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 that wear or 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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1. INTRODUCTION

GEOKON vibrating wire embedment strain gauges are designed for direct embedment in concrete. This can be accomplished by attaching the gauge to rebar or tensioning cables and then casting the gauge into a concrete briquette, which is subsequently cast into the structure, or grouting the gauge into boreholes in the concrete.

Strains are measured using the vibrating wire principle. A length of steel wire is tensioned between two end blocks that are firmly in contact with the mass concrete. Deformations in the concrete will cause the two end blocks to move in relation to each other, altering the tension in the steel wire. This change in tension is measured as a change in the resonant frequency of vibration of the wire.

Two coils, one with a magnet insert, the other with a pole piece insert, are located close to the vibrating wire. In use, a pulse of varying frequency (swept frequency) is applied to the coils causing the wire to vibrate primarily at its resonant frequency.

Portable readouts and dataloggers are available from GEOKON. These models, when used in conjunction with vibrating wire strain gauges, will provide the necessary voltage pulses to pluck the wire. During vibration, a sinusoidal signal is induced in the coils and transmitted to the readout box where it is conditioned and displayed.

This manual contains installation instructions, readout and data reduction procedures, and troubleshooting guidelines.

Note: Do not rotate or pull on the gauge end blocks, because this will alter the readings and may cause permanent damage.
2. MODELS

GEOKON vibrating wire strain gauges come in a variety of models, all easily identifiable by the color of heat shrink which covers the protective tubes, as shown in the table below.*

<table>
<thead>
<tr>
<th>Model</th>
<th>Heat Shrink Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>4200 (4,000 ( \mu \varepsilon ))</td>
<td>Blue</td>
</tr>
<tr>
<td>4200L</td>
<td>Black</td>
</tr>
<tr>
<td>4200L+ (5,000 ( \mu \varepsilon ))</td>
<td>Red</td>
</tr>
<tr>
<td>4200L+ (10,000 ( \mu \varepsilon ))</td>
<td>Green</td>
</tr>
<tr>
<td>4200X</td>
<td>Yellow (dependent on the reason for the X designation)</td>
</tr>
</tbody>
</table>

*Applicable only to products manufactured after September 2016.

**TABLE 1: Heat Shrink Color Designations**

The following sections describe in brief the various embedment strain gauges available from GEOKON.

2.1 MODELS 4200 AND 4200L

GEOKON Models 4200 and 4200L are designed primarily for long-term strain measurements inside mass concrete, in structures such as foundations, piles, bridges, dams, containment vessels, tunnel liners, etc.

The 4200L is a low-modulus version designed to enable early curing strains to be measured. The length of the 4200 gauge is 152 mm (6”).

**FIGURE 2: Model 4200 Vibrating Wire Strain Gauge**

**FIGURE 3: Model 4200L Vibrating Wire Strain Gauge**
2.2 MODELS 4200-6 AND 4200-7
Model 4200-6 and 4200-7 strain gauges are supplied fully sealed and pretensioned with the plucking coil mounted. Note the small collar under the shrink tube at one end.

![Model 4200-6 Vibrating Wire Strain Gauge](image)

**FIGURE 4:** Model 4200-6 Vibrating Wire Strain Gauge

![Model 4200-7 Vibrating Wire Strain Gauge](image)

**FIGURE 5:** Model 4200-7 Vibrating Wire Strain Gauge

2.3 MODEL 4202
Model 4202 is designed for direct embedment in grout, mortar, and small aggregate concrete. It is also useful for model studies. The length of the 4202 gauge is 50 mm (2”).

![Model 4202 Vibrating Wire Strain Gauge](image)

**FIGURE 6:** Model 4202 Vibrating Wire Strain Gauge
2.4 MODEL 4210

Model 4210 is designed for embedment in large aggregate concrete (greater than 3/4 of an inch). The standard gauge length is 254 mm (10”), other gauge lengths available include: Model 4212: 305 mm (12”), and Model 4214: 356 mm (14”).

FIGURE 7: Model 4210 Vibrating Wire Strain Gauge
3. PRIOR TO INSTALLATION

3.1 ADJUSTING GAUGE TO THE DESIRED RANGE

GEOKON embedment strain gauges are supplied fully sealed and pretensioned. Model 4200 gauges are normally supplied with the wire tension set near the middle of their range. If the range needs to be adjusted for some reason, the wire tension may be changed by the following procedure:

1. Attach the red and black leads to a readout box that has been set to position D, reading in microstrain.
2. Grip the small collar under the shrink tube and rotate the end flange as shown in the figure below.
3. Rotate clockwise to decrease the initial reading; rotate counterclockwise to increase the reading. For example, if the gauge will see all compression, it should be set to about 4000 microstrain.

![Collar](image)

**FIGURE 8: Adjusting the Range of the Strain Gauge**

Model 4200-6 / 4200-7 Note: Although the readings are taken on position D, the digits shown must be converted to microstrain manually. To do this, multiply the observed digit change by the gauge factor given on the calibration sheet provided with the strain gauge.

3.2 GAUGE AND CABLE ASSEMBLY

Insert the flat part of the gauge into the slot in the coil assembly located at the end of the cable. Slide the hose clamp over the assembly and tighten.

![Assembled Gauge and Coil Housing](image)

**FIGURE 9: Assembled Gauge and Coil Housing**

Alternatively, the coil housing can be glued in place using cyanoacrylate glue. If this method is chosen, it will no longer be possible to remove the gauge from the coil housing.

3.3 PRELIMINARY CHECK

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

1. Using an ohmmeter, check the resistance between the two lead wires (usually red and black).
For Models 4200, 4200L, 4200-6, 4200-7, and 4210/12/14 it should be about 180 ohms.

For Model 4202, it should be about 50 ohms.

Remember to add the cable resistance at approximately 14.7Ω/1000’ or 48.5Ω/km at 20 °C. Multiply these factors by two to account for both directions.

2. Using an ohmmeter, check the resistance between the two thermistor wires (usually white and green). Using Table 11 on page 24, convert the resistance to temperature. Compare the result to the current ambient temperature. (For Model 4200HT see Table 12 on page 25.)

3. Connect the gauge to a readout box. (See readout instructions, Section 5.) Observe the displayed readout. The reading should be about the midrange position as defined in Table 2 on page 11.

4. Press on the gauge ends and confirm that it makes the reading decrease.

Return any faulty gauges to the factory. Gauges should not be opened in the field.
4. INSTALLING THE GAUGES IN CONCRETE

GEOKon strain gauges are typically set into concrete in one of two ways:

1. Cast the units directly into the concrete mix (see Sections 4.1 through 4.3)
2. Cast them into briquettes that are subsequently cast into the concrete structure (see Section 4.4).

When casting the gauge directly into the concrete mix, take care to avoid applying any large forces to the end blocks during installation. This is most imperative when installing Model 4202 gauges.

**Model 4202 Note:** Do not wrap an iron tie wire around the body of the gauge; doing so could cause damage due to its delicate construction. Instead, use the holes in the end blocks to affix the gauge to the rebar, being sure that the gauge is not tensioned or compressed in the longitudinal direction.

**Model 4200L Note:** This gauge is specifically designed to allow strains to be measured in curing concrete. However, do not bury the gauge more than one meter deep; doing so could damage the gauge.

### 4.1 DIRECT ATTACHMENT TO REBAR

1. Place two pieces of wood or polystyrene foam between the gauge and the rebar as shown in Figure 10 on this page.
2. Use soft iron tie wire, similar to the kind that is normally used for tying rebar cages together. Run the wire around the body of the strain gauge and around the rebar. Twist the wire around itself to hold the gauge in place.
3. Tie the instrument cable off to the rebar using nylon cable ties.

**Note:** Don’t tie the wires too tightly, since rebar and tension cables tend to move during concrete placement and vibration. Take care not to damage the cable with the vibrator. The gauge can also be placed directly into the mix if it can be assured that the orientation will be correct after the gauge placement.

### 4.2 SUSPENSION METHOD

1. Wrap a layer of self-vulcanizing rubber tape 3 cm from each gauge end, as shown in Figure 11 on page 8.
2. Use soft iron tie wire, the kind normally used for tying rebar cages together. Wrap the wire around the rubber strips twice.
3. Twist two loops in the wire, one on either side of the gauge, at a distance of 3 cm from the gauge body. Repeat this process at the other end.
4. Position the gauge between the rebar and twist the wire ends twice around the rebar, then around itself.
5. Tighten the wire and orient the gauge by twisting the loops between the gauge and the rebar.

---

**FIGURE 10: Attaching Gauges to Rebar**
6. Attach the plucking coil using a hose clamp. Tie the instrument cable off to one of the rebar using nylon cable ties.

**FIGURE 11:** Suspending Model 4200/4200L/4200HT Strain Gauges Between Rebar

### 4.3 ALTERNATIVE SUSPENSION METHOD

Tie two short pieces of steel rebar to the existing rebar using nylon cable ties, as shown in the figure below. Then tie the strain gauge to the short pieces of rebar again using more nylon cable ties. This method avoids the resonance problems associated with the previous method.

**FIGURE 12:** Alternative Method for Attaching Model 4200/4200HT Strain Gauges to Rebar
4.4 USING PRE-CAST BRIQUETTES, SHOTCRETE, OR GROUTING

An alternative to casting the units into the concrete mix directly is to precast the gauges into briquettes of the same mix as the mass concrete and then place the briquettes in the structure prior to concrete placement. The briquettes should be constructed no more than three days prior to installation, but no less than one day prior, and should be continuously cured with water while awaiting placement in the mass concrete.

GEOKON strain gauges may also be used in shotcrete, as well as in holes drilled in rock or concrete that are subsequently grouted. When used in shotcrete, special care should be taken to protect the lead wires, such as encasing them in conduit or heavy tubing. The gauges may be placed by packing the immediate area around the gauge by hand and then proceeding with the shotcrete operation.

4.5 CABLE SPLICING AND TERMINATION

The cable from the strain gauges can be protected by using flexible conduit, which can be supplied by GEOKON.

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.

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 be beneficial. The cable used for making splices should be a high-quality twisted pair type, with 100% shielding and an integrated 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, which 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 itself in strength and electrical properties. Contact GEOKON for splicing materials and additional cable splicing instructions.

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.

4.6 LIGHTNING PROTECTION

Unlike numerous other types of instrumentation available from GEOKON, embedment strain gauges do not have any integrated 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 or grout and are somewhat isolated from potentially damaging electrical transients. However, there may be occasions where some sort of lightning protection is desirable. One such example is where the gauge is in contact with rebar that may be 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**

- 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 in the event that 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 gauge. See the figure below.

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

Consult the factory for additional information on available lightning protection.

*FIGURE 13: Lightning Protection Scheme*
5. TAKING READINGS

5.1 MICRO-6000 DATALOGGER
GEOKON recommends the parameters in the table below when using strain gauges with the MICRO-6000 datalogger or any other CR1000 based datalogger. It shows the recommended gauge type selection and gauge factor G entry to convert to microstrain. The table also lists the starting and ending frequency settings for the excitation sweep when writing a program for the CR1000 using the P28 vibrating wire measurement instruction.

Alternately, if a calibration sheet is supplied with the strain gauge, the exact values can be calculated from the start and end frequencies of the calibration.

To maximize the stability and resolution of the sensor, a relatively narrow band of excitation frequency should be selected. Calculate these settings by taking an initial reading and then setting the starting frequency to 200 Hz below and the ending frequency 200 Hz above.

<table>
<thead>
<tr>
<th>MICRO-6000 Gauge Type</th>
<th>4200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauge Factor G</td>
<td>Shown on calibration sheet</td>
</tr>
<tr>
<td>Start Frequency (P28)</td>
<td>4 (400 Hz)</td>
</tr>
<tr>
<td>End Frequency (P28)</td>
<td>12 (1200 Hz)</td>
</tr>
</tbody>
</table>

**TABLE 2: Embedment Strain Gauge Datalogger Parameters**

5.2 EMBEDMENT STRAIN GAUGE READOUT POSITIONS
The following table indicates the readout position detail for each strain gauge model.

<table>
<thead>
<tr>
<th>Model</th>
<th>4200/4200HT</th>
<th>4200-6/7</th>
<th>4202</th>
<th>4204</th>
<th>4210/4212/4214</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readout Position</td>
<td>D</td>
<td>D</td>
<td>E</td>
<td>A (Mode: digits)</td>
<td>B</td>
</tr>
<tr>
<td>Display Units</td>
<td>microstrain (με)</td>
<td>readout units</td>
<td>microstrain (με)</td>
<td>digits (10^-3)</td>
<td>digits (10^-3)</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>450-1200 Hz</td>
<td>400-1200 Hz</td>
<td>1400-3500 Hz</td>
<td>800-1600 Hz</td>
<td>1400-3500 Hz</td>
</tr>
<tr>
<td>Mid-Range Reading</td>
<td>2500 με</td>
<td>2000</td>
<td>2500 με</td>
<td>1700 digits</td>
<td>6000 digits</td>
</tr>
<tr>
<td>Minimum Reading</td>
<td>1000 με</td>
<td>1000</td>
<td>1000 με</td>
<td>650 digits</td>
<td>2000 digits</td>
</tr>
<tr>
<td>Maximum Reading</td>
<td>4000 με</td>
<td>3000</td>
<td>4000 με</td>
<td>2750 digits</td>
<td>10000 digits</td>
</tr>
</tbody>
</table>

**TABLE 3: Readout Positions**

The following sections describe how to take readings using readout equipment available from GEOKON.

5.3 GK-404 READOUT BOX
The Model GK-404 Vibrating Wire Readout is a portable, low-power, hand-held unit that is capable of running for more than 20 hours continuously on two AA batteries. It is designed for the readout of all GEOKON vibrating wire instruments, 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 transducer (embedded thermistor) with a resolution of 0.1 °C.
5.3.1 OPERATING THE GK-404

1. Attach the flying leads to the GK-404 by aligning the red circle on the silver Lemo connector with the red line on the top of the GK-404 (see Figure 15 on this page). Insert the Lemo connector into the GK-404 until it locks into place.

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

3. To turn on the GK-404, press the ON/OFF button on the front panel of the unit. The initial startup screen will display.

4. After a delay, 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 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 instrument in degrees Celsius.

Use the POS and MODE buttons to select the correct position and display units for the model of equipment purchased.

The GK-404 will continue to take measurements and display readings until the unit is turned off, either manually or by the Auto-Off timer (if enabled).

For more information, consult the GK-404 manual.

5.4 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.
- The GK-405 Remote Module, which is housed in a weather-proof enclosure.

The remote module can be wire-connected to the sensor by means of:

- Flying leads with alligator clips, if the sensor cable terminates in bare wires.
A 10 pin connector.

The two units communicate wirelessly using Bluetooth®, a reliable digital communications protocol. Using Bluetooth, the unit can operate from the cradle of the remote module, or, if more convenient, can be removed and operated up to 20 meters away from the remote module.

The GK-405 displays the thermistor temperature in degrees Celsius.

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

5.4.1 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 sensor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

5.4.2 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).

5.4.3 OPERATING THE GK-405

Press the power button on the Readout Unit. After start-up completes, a blue light will begin flashing, signifying that the two components are ready to connect wirelessly. Launch the GK-405 VWRA program by doing the following:

1. Tap Start on the hand-held PC’s main window.
2. Select Programs.
3. Tap the GK-405 VWRA icon.

After a few seconds, the blue light should stop flashing and remain lit. The Live Readings window will display on the hand-held PC.

Set the Display mode to the correct letter required by your equipment. For more information, consult the GK-405 Instruction Manual.
5.5 **GK-403 READOUT BOX (OBSOLETE MODEL)**

The GK-403 can store instrument readings, as well as apply calibration factors to convert readings to engineering units. The GK-403 displays the thermistor temperature in degrees Celsius.

5.5.1 **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 sensor or load cell). Push in the connector, and then twist the outer ring of the male connector until it locks.

5.5.2 **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).

5.5.3 **OPERATING THE GK-403**

1. Set the display selector to the correct position for your equipment.
2. Power on the unit.
3. A reading will appear in the front display window. (The last digit may change one or two digits while reading.)
4. The thermistor will be read and displayed on the screen above the instrument reading in degrees Celsius.
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 two minutes to conserve power.

For more information, consult the GK-403 manual.

5.6 **MEASURING TEMPERATURES**

All GEOKON vibrating wire transducers are equipped with a thermistor for reading temperature. The thermistor 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 Celsius.

**Note:** You must use an ohmmeter to read the 4200HT strain gauge.

**TO READ TEMPERATURES USING AN OHMMETER:**

1. Connect an ohmmeter to the green and white thermistor leads coming from the equipment. 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 $14.7 \Omega$ per 1000 feet ($48.5 \Omega$ 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 C. For the 4200HT use Appendix D.
6. DATA REDUCTION

The table below shows the readout position, theoretical gauge factors, and experimental data derived from batch calibrations for each model of strain gauge. (Individual calibrations are available at an additional cost; contact GEOKON for more information.)

<table>
<thead>
<tr>
<th>Model</th>
<th>Readout Position</th>
<th>Theoretical Gauge Factor</th>
<th>Typical Batch Factor</th>
<th>Typical Gauge Factor</th>
<th>Experimental Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>4200</td>
<td>D</td>
<td>3.304</td>
<td>0.97 to 0.98</td>
<td>N/A</td>
<td>3.237</td>
</tr>
<tr>
<td>4200-J</td>
<td>D</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td>4202</td>
<td>E</td>
<td>0.391</td>
<td>0.91</td>
<td>N/A</td>
<td>0.356</td>
</tr>
<tr>
<td>4204</td>
<td>A</td>
<td>N/A</td>
<td>N/A</td>
<td>1.422</td>
<td>N/A</td>
</tr>
<tr>
<td>4210</td>
<td>B</td>
<td>N/A</td>
<td>N/A</td>
<td>0.3568</td>
<td>0.3423</td>
</tr>
<tr>
<td>4212</td>
<td>B</td>
<td>N/A</td>
<td>N/A</td>
<td>0.3624</td>
<td>N/A</td>
</tr>
<tr>
<td>4214</td>
<td>B</td>
<td>N/A</td>
<td>N/A</td>
<td>0.3665</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The exact Gauge Factor is determined by actual calibration, there is no Batch Factor to apply.

**TABLE 4: Embedment Strain Gauge Factors**

6.1 READOUT BOX POSITION A

Use position A for the following models:
- Model 4204
- GK-404 (select digits mode)
- GK-403 and GK-405 (convert the period to digits using this formula:)

\[
\text{Digits} = \frac{\text{Hz}^2}{1000}
\]

**EQUATION 1: Period to Digits Conversion**

6.2 READOUT BOX POSITION B

For gauges read in position B, gauge factors must be applied to the change in readings. These gauge factors are either average gauge factors for that batch of gauges, or gauge factors from individual calibrations.

6.3 READOUT BOX POSITIONS D & E

Reading for Models 4200 (position D) and 4202 (position E) are displayed on the readout box directly in microstrain based on the theoretical equation:

\[
\mu_{\text{theory}} = G(\Delta f^2 \times 10^{-3})
\]

**EQUATION 2: Theoretical Strain**

Where:
- \(f\) is the frequency in digits.
- \(G\) is the theoretical gauge factor, equal to 3.304 for the 4200 gauge and 0.3910 for the 4202 gauge.

In practice, the act of clamping shortens the vibrating wire slightly, causing it to over-register the strain. You can compensate for this by applying the batch gauge factor supplied with each gauge. With the batch gauge factor applied, the apparent change in strain shown on the readout box is equal to:

\[
\mu_{\text{apparent}} = (R_1 - R_0)B
\]

**EQUATION 3: Apparent Strain**

Where:
- \(R_0\) is the initial reading
- \(R_1\) is the current reading from the readout box, taken in position D or E.
Note: When \((R_1 - R_0)\) is positive, the strain is tensile. 
B is the batch gauge factor supplied with each gauge.

6.4 STRAIN RESOLUTION

When using the GK-403 Readout, refer to the following table for the strain resolution in microstrains.

<table>
<thead>
<tr>
<th>Model</th>
<th>Position</th>
<th>Strain Resolution (microstrain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4200 / 4200HT</td>
<td>D</td>
<td>±0.1</td>
</tr>
<tr>
<td>4200-6 / 4200-7</td>
<td>D</td>
<td>N/A</td>
</tr>
<tr>
<td>4202</td>
<td>E</td>
<td>±0.1</td>
</tr>
<tr>
<td>4210 / 4212 / 4214</td>
<td>D</td>
<td>0.1 x gauge factor</td>
</tr>
</tbody>
</table>

Table 5: Strain Resolution

Note: For some gauges the reading may fluctuate by one digit, so this resolution may not be useful.

6.5 TEMPERATURE CORRECTIONS

Temperature variations of considerable magnitude are not uncommon, particularly during concrete curing; therefore, it is always advisable to measure temperatures along with the measurement of strain.

Temperature-induced expansions and contractions can give rise to real changes in the stress of the concrete if the concrete is restrained in any way. These stresses are superimposed on any other load-related stresses.

Temperature can also affect the strain gauge. Increasing temperatures will cause the vibrating wire to elongate and thus go slack, indicating what would appear to be a compressive strain in the concrete. This effect is balanced to some degree by a corresponding stretching of the wire, caused by expansion of the concrete. If the concrete expanded by exactly the same amount as the wire, the wire tension would remain constant, and no correction would be necessary.

However, the steel expansion coefficient is different from the concrete expansion coefficient. Due to this difference, a temperature correction is required equal to:

\[
\text{EQUATION 4: Correction for Temperature Effects on the Gauge}
\]

Where:
- \(T_0\) is the initial temperature.
- \(T_1\) is the current temperature.
- \(C_1\) is the coefficient expansion of steel: 12.2 microstrains/°C. (\(C_1\) for Model 4200HT gauges is 17.3 microstrains/°C.)
- \(C_2\) is the coefficient of expansion of concrete: ~10 microstrains/°C. (Users should use their own values for \(C_2\) if known.)

Load-related strain in concrete (a composite of both external load and temperature effects) corrected for temperature, is given by:

\[
\text{EQUATION 5: True, Load-Related Strain Corrected for Temperature}
\]

Where:
- \(R_0\) is the initial reading.
- \(R_1\) is the current reading from the readout box, taken in position D or E.

Note: When \((R_1 - R_0)\) is positive, the strain is tensile.

B is the batch gauge factor supplied with each gauge.

\(T_0, T_1, C_1,\) and \(C_2\) are the same values as shown in Equation 4 on page 16.

A theoretical example of the above is shown below.
EXAMPLE:

If:
\[ R_0 = 3000 \text{ in position D} \]
\[ R_1 = 2900 \text{ in position D} \]
\[ T_0 = 20^\circ\text{C} \]
\[ T_1 = 30^\circ\text{C} \]
\[ B = 0.975 \text{ (batch calibration factor)} \]

Then:
The apparent strain = \((2900 - 3000) \times 0.975 = -97.5\) \(\mu\text{strain} \) (compression).
The load-related strain, corrected for temperature effects on the gauge =
\((2900 - 3000) \times 0.975 + (30 - 20) \times (12.2 - 10) = -75.5\) \(\mu\text{strain} \) (compression).

Note: The actual strain undergone by the concrete, (i.e., that which would be measured by a measuring scale) is given by the formula:
\[
\varepsilon_{\text{actual}} = (R_1 - R_0) B + (T_1 - T_0) (C_1)
\]

**EQUATION 6: Actual Strain**

Which in the current example = \((2900 - 3000) \times 0.975 + (30 - 20) \times (12.2) = 24.5\) \(\mu\text{strain} \) (expansion).

See Appendix G for further information.

6.5.1 MODEL 4200-6 / 4200-7 CORRECTIONS

The effect of temperature on the 4200-6 and 4200-7 strain gauges is complex; it varies depending on the strain level. A typical temperature correction factor to be applied to the 10,000 \(\mu\text{strain} \) 4200-7 model is as follows:

Temperature Correction Factor = \((0.000401 \times R_1 - 1.067)(T_1 - T_0)\)

Where:
\[ R_1 \] is the current gauge reading.
\[ T_1 \] is the current temperature in degrees Celsius.
\[ T_0 \] is the initial temperature in degrees Celsius.

This correction factor was developed by testing four gauges at three different parts of their range (i.e., at microstrain levels of 4000, 8000, and 12000), at five different temperature levels, i.e., -40, -20, 0, 20, 40, and 60 degrees Celsius).

When using the polynomial expression to calculate the strain, this correction factor must be applied to the current reading \(R_1\). The modified value of \(R_1\) is then inserted into the polynomial.

Thus, the modified value of \(R_1\) to be inserted into the polynomial is:
\[ R_1 + (0.000401 \times R_1 - 1.067) \times (T_1 - T_0) \]

6.6 SHRINKAGE EFFECTS

A well-known 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 microstrain.

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 gauge 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.

6.7 CREEP EFFECTS

It is also well-known that concrete will creep under a sustained load. What may seem to be a gradually increasing load, as evidenced by a gradually-increasing
strain, may actually be strain due to the concrete creeping under a constant, sustained load.

On some projects, gauges have been cast into concrete blocks in the laboratory and kept loaded by means of springs inside a load frame. In this manner, the creep phenomenon can be quantified.

6.8 EFFECT OF AUTOGENOUS GROWTH

Some older concretes that have a particular combination of aggregates and alkaline cements may expand with time as they undergo a chemical change and recrystallization. This is called autogenous growth and is like creep, but in the opposite direction, and is difficult to quantify. $\mu\varepsilon$.

6.9 CONVERTING STRAIN TO LOAD

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

$$L = \frac{E \mu\varepsilon A}{E}$$

*EQUATION 7: Strain to Load Formula*

Where:

$E$ is the load.

$E$ is the elastic modulus of the structural element in the appropriate units.

$\mu\varepsilon$ is the strain in microstrain.

$A$ is the cross-sectional area in the appropriate units.

When installing strain gauges 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 gauges close to the top of the pile. The measured strain of these two gauges is used to calculate the modulus of the concrete.

6.10 EFFECTIVE MODULUS

For some concrete strain measurements during the early stages of curing it is important to know the effective modulus of the strain gauge. The effective modulus of the various embedment gauges is shown in the following table:

<table>
<thead>
<tr>
<th>Model</th>
<th>$E$, approximate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4200</td>
<td>596,000 psi</td>
</tr>
<tr>
<td>4200L</td>
<td>56,500 psi</td>
</tr>
<tr>
<td>4200-6 / 4200-7</td>
<td>N/A</td>
</tr>
<tr>
<td>4200HT</td>
<td>596,000 psi</td>
</tr>
<tr>
<td>4200HT-T</td>
<td>11,950,000 psi</td>
</tr>
<tr>
<td>4202</td>
<td>610,000 psi</td>
</tr>
<tr>
<td>4204</td>
<td>596,000 psi</td>
</tr>
<tr>
<td>4210 / 4212 / 4214</td>
<td>2,350,000 psi</td>
</tr>
</tbody>
</table>

*TABLE 6: Effective Modulus*
7. TROUBLESHOOTING

Maintenance and troubleshooting of embedment strain gauges is confined to periodic checks of cable connections and maintenance of terminals. Once installed, the gauges are usually inaccessible and remedial action is limited. Should difficulties arise, consult the following list of problems and possible solutions.

Return any faulty gauges to the factory. **Gauges should not be disassembled in the field.**

For additional troubleshooting and support, contact GEOKON.

**SYMPTOM: THERMISTOR RESISTANCE IS TOO HIGH**
- There may be an open circuit. Check all connections, terminals, and plugs. If a cut is located in the cable, splice according to instructions in Section 4.5.

**SYMPTOM: THERMISTOR RESISTANCE IS TOO LOW**
- There may be a short. Check all connections, terminals, and plugs. If a short is located in the cable, splice according to instructions in Section 4.5.
- Water may have penetrated the interior of the transducer. There is no remedial action.

**SYMPTOM: STRAIN GAUGE 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 the strain reading outside the specified compressive or tensile range of the instrument? The gauge may have become too slack or too tight; inspect the data to determine whether this is a possibility.
- 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.
- Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.

**SYMPTOM: STRAIN GAUGE FAILS TO READ**
- Is the cable cut or crushed? Check the resistance of the cable by connecting an ohmmeter to the sensor leads. Table 7 on page 20 shows the expected resistance for the various wire combinations. Table 8 on page 20 is provided for you to fill in the actual resistance found. Cable resistance is approximately 14.7Ω per 1000 ft. (48.5Ω per km) of 22 AWG wire. Multiply this factor by two to account for both directions.
- If the resistance is very high or infinite, the cable is probably broken or cut. If the resistance is very low, the gauge conductors may be shorted. If a cut or a short is located in the cable, splice according to the instructions in Section 4.5.
- Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.
### TABLE 7: Sample Resistance

<table>
<thead>
<tr>
<th>Vibrating Wire Sensor Lead Grid - SAMPLE VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Red</strong></td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>Black</td>
</tr>
<tr>
<td>White</td>
</tr>
<tr>
<td>Green</td>
</tr>
</tbody>
</table>

### TABLE 8: Resistance Work Sheet

<table>
<thead>
<tr>
<th>Vibrating Wire Sensor Lead Grid - SENSOR NAME/##</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Red</strong></td>
</tr>
<tr>
<td>Red</td>
</tr>
<tr>
<td>Black</td>
</tr>
<tr>
<td>Shield</td>
</tr>
</tbody>
</table>

*TABLE 7: Sample Resistance*

*TABLE 8: Resistance Work Sheet*
APPENDIX A. SPECIFICATIONS

A.1 STRAIN GAUGE

The table below lists the specifications for all strain gauge models.

<table>
<thead>
<tr>
<th>Model</th>
<th>4200</th>
<th>4200-6</th>
<th>4202</th>
<th>4204</th>
<th>4210</th>
<th>4212</th>
<th>4214</th>
<th>4200HT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (Nominal)</td>
<td>3000 με</td>
<td>5,000 με</td>
<td>10,000 με</td>
<td>3000 με</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>1.0 με¹</td>
<td>0.5 με¹</td>
<td>0.4 με¹</td>
<td>1.0 με¹</td>
<td>0.4 με¹</td>
<td>0.4 με¹</td>
<td>1.0 με¹</td>
<td></td>
</tr>
<tr>
<td>Calibration Accuracy</td>
<td>±0.1% Full Scale Reading (FSR)</td>
<td>±0.5% FSR</td>
<td>±0.1% FSR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical Batch Factor</td>
<td>0.98</td>
<td>N/A</td>
<td>0.91</td>
<td>N/A</td>
<td>0.95</td>
<td>N/A</td>
<td>N/A</td>
<td>0.98</td>
</tr>
<tr>
<td>Batch Factor Accuracy</td>
<td>±0.5% FSR</td>
<td>N/A</td>
<td>±0.5% FSR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Accuracy</td>
<td>±2.0% FSR²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>0.1% Full Scale (FS)/yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linearity</td>
<td>0.5% FSR</td>
<td>0.3% FSR</td>
<td>0.5% FSR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Coefficient³</td>
<td>12.2 με/°C³</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency Range (Hz)</td>
<td>450-1200</td>
<td>450-1200</td>
<td>1400-3500</td>
<td>800-1600</td>
<td>1400-3500</td>
<td>1400-3500</td>
<td>450-1200</td>
<td></td>
</tr>
<tr>
<td>Dimensions (gauge) (LxD)</td>
<td>6.125 x 0.750”</td>
<td>6.00 x 0.750”</td>
<td>155 x 19 mm</td>
<td>2.250 x 0.625”</td>
<td>4.125 x 0.750”</td>
<td>10.250 x 2”</td>
<td>311 x 50 mm</td>
<td>6.125 x 0.750”</td>
</tr>
<tr>
<td>Dimensions (coil)</td>
<td>0.875 x 0.875”</td>
<td>N/A</td>
<td>0.875 x 0.875”</td>
<td>N/A</td>
<td>0.875 x 0.875”</td>
<td>22 x 22 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coil Resistance</td>
<td>180Ω</td>
<td>50Ω</td>
<td>50Ω</td>
<td>180Ω</td>
<td>180Ω</td>
<td>180Ω</td>
<td>180Ω</td>
<td>120Ω</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-20 to +80 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-20 to +200 °C</td>
</tr>
</tbody>
</table>

**TABLE 9: Strain Gauge Specifications**

**Notes:**

1. Possible resolution depends on the readout; the figures in the above table pertain to the GK-404.

2. System Accuracy takes into account hysteresis, nonlinearity, misalignment, batch factor variations, and other aspects of the actual measurement program. System Accuracy to ±1.0% FS may be achieved through individual calibration of each strain gauge.

3. Model 4200HT-T high-temperature strain gauge has a Thermal Coefficient of 17.3 / °C.

A.2 THERMISTOR

For more information, refer to Appendix C.

Range: -80 to +150 °C

Accuracy: ±0.5 °C
APPENDIX B. THEORY OF OPERATION

A vibrating wire attached to the surface of a deforming body will deform in a manner similar to that of the deforming body. These deformations alter the tension of the wire, which alters its natural frequency of vibration (resonance).

The examples below are calculated using the Model 4200 gauge parameters. Substitute the values from the table below for Models 4202 and 4204.

Note: These equations do not apply to Models 4210, 4212, and 4214.

<table>
<thead>
<tr>
<th>Model:</th>
<th>4200/4200HT</th>
<th>4202</th>
<th>4204</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauge Length (Lg):</td>
<td>6 inches</td>
<td>2 inches</td>
<td>4 inches</td>
</tr>
<tr>
<td>Wire Length (Lw):</td>
<td>5.875 inches</td>
<td>2 inches</td>
<td>3.875 inches</td>
</tr>
<tr>
<td>Gauge Factor:</td>
<td>3.304</td>
<td>0.391</td>
<td>1.422</td>
</tr>
</tbody>
</table>

TABLE 10: Embedment Strain Gauge Theoretical Parameters

The relationship between frequency (period) and deformation (strain) is described as follows:

1. The fundamental frequency (resonant frequency) of vibration of a wire is related to its tension, length, and mass. The fundamental frequency may be determined by the equation:

   \[ f = \frac{1}{2L_w} \sqrt{\frac{F}{m}} \]

   Where:
   - \( L_w \) is the length of the wire in inches.
   - \( F \) is the wire tension in pounds.
   - \( m \) is the mass of the wire per unit length (pounds, seconds\(^2\)/inches\(^2\)).

2. Note that:

   \[ m = \frac{W}{L_w g} \]

   Where:
   - \( W \) is the weight of \( L_w \) inches of wire in pounds.
   - \( g \) is the acceleration of gravity (386 inches/seconds\(^2\)).

3. And:

   \[ W = \rho a L_w \]

   Where:
   - \( \rho \) is the wire material density (0.283 pounds/inches\(^3\)).
   - \( a \) is the cross-sectional area of the wire in inches\(^2\).

4. Combining the equations from steps one, two, and three gives:

   \[ f = \frac{1}{2L_w} \sqrt{\frac{F g}{\rho a}} \]

5. Note that the tension (F) can be expressed in terms of strain, e.g.,

   \[ F = \varepsilon_w E a \]

   Where:
   - \( \varepsilon_w \) is the wire strain (inches/inches).
   - \( E \) is the Young’s Modulus of the wire (30 x 10\(^6\) Psi).
6. Combining the equations from steps four and five gives:

\[
f = \frac{1}{2L_W} \sqrt{\frac{\varepsilon_W E g}{\rho}}
\]

7. Substituting the given values for \(E\), \(g\), and \(\rho\) yields:

\[
f = \frac{101142}{L_W} \sqrt{\varepsilon_W}
\]

8. In position A, (which displays the period of vibration, \(T\)) multiplied by a factor of \(10^6\):

\[
T = \frac{10^6}{f}
\]

9. Combining the equations from steps seven and eight gives:

\[
\varepsilon_W = \frac{97.75 L_W^2}{T^2}
\]

10. The equation from step nine must now be expressed in terms of the strain in the surface of the body to which the gauge is attached. Since the deformation of the body must equal the deformation of the wire:

\[
\varepsilon_W L_W = \varepsilon L_g
\]

Where:
\(\varepsilon\) is the strain in the body.
\(L_g\) is the gauge length in inches.

11. Combining the equations from steps nine and ten gives:

\[
f = \frac{1}{2L_W} \sqrt{\frac{f_g}{\rho a}}
\]

Where: (for Model 4200)
\(L_w\) is 5.875 inches.
\(L_g\) is 6.000 inches.

12. Therefore:

\[
\varepsilon = 3.304 \times 10^3 \left[ \frac{1}{T^2} \right]
\]

13. The display on position “D” of the readout is based on the equation:

\[
\varepsilon = 3.304 \times 10^9 \left[ \frac{1}{T^2} \right]
\]

The squaring, inverting, and multiplication by the factor \(3.304 \times 10^9\) is all done internally by the microprocessor of the readout so that the displayed reading in position D is given in microinches per inch (\(\varepsilon\)).

**Note:** In the previous steps, \(T\) is seconds \(\times 10^6\) and \(\varepsilon\) is microinches per inch. An alternative is: \(\varepsilon = 3.304 \times 10^{-3} f^2\) microstrain.

Where \(f\) is the frequency in Hz.
APPENDIX C. THERMISTOR TEMPERATURE DERIVATION

Thermistor type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Resistance to Temperature Equation:

\[ T = \frac{1}{A + B \ln(R) + C (\ln(R))^3} - 273.2 \]

**EQUATION 8: Resistance to Temperature**

Where:

- \( T \) = Temperature in °C
- \( \ln(R) \) = 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.

**TABLE 11: Thermistor Resistance versus Temperature**

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<th>Temp</th>
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TABLE 11: Thermistor Resistance versus Temperature
APPENDIX D. HIGH-TEMPERATURE THERMISTOR LINEARIZATION

Resistance to Temperature Equation for US Sensor 103JL1A:

\[
T = \frac{1}{A + B(LnR) + C(LnR)^3 + D(LnR)^5 - 273.2}
\]

**EQUATION 9: High-Temperature Resistance to Temperature**

Where:
- \( T \) = Temperature in °C
- \( LnR \) = Natural Log of Thermistor Resistance.
- \( A = 1.127670 \times 10^{-3} \)
- \( B = 2.344442 \times 10^{-4} \)
- \( C = 8.476921 \times 10^{-8} \)
- \( D = 1.175122 \times 10^{-11} \)

**Note:** Coefficients optimized for a curve J thermistor over the temperature range of 0 °C to +250 °C.

**TABLE 12: Thermistor Resistance versus Temperature for Model 4200HT**

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APPENDIX E. NO STRESS STRAIN ENCLOSURE

GEOKON’s Model 4200-4 No Stress Strain Enclosure is made of double PVC walls and is filled with polystyrene foam. The figure below shows a standard 4200-4 installation.

**FIGURE 17: No Stress Strain Enclosure**

The purpose of the no stress enclosure is to position a strain gauge so that it is not subject to changes in strain in the mass concrete surrounding it, yet still remains subject to changes in strain caused by the fluctuation of moisture content, temperature, and alkali/aggregate reaction. The data gleaned from the No Stress Strain Gauge can be used to apply corrections for these phenomena to the other strain gauges in the mass concrete, allowing the user to quantify only those strains that result from stress changes.

**INSTALLING THE 4200-4 ENCLOSURE**

1. Position the enclosure inside the concrete mass with the top open so that it can be easily filled with concrete. (Often the 4200-4 will be placed next to a strain gauge rosette.)

2. Mount the strain gauge by wrapping two turns of tie wire around the gauge and then feeding the ends of the wire through the holes in the opposite sides of the enclosure.

3. Wrap the ends of the tie wire around the outside of the enclosure and tie together.

4. Use a tie wire tightening tool or similar device to tighten the wire.
5. Repeat this procedure, using another tie wire and the second set of holes in the enclosure.

6. Arrange the instrument cable so that it exits through the top of the enclosure.

7. When pouring concrete into the enclosure, remove aggregate that is too large. Be careful not to disturb the gauges during the filling process.
APPENDIX F. MODEL 4200HT-T HIGH-TEMPERATURE STRAIN GAUGE

GEOKON Model 4200HT-T High-Temperature Embedment Strain Gauge is similar to the Model 4200, but is constructed using components that can withstand temperatures up to 220 °C. It is particularly useful for measurements in autoclaved spun concrete piles.

**FIGURE 18: Model 4200HT-T**

Data interpretation is the same as that outlined in Section 6, with the exception of the Temperature Coefficient, which for the 4200HT-T is 17.3 με / °C. Coil resistance for Model 4200HT-T is 50 ohms.

The thermistor included with the gauge is a high-temperature thermistor, which uses the resistance to temperature conversion table shown in Table 12 on page 25. When using a readout box, it is not necessary to connect the green and white wires to the readout because the temperature shown on the readout will be incorrect. Instead, use a digital ohmmeter.

**TO READ TEMPERATURES USING AN OHMMETER**

1. Connect an ohmmeter to the green and white thermistor leads coming from the strain gauge. (Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant.)

2. Look up the temperature for the measured resistance in Table 12 on page 25.
APPENDIX G. MEASUREMENT AND CORRECTION OF TEMPERATURE EFFECTS

If the ends of the structural member are free to expand or contract without restraint, strain changes can take place without any change in stress. On the other hand, if the ends of the structural member are restrained by some semi-rigid medium, then any increase in temperature of the structural member will result in a buildup of compressive load-related strain in the member, even though the actual strain would be tensile.

The reason for this is because the member is restrained from expansion but the vibrating wire is not. An increase in temperature will produce expansion in the vibrating wire, which in turn will cause a reduction in wire tension. This results in a decrease in the vibrational frequency. The magnitude of this temperature-induced, compressive strain increase would be measured accurately by the strain gauge, and can be determined using Equation 5 on page 16.

These temperature-induced stresses can be separated from any external, load-induced stresses by reading both the strain and temperature of the gauge at frequent intervals. These readings should take place during a period when the external loading from construction activity remains unchanging. When these strain changes are plotted against the corresponding temperature changes, the resulting graph will show a straight-line relationship, the slope of which yields a factor $K_T$ microstrain/degree. This factor can be used to calculate the temperature-induced stress, as shown by the following equation:

$$\sigma_{\text{temperature induced}} = K_T (T_1-T_0)E$$

Equation 10: Temperature-Induced Stress

This can be subtracted, if desired, from the combined load related stress change using the following equation:

$$\sigma_{\text{combined temp and load related}} = [(R_1-R_0)B + (T_1-T_0)(C_1-C_2)]E$$

Equation 11: Combined Temperature and Load-Related Stress

To give that part of the stress change due to construction activity loads only, use the following equation:

$$\sigma_{\text{external load}} = [(R_1-R_0)B + (T_1-T_0)(C_1-C_2) - K_T (T_1-T_0)]E$$

Equation 12: External Load Stress

Note that the correction factor ($K_T$) may change with time and with construction activity as the rigidity of the restraint may change. In such a case, it would be advisable to calculate a new temperature correction factor by repeating the above procedure.

If, for whatever reason, the actual strain of the concrete member is required (e.g., the change of unit length that would be measured by a dial gauge attached to the surface), this is given by the equation:

$$\mu_{\text{actual}} = (R_1-R_0)B + (T_1-T_0)C_1$$

Equation 13: Actual Strain

Where $C_1$ represents the coefficient of expansion of steel = 12.2 microstrain/°C.

This equation may seem less than intuitive and therefore requires some explanation. As an example, assume first that the strain gauge is inside a concrete slab that is perfectly restrained at its ends. If the temperature rises by one °C, then the vibrating wire undergoes an expansion of 12.2 microstrains and
(R_1-R_0)B would be -12.2 microstrains, therefore the result of Equation 5 on page 16 in Section 6.5 would be zero actual strain in the concrete slab.

On the other hand, if the concrete slab is free of all restraint, and experiences a temperature change of 1 °C, then the concrete would expand 10 microstrains, while the vibrating wire would expand 12.2 microstrains. The value of (R_1-R_0)B would then be -2.2 microstrains (the vibrating wire would slacken slightly), and Equation 5 would yield a value of 10 microstrains.