The World Leader in Vibrating Wire Technology

48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603•448•1562
Fax: 603•448•3216
E-mail: geokon@geokon.com
http://www.geokon.com

Installation Manual

Models 4911A/4911

VW Rebar Strain Meters

(Doc Rev M, 08/10)

Warranty Statement

Geokon, Inc. 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.

Geokon manufactures scientific instruments whose misuse is potentially dangerous. The instruments are intended to be installed and used only by qualified personnel. There are no warranties except as stated herein. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Geokon, Inc. is not responsible for any damages or losses caused to other equipment, whether direct, indirect, incidental, special or consequential which the purchaser may experience as a result of the installation or use of the product. The buyer's sole remedy for any breach of this agreement by Geokon, Inc. or any breach of any warranty by Geokon, Inc. shall not exceed the purchase price paid by the purchaser to Geokon, Inc. for the unit or units, or equipment directly affected by such breach. Under no circumstances will Geokon reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

Every precaution for accuracy has been taken in the preparation of manuals and/or software, however, Geokon, Inc. 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.

TABLE of CONTENTS

Page

LIST of FIGURES, TABLES and EQUATIONS

Page

1. INTRODUCTION

Geokon Vibrating Wire Rebar Strain Meters are designed primarily for monitoring the stresses in reinforcing steel in concrete structures, such as bridges, concrete piles and diaphragm walls. The strain meter is comprised of a length of high strength steel, bored along its central axis to accommodate a miniature vibrating wire strain gage. Readout of load or stress is achieved remotely using a portable readout or datalogging system available from Geokon.

The Model 4911A Vibrating Wire Rebar Strain Meter consists of a short length of high strength steel welded between two 18" (457 mm) long sections of reinforcing bar. It is designed to be welded between sections of structural concrete reinforcing bar. The cable exits from the strain meter via a compression fitting. See Figure 1.

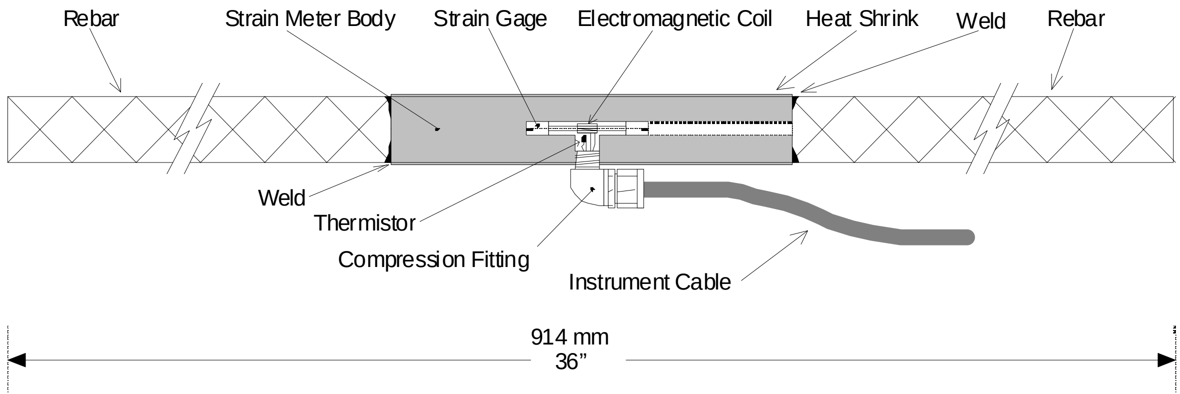

Figure 1 - Model 4911A Rebar Strain Meter

The Model 4911 Vibrating Wire Rebar Strain Meter or "Sister Bar" consists of a short length of high strength steel welded between two 14" (356 mm) long sections of reinforcing bar. It is designed to be wire tied in parallel with the structural rebar. The small diameter of the bar minimizes its affect on the sectional modulus of the concrete. The cable exits from the strain meter through a small block of protective epoxy. See Figure 2.

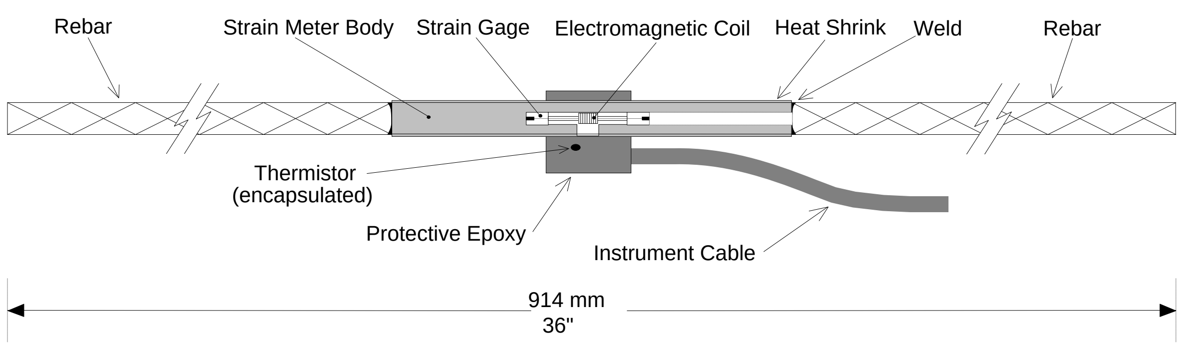

Figure 2 - Model 4911 Rebar Strain Meter

Both models of strain meters are robust, reliable and easy to install and read, and are unaffected by moisture, cable length or contact resistance. The long term stability of these instruments has proven to be excellent.

2. INSTALLATION

2.1. Preliminary Tests

It is always wise, before installation commences, to check the strain meters for proper function. Each strain meter is supplied with a calibration sheet that shows the relationship between readout digits and microstrain and also shows the initial no load zero reading. The strain meter electrical leads (usually the red and black leads) are connected to a readout box (see section 3) and the zero reading given on the sheet is now compared to a current zero reading. Under normal circumstances the two readings should not differ by more than about 25 digits (10 microstrain). Shipping shocks may, however, cause larger shifts. If the reading is within 100 digits (40 microstrain) of the factory zero, and is stable, it is safe to proceed with the installation.

By pulling on the strain meter it should be possible to change the readout digits, causing them to rise as tension increases.

Checks of electrical continuity can also be made using an ohmmeter. For the 4911A, resistance between the gage leads should be approximately 50 Ω, ±10 Ω, for the 4911, 50 Ω, ±10 Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). Between the green and white should be approximately 3000 ohms at 25° (see Table B-1), and between any conductor and the shield should exceed 2 megohm.

Note: Do not lift the strain meter by the cable.

2.2. Rebar Strain Meter Installation

2.2.1. Model 4911A

The normal procedure is to weld the strain meter in series with the reinforcing steel that is to be instrumented on the site. For a typical installation see Figure 3. The strain meter is long enough so that it may be welded in place without damaging the internal strain gage element (Figure 1). 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. Also, take care not to damage or burn the instrument cable when welding. After welding, route the instrument cable along the rebar system and tie it off every 3-4 feet (1 meter) using nylon cable ties. Avoid using iron tie wire to secure the cable as the cable could be cut.

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

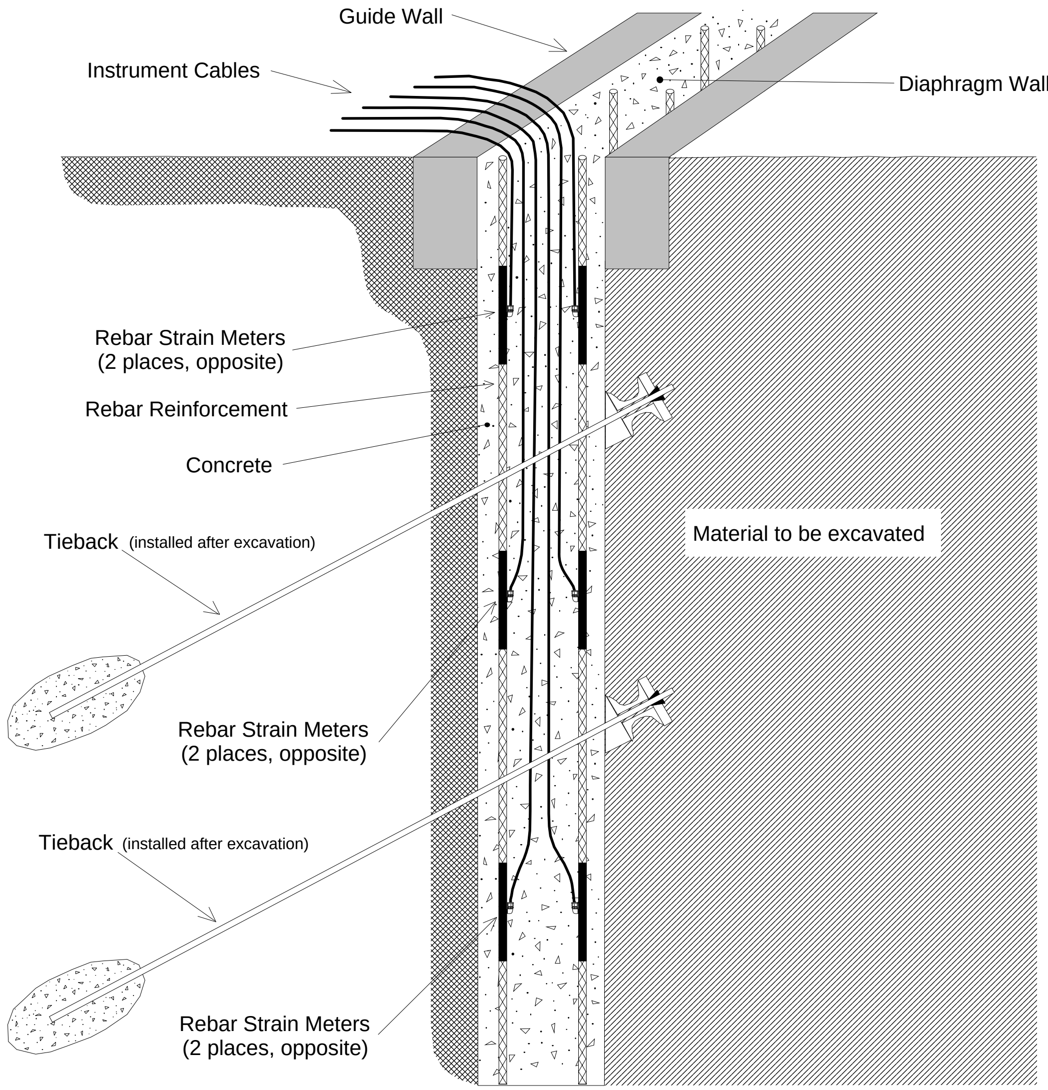

Figure 3 - Model 4911A Installation

2.2.2. Model 4911 "Sister Bar"

The "Sister Bar" is usually installed using standard iron tie wire. Normally ties near the ends and at the one third points are sufficient if the gage is being wired to a larger section of rebar or to horizontal bars. Wiring at the one third points alone is sufficient if the gage is being wired in parallel to the structural rebar. See Figures 4 and 5. Route the instrument cable along the rebar system and tie it off every 3-4 feet (1 meter) using nylon cable ties. Avoid using the tie wire on the instrument cable as it could cut the cable.

Be sure when installing the strain meters to note the location and serial numbers of all instruments. This is necessary for applying the proper calibration factors and determining load characteristics when reducing data.

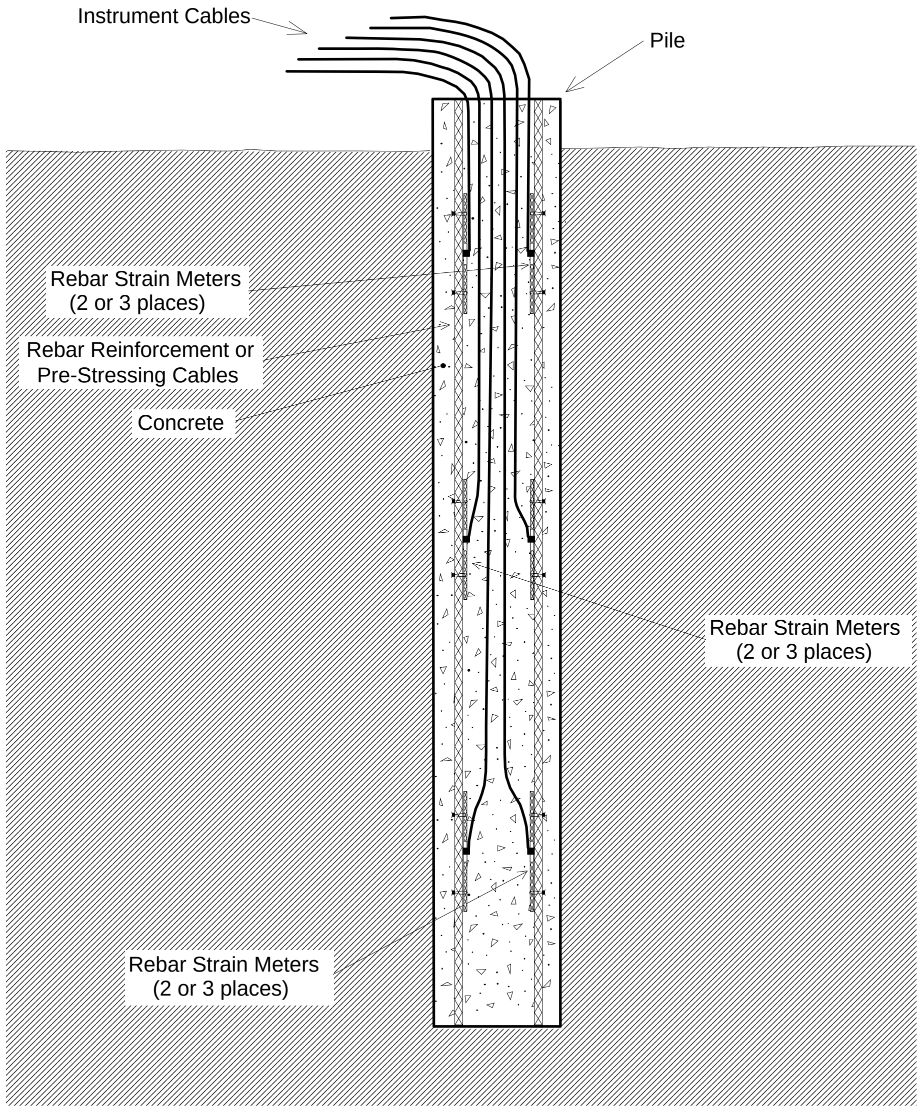

Figure 4 - Model 4911 "Sister Bar" Installation

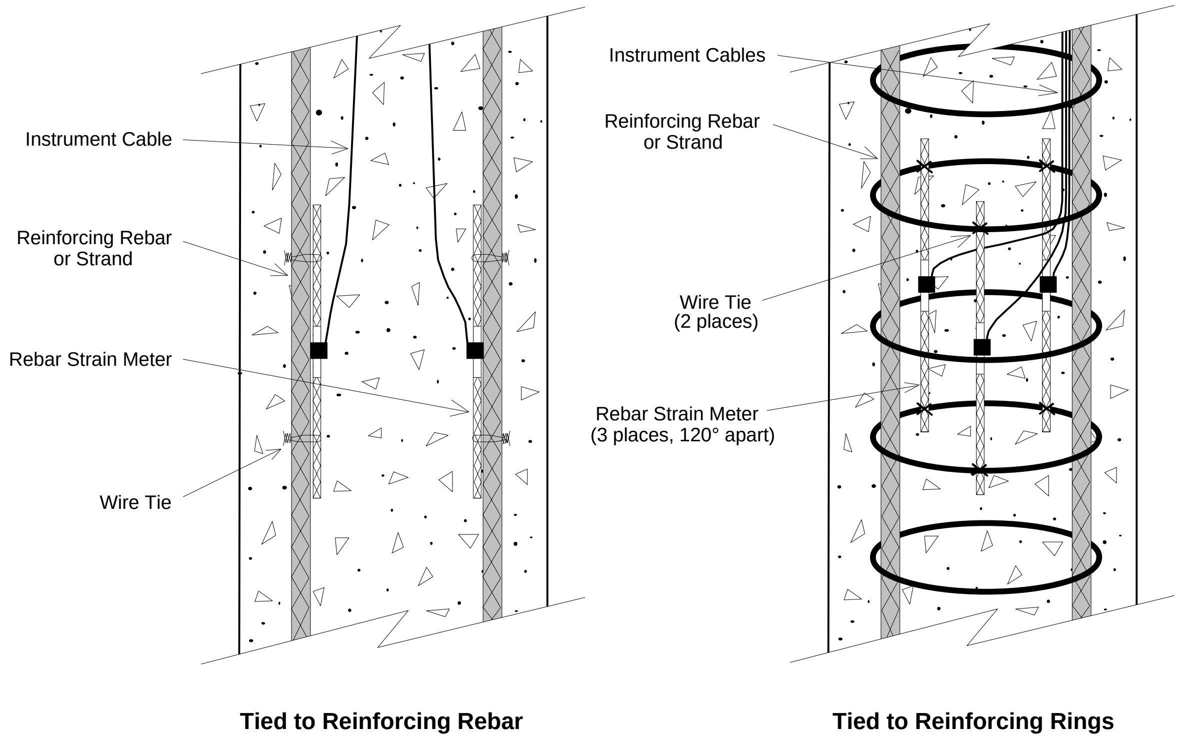

Figure 5 - Model 4911 "Sister Bar" Installation Detail

2.3. Cable Installation

As noted in the installation sections, route the instrument cables along the structural rebar and tie off using nylon cable ties every 2-3 feet (1 meter) to secure. Outside of the instrumented structure, the cable should be protected from accidental damage caused by moving equipment or other construction activity.

Cables may be spliced to lengthen them, without affecting gage readings. Always waterproof the splice completely, especially when embedding within the concrete, preferably using an epoxy based splice kit such the 3M Scotchcast™, model 82-A1. These kits are available from the factory.

3. TAKING READINGS

3.1. Operation of the GK-401 Readout Box

The GK-401 is a basic readout for all vibrating wire gages.

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the green or blue clip for the shield drain wire. The GK-401 cannot read the thermistor (see Section 3.4).

1. Turn the display selector to position "B". Readout is in digits (Equation 1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Record the value displayed. If zeros are displayed or the reading is unstable see section 5 for troubleshooting suggestions.

3. The unit will automatically turn itself off after approximately 4 minutes to conserve power.

3.2. Operation of the GK-403 Readout Box

The GK-403 can store gage readings and also apply calibration factors to convert readings to engineering units. Consult the GK-403 Instruction Manual for additional information on Mode "G" of the Readout. The following instructions will explain taking gage measurements using Mode "B".

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the white and green clips are for the thermistor and the blue for the shield drain wire.

1. Turn the display selector to position "B". Readout is in digits (Equation 1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. 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 thermistor will be read and output directly in degrees centigrade.

3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.3 Operation of the GK404 Readout Box

The GK404 is a palm sized readout box which displays the Vibrating wire value and the temperature in degrees centigrade.
The GK-404 Vibrating Wire Readout arrives with a patch cord for connecting to the vibrating wire gages. One end will consist of a 5-pin plug for connecting to the respective socket on the bottom of the GK-404 enclosure. The other end will consist of 5 leads terminated with alligator clips. Note the colors of the alligator clips are red, black, green, white and blue. The colors represent the positive vibrating wire gage lead (red), negative vibrating wire gage lead (black), positive thermistor lead (green), negative thermistor lead (white) and transducer cable drain wire

(blue). The clips should be connected to their respectively colored leads from the vibrating wire gage cable.

Use the **POS** (Position) button to select position **B** and the MODE button to select **Dg** (digits). Other functions can be selected as described in the GK404 Manual.

The GK-404 will continue to take measurements and display the readings until the OFF button is pushed, or if enabled, when the automatic Power-Off timer shuts the GK-404 off.

The GK-404 continuously monitors the status of the (2) 1.5V AA cells, and when their combined voltage drops to 2V, the message **Batteries Low** is displayed on the screen. A fresh set of 1.5V AA batteries should be installed at this point

3.4. Measuring Temperatures

Each Vibrating Wire Rebar Strain Meter is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor. The Model GK-401 readout Box does not read temperatures – a digital ohmmeter is required,

1. Connect the ohmmeter to the two thermistor leads coming from the strain meter. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)

2. Look up the temperature for the measured resistance in Table B-1. Alternately the temperature could be calculated using Equation B-1.

Note: The GK-403 and GK-404 readout boxes will read the thermistor and display temperature in °C automatically.

4. DATA REDUCTION

4.1. Strain Calculation

The basic units utilized by Geokon for measurement and reduction of data from Vibrating Wire Rebar Strain Meters are "digits". Calculation of digits is based on the following equation;

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

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;

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

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 sheet (see Figure 6).

For example, assume an initial reading, R_0, of 8000 digits, a current reading, R_1, of 7700, and a calibration factor, C, of 0.343 microstrain per digit.

$$\varepsilon_{apparent} = (7700 - 8000) \times 0.343 = -102.9\ \mu\varepsilon \text{ (compression)}$$

4.2. Temperature Correction

Rebar strain meters are usually embedded in concrete and strained by the concrete, the assumption being that ***the strain in the meter is equal to the strain in the concrete***. 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 expansion are:

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

Hence a correction is required to the apparent strains equal to the difference of these two coefficients. See Equation 3.

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

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 example : R_0 = 8000 digits on channel B and R_1 = 7700 digits on channel B
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)

$$= (7700 - 8000)\ 0.343 + (60 - 20)\ (12.2 - 10) = -14.9\ \mu\text{strain (compression)}$$

Note that the actual strain, i.e the strain actually undergone by the concrete is given by the expression

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

Equation 4 –Actual strain

The **apparent** strain =

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

The **load related** strain =

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

The **actual strain** =

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

From this 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 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 or reservoir levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

4.4. Converting Strains to Loads

The load L in any structural element to which the rebar strain gage or Sister-Bar Strain Gage is attached is given by the formula

$$L = E \nu A$$

Where E is the elastic modulus of the structural element, in the appropriate units
ν is the strain in microstrain and
A is the cross-sectional area in the appropriate units

Where strain gages are installed in concrete piles it is standard practice to install them in pairs on either side of the neutral axis, at each depth horizon. This is done so that any strains imposed by bending can be cancelled out by taking the average strain of the two strain gages. It is also standard practice to install a pair of strain gages close to the top of the pile where the measure strain is used to calculate E, the modulus of the concrete.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

Sister Bar Calibration Report

Model Number : 4911-4

Serial Number: 05-13400

Prestress: 35,000 psi

Temperature: 23.3 °C

Calibration Instruction: CI-VW Rebar Rev: B

Calibration Date: August 24, 2005

Cal. Std. Control Numbers: 85888-1, 398

Cable Length: 100 ft.

Factory Zero Reading: 7131

Regression Zero: 7137

Technician:

Applied Load: (pounds)	Readings				Linearity % Max.Load
	Cycle #1	Cycle #2	Average	Change	
100	7193	7196	7195		
1,500	7868	7873	7871	676	-0.27
3,000	8610	8619	8615	744	-0.18
4,500	9364	9371	9368	753	0.22
6,000	10100	10106	10103	736	0.02
100	7197				

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

Gage Factor: 0.343 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.
This report shall not be reproduced except in full without written permission of Geokon Inc.

Figure 6 - Sample Model 4911 Calibration Sheet

5. TROUBLESHOOTING

Maintenance and trouble shooting of Vibrating Wire Rebar Strain Meters are confined to periodic checks of cable connections. Once installed, the meters are usually inaccessible and remedial action is limited.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

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? Channel A of the GK-401 and GK-403 can be used to read the strain meter. To convert the Channel A period display to digits use Equation 1.
- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger. If using the GK-401 Readout connect the clip with the green boot to the bare shield drain wire of the strain meter cable. If using the GK-403 connect the clip with the blue boot to the shield drain wire.
- ✓ Does the readout work with another strain meter? If not, the readout may have a low battery or be malfunctioning.

Symptom: Strain Meter Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. For the 4911A, nominal resistance between the two gage leads (usually red and black leads) is 50Ω, ±5Ω, the same for the 4911,50Ω, ±5Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). If the resistance reads infinite, or very high (megohms), a cut wire must be suspected. If the resistance reads very low (<20Ω) a short in the cable is likely.
- ✓ Does the readout or datalogger work with another strain meter? If not, the readout or datalogger may be malfunctioning.

Symptom: Thermistor resistance is too high.

- ✓ Is there an open circuit? Check all connections, terminals and plugs. If a cut is located in the cable, splice according to instructions in Section 2.3.

Symptom: Thermistor resistance is too low.

- ✓ Is there a short? Check all connections, terminals and plugs. If a short is located in the cable, splice according to instructions in Section 2.3.
- ✓ Water may have penetrated the interior of the strain meter. There is no remedial action.

APPENDIX A - SPECIFICATIONS

A.1. Rebar Strain Meters

Model:	4911A	4911 "Sister Bar"
Range:	2500 με	
Rebar Sizes Available:[1]	#6, #7, #8, #9, #10, #11	#4, #5
Sensitivity:	0.025% FSR	
Accuracy:	0.25% FSR	
Linearity:	0.25% FSR	
Operating Temperature:	-40 to +90° C -40 to 200° F	
Operating Frequency:	1200-2800 Hz	
Coil Resistance:	50+/- 5 Ω	50+/-5 Ω
Length:	43.5", 1105 mm	36", 914 mm
Materials:	Grade 60 Rebar and High Strength Steel	
Electrical Cable:	2 twisted pair (4 conductor) 22 AWG Foil shield, PVC jacket, nominal OD=6.3 mm (0.250")	

Table A-1 Model 4911A/4911 Strain Meter Specifications

Notes:
[1] 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:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

Equation B-1 Convert Thermistor Resistance to Temperature

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

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 B-1 Thermistor Resistance versus Temperature

APPENDIX C – DERIVING THE CALIBRATION FACTOR, C, FROM THE TEST DATA

The Model 4911A/4911 Strain Meters are calibrated by loading them in a testing machine hence the gage 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, (7.5" or 19.05 cm long) contains a vibrating wire sensor located axially at the mid-section. See Figure C-1.

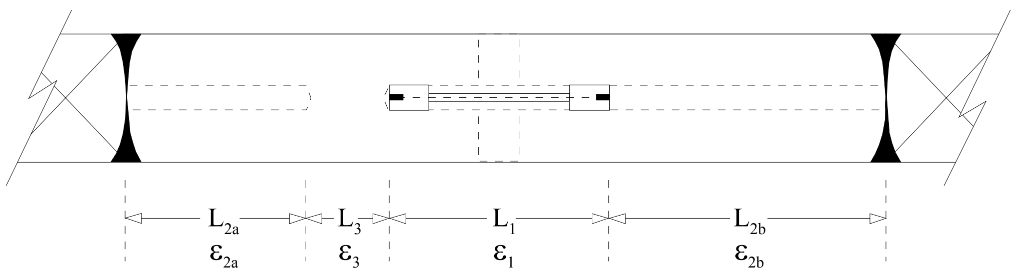

Figure C-1 Rebar Strain Meter Schematic

To convert the observed change in readout digits, ΔR, into a strain, ε_t, for the entire length (7.5 in., 19.05 cm) of the unbonded section, requires solution of 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 C-1 Total Strain Calculation

Where: ε_t is the total strain of the unbonded section.

ε_1 is the strain in zone 1, determined empirically from the equation for the vibrating wire sensor itself, 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 2 and 3, respectively, dependent on the load and cross-sectional area, see Equations C-2 and C-3.

L_1 is 2.000" (5.08 cm).

L_2 is 5.000" (12.7 cm).

L_3 is 0.500" (1.27 cm).

$$\varepsilon_2 = \frac{P}{a_2 \times E} \qquad\qquad \varepsilon_3 = \frac{P}{a_3 \times E}$$

Equation C-2 Zone 2 Calculation Equation C-3 Zone 3 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 C-1.

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: $P = \Delta R \times F$

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 C-1 Unbonded Section Dimensions

By making the various substitutions of Table C-1 we can obtain the relationship between strain in the unbonded section versus change in readout digits.
For example, let us make the substitutions, using English conventions, for the #6 rebar;

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

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

Similarly, for the other sizes of rebar yielding the table below.
So, to obtain the micro-strain/digit gage factor (C) from the lbs.or kg. per digit gage 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 C-2 Microstrain Conversion Factors