminishes and to swell as it absorbs water. This shrinkage and swelling can give rise to large strain changes that are not related to load or stress. The magnitude of these strains can be several hundred microstrains.

It is difficult to compensate for these unwanted strains. An attempt may be made to keep the concrete under a constant condition of water content, but this is frequently impossible on concrete structures exposed to varying weather conditions. The shrinkage and/or swelling effect may be measured by casting a strain meter inside a concrete block that remains unloaded, yet still exposed to the same moisture conditions as the active gauges. Strains measured on this gauge may be used as a correction factor.

4.5 Converting Strains to Loads

The load in any structural element to which the strain meter is attached is given by the formula:

$$L = E \mu A$$

Equation 5 - Strain to Load Formula

Where;
L is the load.
E is the elastic modulus of the structural element in the appropriate units.
μ is the strain in microstrain.
A is the cross-sectional area in the appropriate units.

When installing strain meters in concrete piles it is standard practice to install them in pairs on either side of the neutral axis. This allows any strains imposed by bending to be corrected by taking the average strain of the two gauges. It is also standard practice to install a pair of strain meters close to the top of the pile. The measured strain of these two gauges is used to calculate the modulus of the concrete.

5. TROUBLESHOOTING

Maintenance and troubleshooting of rebar strain meters is confined to periodic checks of cable connections and maintenance of terminals. Once installed, the strain meters are usually inaccessible and remedial action is limited. **Gauges should not be opened in the field.**

Should difficulties arise, consult the following list of problems and possible solutions. Return any faulty gauges to the factory. For additional troubleshooting and support contact Geokon.

Symptom: Thermistor resistance is too high

- ✓ It is likely that there is an open circuit. Check all connections, terminals, and plugs. If a cut is located in the cable, splice according to instructions in Section 2.5.

Symptom: Thermistor resistance is too low

- ✓ It is likely that there is a short. Check all connections, terminals, and plugs. If a short is located in the cable, splice according to instructions in Section 2.5.
- ✓ Water may have penetrated the interior of the strain meter. There is no remedial action.

Symptom: Strain Meter Readings are Unstable

- ✓ Is the readout box position set correctly? If using a datalogger to record readings automatically, are the swept frequency excitation settings correct?
- ✓ Is there a source of electrical noise nearby? Likely candidates are generators, motors, arc welding equipment, high voltage lines, etc. If possible, move the instrument cable away from power lines and electrical equipment or install electronic filtering.
- ✓ Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger. Connect the shield drain wire to the readout using the blue clip. (Green for the GK-401.)
- ✓ Does the readout work with another strain meter? If not, it may have a low battery or possibly be malfunctioning.

Symptom: Strain Meter Fails to Read

- ✓ Is the cable cut or crushed? Check the resistance of the cable by connecting an ohmmeter to the gauge leads. Table 2 shows the expected resistance for the various wire combinations; Table 3 is provided for the user to fill in the actual resistance found. Cable resistance is approximately 14.7Ω per 1,000 feet (48.5Ω per km); multiply this factor by two to account for both directions. If the resistance is very high or infinite (megohms), the cable is probably broken or cut. If the resistance is very low (<20Ω), the gauge conductors may be shorted. If a cut or a short is located in the cable, splice according to the instructions in Section 2.5.
- ✓ Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.

Vibrating Wire Sensor Lead Grid - SAMPLE VALUES					
	Red	**Black**	**White**	**Green**	**Shield**
Red	N/A	≅50Ω	infinite	infinite	infinite
Black	≅50Ω	N/A	infinite	infinite	infinite
White	infinite	infinite	N/A	3000Ω at 25°C	infinite
Green	infinite	infinite	3000Ω at 25°C	N/A	infinite
Shield	infinite	infinite	infinite	infinite	N/A

Table 2 - Sample Resistance

Vibrating Wire Sensor Lead Grid - SENSOR NAME/## :					
	Red	**Black**	**White**	**Green**	**Shield**
Red					
Black					
White					
Green					
Shield					

Table 3 - Resistance Work Sheet

APPENDIX A. SPECIFICATIONS

A.1 Rebar Strain Meters

Model:	4911 "Sister Bar"	4911A
Range[1]:	3000 με	
Rebar Sizes Available[2]:	#4	#5, #6, #7, #8, #9, #10, #11, #14
Sensitivity:	± 0.025% F.S.	
Accuracy:	± 0.25% F.S.	
Linearity:	< 0.5% F.S.	
Operating Temperature:	-20 to +80 °C	
Operating Frequency:	1400-3200 Hz	
Coil Resistance:	50Ω, ±5Ω	
Length:	914 mm (36")	1105 mm (43.5")
Materials:	Grade 60 Rebar, (60 ksi yield), and High Strength Steel	
Electrical Cable:	Two twisted pair (Four conductor) 22 AWG Foil shield, PVC jacket, nominal OD=6.3 mm (0.250")	

Table 4 - Model 4911A/4911 Strain Meter Specifications

Notes:
[1] The standard factory setting allows for 2000 με in compression and 1000 με in tension. Other initial settings available upon request.
[2] Consult the factory for other sizes available.

A.2 Thermistor
(See Appendix B also)

Range: -80 to +150° C
Accuracy: ±0.5° C

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3
Resistance to Temperature Equation:

$$T=\frac{1}{A+B(\mathrm{LnR})+C(\mathrm{LnR})^3}-273.15\ ^\circ\mathrm{C}$$

Equation 6 - Resistance to Temperature

Where;
T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance.
$A = 1.4051 \times 10^{-3}$
$B = 2.369 \times 10^{-4}$
$C = 1.019 \times 10^{-7}$
Note: Coefficients calculated over the −50 to +150° C. span.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	**3000**	**25**	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

Table 5 - Thermistor Resistance Versus Temperature

APPENDIX C. DERIVING THE CALIBRATION FACTOR (C) FROM THE TEST DATA

Geokon Rebar Strain Meters are calibrated by loading them in a testing machine; hence, the gauge factor (C) must be determined after converting loads to strains. This is done as follows:

The central section of the rebar strain meter, (the unbonded length) which is 7.5" or 19.05 cm long, contains a vibrating wire sensor located axially at the midsection. See Figure 9.

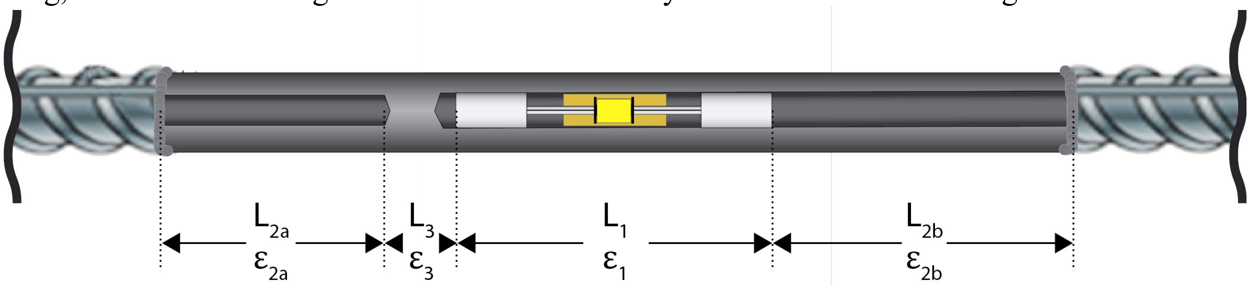

Figure 9 - Rebar Strain Meter Schematic

To convert the observed change in readout digits (ΔR) into a strain (ε_t) for the entire length of the unbonded section (7.5 in./19.05 cm), requires the following equation:

$$\varepsilon_t = \frac{(\varepsilon_1 \times L_1) + (\varepsilon_2 \times L_2) + (\varepsilon_3 \times L_3)}{L_1 + L_2 + L_3}$$

Equation 7 - Total Strain Calculation

Where;
L_1 is 2.000" (5.08 cm).
L_2 is 5.000" (12.7 cm).
L_3 is 0.500" (1.27 cm).
ε_t is the total strain of the unbonded section.

ε_1 is the strain in zone one, determined empirically from the equation for the vibrating wire sensor, i.e., $\varepsilon_1 = \Delta R \times 0.359 \times 10^{-6}$ where ΔR is the change in readout digits.

ε_2, ε_3 are the strains in zones two and three, respectively, dependent on the load and cross-sectional area, see Equation 8 and Equation 9.

$$\varepsilon_2 = \frac{P}{a_2 \times E}$$

Equation 8 - Zone Two Calculation

$$\varepsilon_3 = \frac{P}{a_3 \times E}$$

Equation 9 - Zone Three Calculation

Where;
P is the load in pounds or kilograms.
a_2 and a_3 are the cross-sectional areas in $inches^2$ or cm^2. See Table 6.
E is the Young's Modulus, 30×10^6 psi or 2.1×10^6 kg/cm^2 (or MPa × 10.197)

P is also given by the following equation:

$$P = \Delta R \times F$$

Equation 10 - Load in Pounds/Kilograms

Where;
P is the applied load in pounds or kilograms.
ΔR is the corresponding change in readout digits.
F is the calibration factor expressed as lbs. or kg. per readout digit.

Rebar Size	Diameter	a_2	a_3
#4	0.500 in. 1.27 cm	0.196 in^2 1.264 cm^2	0.248 in^2 1.60 cm^2
#5	0.625 in. 1.59 cm	0.3058 in^2 1.973 cm^2	0.357 in^2 2.303 cm^2
#6	0.750 in. 1.905 cm	0.390 in^2 2.516 cm^2	0.442 in^2 2.852 cm^2
#7	0.875 in. 2.222 cm	0.549 in^2 3.542 cm^2	0.601 in^2 3.877 cm^2
#8	1.000 in. 2.54 cm	0.733 in^2 4.729 cm^2	0.785 in^2 5.065 cm^2
#9	1.125 in. 2.858 cm	0.942 in^2 6.077 cm^2	0.994 in^2 6.413 cm^2
#10	1.250 in. 3.175 cm	1.175 in^2 7.580 cm^2	1.227 in^2 7.916 cm^2
#11	1.375 in. 3.493 cm	1.432 in^2 9.239 cm^2	1.485 in^2 9.580 cm^2
#12	1.500 in	1.714 in^2	1.766 in^2
#14	1.750 in	2.352 in^2	2.404 in^2

Table 6 - Unbonded Section Dimensions

By making the various substitutions of Table 6 the relationship between strain in the unbonded section versus change in readout digits can be obtained.

Using the #6 rebar as an example, with English conventions, yields the following:

$$\varepsilon_t = \Delta R \times \left(\frac{0.359 \times 2 + F\left(\frac{5}{30 \times 0.390} + \frac{0.5}{30 \times 0.442} \right)}{7.5} \right) \times 10^{-6}$$

$$\varepsilon_t = \Delta R \left(0.0957 + F(0.06205) \times 10^{-6} \right)$$

Doing these calculations for the other sizes of rebar yields the data shown in Table 7. Use Table 7 to obtain the microstrain/digit gauge factor (C) from the lbs. or kg. per digit gauge factor (F).

Rebar Size	Conversion Formula - English	Conversion Formula - Metric
#4	C = 0.0957 + F x 0.12220	C = 0.0957 + F x 0.2707
#5	C = 0.0957 + F x 0.07888	C = 0.0957 + F x 0.2091
#6	C = 0.0957 + F x 0.06205	C = 0.0957 + F x 0.1373
#7	C = 0.0957 + F x 0.04416	C = 0.0957 + F x 0.0977
#8	C = 0.0957 + F x 0.03310	C = 0.0957 + F x 0.0733
#9	C = 0.0957 + F x 0.02584	C = 0.0957 + F x 0.0572
#10	C = 0.0957 + F x 0.02073	C = 0.0957 + F x 0.0459
#11	C = 0.0957 + F x 0.01700	C = 0.0957 + F x 0.0377
#12	C = 0.0957 + F x 0.01422	C = 0.0957 + F x 0.0315
#14	C = 0.0957 + F x 0.01037	C = 0.0957 + F x 0.0230

Table 7 - Microstrain Conversion Factors

APPENDIX D. SAMPLE CALIBRATION REPORT

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Sister Bar Calibration Report

Model Number: 4911-4-SSME

Date of Calibration: March 27, 2018

This calibration has been verified/validated as of 04/27/2018

Serial Number: 1809585

Cable Length: 3 meters

Temperature: 22.5 °C

Regression Zero: 7002

Calibration Instruction: CI-VW Rebar

Technician:

Applied Load (pounds)	Readings				Linearity % Max. Load
	Cycle #1	Cycle #2	Average	Change	
100	7048	7052	7050		
1500	7731	7734	7733	683	0.03
3000	8458	8464	8461	728	-0.01
4500	9190	9192	9191	730	0.00
6000	9917	9924	9921	730	-0.01
100	7053	7056	7055		

For conversion factor, load to strain, refer to table C-2 of the Installation Manual

Gage Factor: 0.347 microstrain/ digit (GK-401 Pos. "B")

Calculated Strain = Gage Factor(Current Reading - Zero Reading)

Note: The above calibration uses the linear regression method.

Users are advised to establish their own zero conditions.

Linearity: ((Calculated Load - Applied Load)/Max. Applied Load) X 100 percent

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.

Figure 10 - Sample Model 4911 Calibration Report