Model 4200 Series

Vibrating Wire Strain Gauges

Instruction Manual



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Document Revision: HH.3 | Release Date: 8/10/26

Note: The Model 4200HT High Temperature Gauges are not CE approved.

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1. INTRODUCTION

GEOKON Model 4200 Vibrating Wire Strain Gauges are designed for direct embedment in concrete, and are a versatile measurement device with proven long-term stability and exceptional accuracy. They are typically attached to rebar or tensioning cables, then cast into a briquette, which is subsequently cast into the structure or grouted into a borehole.

The working principle is similar to that of a guitar string: a piece of steel wire is tensioned between the two end blocks, then plucked by an electromagnetic coil. Small changes in the distance between the end blocks, conveyed by strain in the surface they are mounted to, cause a large change in the resonant frequency of the wire.

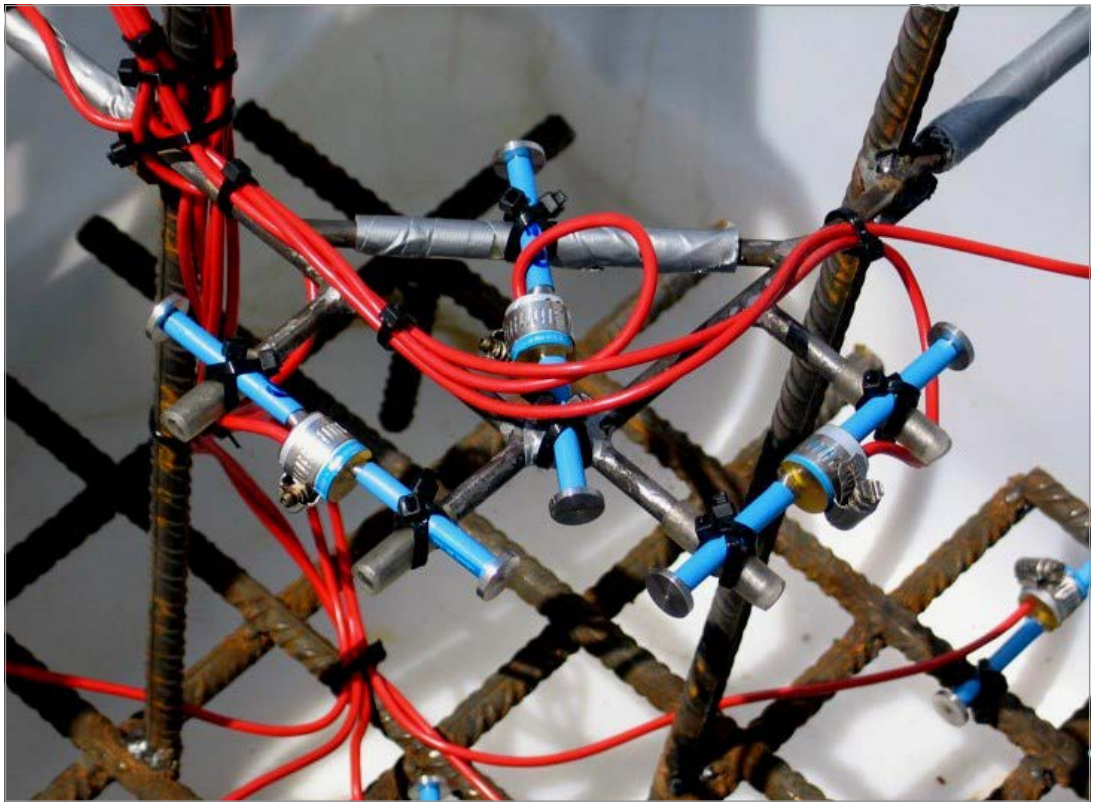


FIGURE 1: *On-Site Installation Using Model 4200 Gauges*

Portable readouts and data loggers 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. In use, a pulse of varying frequency (swept frequency) is applied to the coils causing the wire to vibrate primarily at its resonant frequency. During vibration, a sinusoidal signal is induced in the coils and transmitted to the readout box where it is conditioned and displayed.

2. MODELS

GEOKON offers several strain gauge options that are designed for a variety of installation applications. All standard models feature a range of 3,000 με. GEOKON also offers extended range options (ER-5 and ER-10) designed for use where high strains are anticipated, featuring ranges of 5,000 με (ER-5) and 10,000 με (ER-10).

2.1 MODEL 4200, 4200-ER-5, AND 4200-ER-10 (GENERAL PURPOSE)

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



FIGURE 2: *Model 4200 Vibrating Wire Strain Gauge*



FIGURE 3: *Model 4200-ER-5 Extended Range (5,000 microstrain) Vibrating Wire Strain Gauge*



FIGURE 4: *Model 4200-ER-10 Extended Range (10,000 microstrain) Vibrating Wire Strain Gauge*

2.2 MODEL 4200L (CURING STRAINS)

The Model 4200L Strain Gauge is a low modulus version, designed to enable strain measurement during concrete curing.



FIGURE 5: *Model 4200L Low Modulus Vibrating Wire Strain Gauge*

2.3 MODEL 4200ROS (FOR ROSETTE MOUNT)

The Model 4200ROS Strain Gauge is designed primarily for long-term strain measurements and features a machined female thread on one end meant for use with a Model 4200-3 Rosette Mount (see Appendix F). Utilizing this strain gauge, in conjunction with the rosette mount, allow for measurement of strain in multiple orientations at the same approximate location.

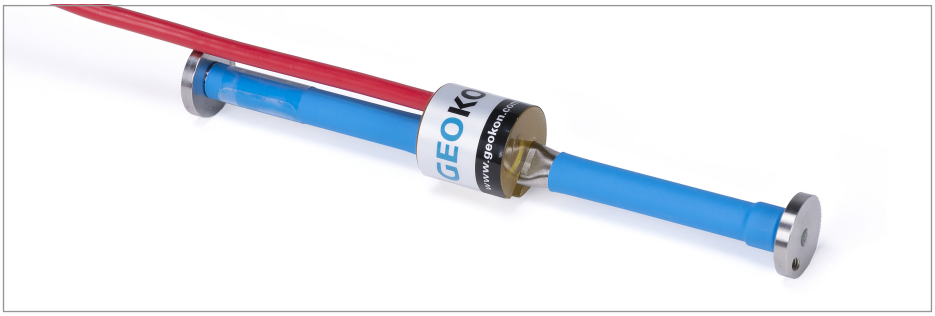


FIGURE 6: *Model 4200ROS Rosette Mount Vibrating Wire Strain Gauge*

2.4 MODEL 4200HT (HIGH TEMPERATURE)

The Model 4200HT High-Temperature Embedment Strain Gauge is similar to the Model 4200, but is constructed using components that can withstand high temperatures (200 °C). This option designed primarily for **short-term use** of strain measurements inside mass concrete, in structures such as foundations, piles, bridges, dams, containment vessels, tunnel liners, etc.

A high temperature thermistor is included with the gauge. Refer to Appendix B, Section B.2 for the resistance to temperature conversion table for this thermistor type. A digital ohmmeter is used (as outlined in Section 6.2) to read high temperature thermistors.

Note: A readout box cannot be used to read high temperature thermistors, as the reading displayed will be incorrect.



FIGURE 7: *Model 4200HT High Temperature Vibrating Wire Strain Gauge*

2.5 MODEL 4202, 4202-ER-5, AND 4202-ER-10 (FOR SMALL AGGREGATE)

The Model 4202 Strain Gauge is designed for embedment in grout, mortar, and small aggregate concrete. It is also useful for model studies.



FIGURE 8: *Model 4202 Vibrating Wire Strain Gauge*

2.6 MODEL 4204 (FOR CONFINED SPACES)

The Model 4204 Strain Gauge is designed to be embedded in concrete where space may be limited.



FIGURE 9: *Model 4204 Vibrating Wire Strain Gauge*

2.6.1 MODEL 4204L (CURING STRAINS, FOR CONFINED SPACES)

The Model 4204 Strain Gauge is a low-modulus version, designed to enable strain measurement during concrete curing where space may be limited.



FIGURE 10: *Model 4204L Low Modulus Vibrating Wire Strain Gauge*

2.7 MODEL 4210 (FOR LARGE AGGREGATE)

The Model 4210 Strain Gauge is designed for embedment in large aggregate concrete, greater than 19 mm (3/4"). This design features a rugged housing and wide end blocks to withstand the rigors of concrete placement.

By request, this model can also be modified for use with a Model 4210-1 Rosette Mount (see Appendix F). Utilizing this strain gauge (modified at GEOKON), in conjunction with the rosette mount, allow for measurement of strain in multiple orientations at the same approximate location.



FIGURE 11: *Model 4210 Vibrating Wire Strain Gauge*

3. PRIOR TO INSTALLATION

3.1 PRELIMINARY CHECKS

GEOKON recommends that each strain gauge is function tested before installing in the field. To perform a preliminary check, complete the following steps:

1. Slide the plucking coil over the flat center section of the strain gauge (if applicable).
2. Connect the cable to a readout. This could be a portable, handheld readout or the data acquisition system that will be used in the final installation.
3. Take readings from the gauge. The strain gauge should have a strong, stable signal. The temperature reading should match the ambient temperature.
4. Gently push on the gauge end blocks; confirm that the numbers on the readout rise as the tension increases. **Do not apply excessive tension (greater than 2 kg / 4 lb), as this may break the vibrating wire!**
5. Check electrical continuity using an ohmmeter. Resistance between the gauge leads (usually red and black) should be approximately 180 Ω (120 Ω for Model 4200HT, 50 Ω for Model 4202 gauges). Remember to add cable resistance, which is approximately 48.5 Ω per km (14.7 Ω per 1000') of 22 AWG stranded copper leads at 20 °C. Multiply this factor by two to account for both directions. Resistance between thermistor leads (usually green and white) will vary based on temperature (see Appendix B). Resistance between any conductor and the shield should exceed two megaohms.

Should any of these preliminary tests fail, see Section 8 for troubleshooting tips.

3.2 GAUGE AND COIL ASSEMBLY

Slide the hose clamp over the plucking coil and tighten to secure (if applicable).

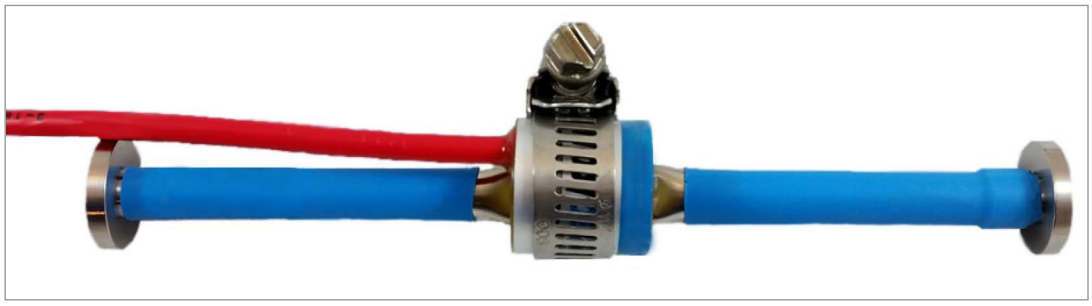


FIGURE 12: *Model 4200 Strain Gauge with Plucking Coil Installed*

Note: Alternatively, the plucking coil can be glued in place with a cyanoacrylate glue. This can be a useful method if installation space is limited or if the strain gauge is already tied into a rebar cage and it is not possible to slide a hose clamp over the end.

3.3 ADJUSTING THE GAUGE TO THE DESIRED RANGE

The procedure for adjusting the range of a strain gauge will differ depending on the model number. **The Model 4210 Strain Gauge is not adjustable.**

Strain gauges are supplied with an initial setpoint near the middle of their usable range. This allows them to see approximately 1,500 με in compression and 1,500 με in tension (for standard 3,000 με range strain gauges). This initial setpoint can be adjusted one way or the other if strains outside of this range are expected. Choose a point within the gauge's output range as defined in Table 1, then adjust according to the applicable section (3.3.1 or 3.3.2).

Model	4200 / 4200ROS 4200L / 4200HT	4200-ER-5 4200-ER-10	4202	4202-ER-5 4202-ER-10	4204 / 4204L
Microstrain (με)[1]	Min: 1000 Mid: 2500 με Max: 4000 με	N/A	Min: 1000 με Mid: 2500 με Max: 4000 με	N/A	N/A
Digits (dg)	Min: 300 dg Mid: 750 dg Max: 1200 dg	Min: 300 dg Max: *See individual calibration*	Min: 2560 dg Mid: 5760 dg Max: 11000 dg	Min: 2560 dg Max: *See individual calibration*	Min: 650 dg Mid: 1700 dg Max: 2750 dg
Frequency (Hz)	Min: 550 Hz Mid: 860 Hz Max: 1100 Hz	Min: 550 Hz Max: *See individual calibration*	Min: 1600 Hz Mid: 2400 Hz Max: 3300 Hz	Min: 1600 Hz Max: *See individual calibration*	Min: 800 Hz Mid: 1300 Hz Max: 1650 Hz
Readout Position	D	A	E	B	A

TABLE 1: *Strain Gauge Position Readings*

[1] Position D and E on GEOKON readouts output the gauge's measurement directly in theoretical microstrain (με). Theoretical microstrain is not a calibrated output, but may provide adequate accuracy for certain situations.

EXAMPLES:

The examples below are based on a Model 4200 gauge with a usable range of 1,000 - 4,000 με :

- Example 1: In an installation where the anticipated strains are primarily compressive, you may choose to set the gauge's initial reading to 80% of its output range. Set the gauge around 3400 με . This setting allows for 2400 με of compressive range, and 600 με of tensile range.
- Example 2: In an installation where all anticipated strains are in the compressive direction. A strain gauge output range of 95 - 100% may be desired. Set the gauge around 3900 με . This setting allows for 2900 με of compressive range, and 100 με of tensile range.

3.3.1 MODEL 4200, 4200ROS, 4200L, 4200HT, AND 4204 STRAIN GAUGES (INCLUDING EXTENDED RANGE MODELS)

1. Grip the small collar under the shrink tube and rotate the end flange as shown below.

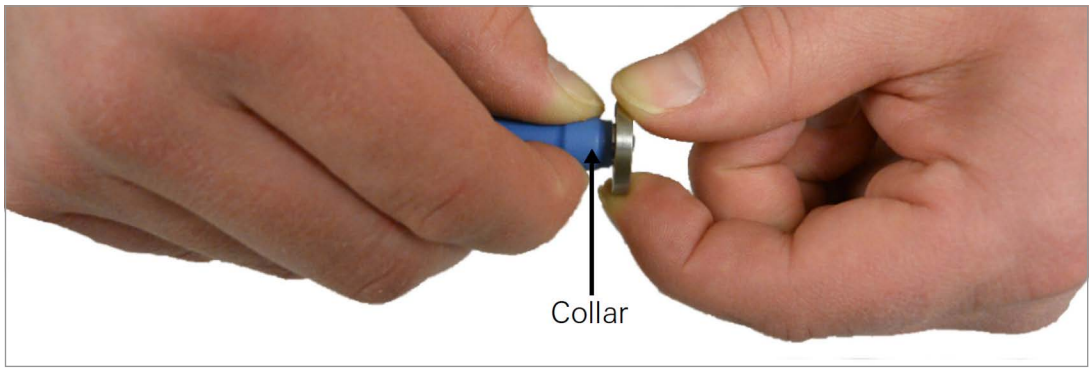


FIGURE 13: *Adjusting the Initial Setpoint of the Strain Gauge*

2. Rotate clockwise to decrease the initial setpoint; rotate counterclockwise to increase the initial setpoint.

3.3.2 MODEL 4202 STRAIN GAUGES (INCLUDING EXTENDED RANGE MODELS)

1. Connect the gauge to a handheld readout or data logger.
2. Grasp the strain gauge at its center and on the end blocks to prevent parts from rotating. Using a small wrench or pliers, rotate the tensioning nut to add or remove spring tension.

Important! Be careful not to let any other parts of the strain gauge rotate as this may damage the wire.

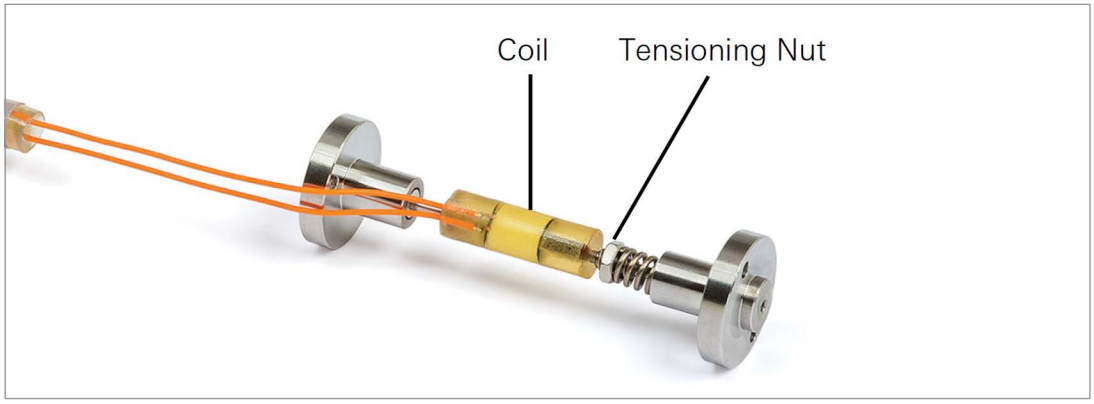


FIGURE 14: *Model 4202 Strain Gauge*

3. After the desired initial setpoint is achieved, apply a thread locker to preserve the setting.

4. INSTALLATION

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

- Casted directly into the concrete mix.

Note: Avoid applying excessive forces to the end blocks of the strain gauges when using this method, especially with Model 4202.

- Casted into a briquette that is subsequently casted into the larger concrete structure.

Model 4200L Note: This strain gauge is specifically designed to measure curing strains in concrete. However, do not embed the gauge more than one meter deep as doing so could damage the gauge.

4.1 CASTING DIRECTLY INTO CONCRETE MIX

Attach to rebar using one of the methods below, lower/install the rebar cages, then cast in concrete mix.

4.1.1 REBAR ATTACHMENT VIA 4200-SPACER (OR ALTERNATIVE SPACER)

Note: This method **can not** be used with Model 4202 Series.

GEOKON provides the Model 4200-SPACER to attach strain gauges to rebar. The spacer holds the strain gauge an adequate distance away from the rebar and takes only seconds to attach.

Note: As and alternative option, this process can also be completed using small pieces of wood or polystyrene in place of the spacers, as shown in Figure 16. Alternative spacers must be used if a Model 4210 Series Strain Gauge is installed using this attachment method.

1. Snap two spacers with pre-installed cable ties onto the strain gauge, one on each side as shown below.

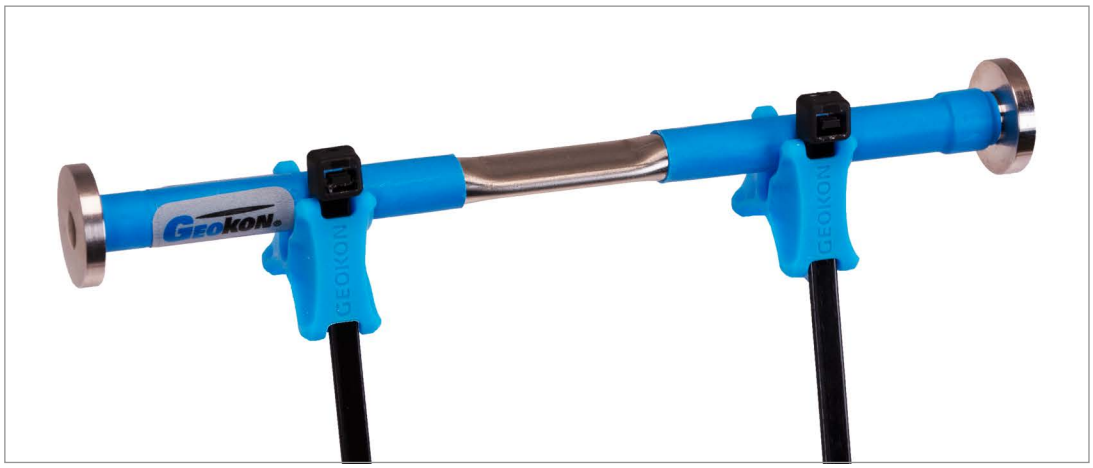


FIGURE 15: *Install Model 4200-SPACER*

2. Place the spacers against the rebar. Wrap the cable ties around the back of the rebar and engage with the head of the cable tie, firmly secure the strain gauge to the rebar (Figure 16). (If utilizing alternative spacers, secure the strain gauge/spacer using wire ties.)
3. Secure the strain gauge cable to the rebar with a cable tie (Figure 16).

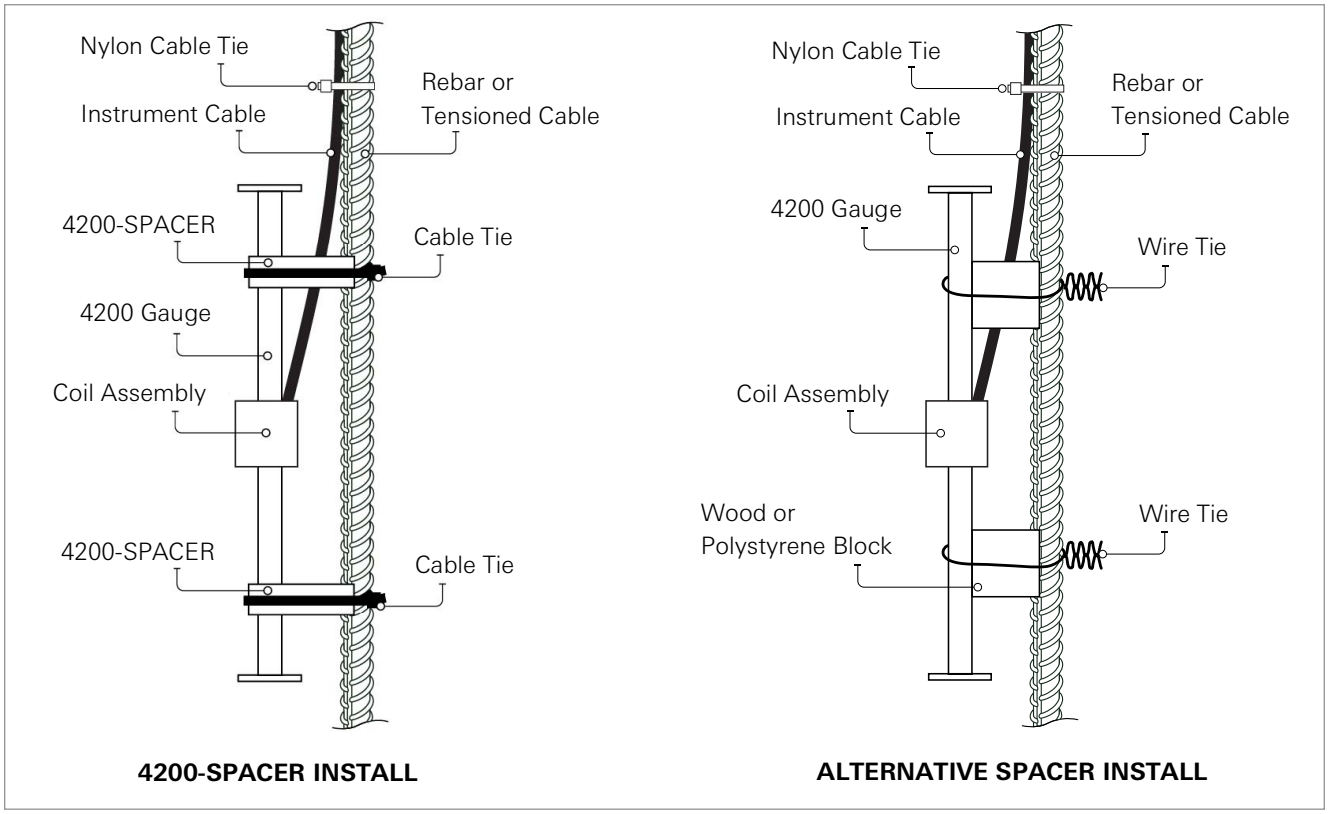


FIGURE 16: *Attachment Via 4200-SPACER or Alternative Spacers*

4.1.2 SUSPENSION METHOD

Strain gauges can also be mounted by suspending them between two pieces of rebar with short sections of wire ties (Figure 17). The wire tie suspension used in this method will have its own resonant frequency that may interfere with that of the strain gauge. This may make readings difficult or unstable prior to pouring concrete. Once the strain gauge is encased in concrete, this effect disappears.

1. Wrap a layer of rubber tape around the body of the strain gauge, approximately 3cm from either end. This helps to dampen the resonant frequency of the wire tie that may interfere with initial readings of the gauge.

Note: This step is not applicable with Model 4202 Strain Gauges.

2. Wrap the wire tie around the strain gauge over the rubber tape.

Note: For Model 4202, do not wrap a wire tie around the body of the strain gauge, as doing so could cause damage. Instead, use the holes in the end blocks.

3. Wrap the free ends of the wire tie around rebar segments to hang the strain gauge in the free space between them. Use care to ensure that the wire ties do not exert any tensile or compressive force on the gauge.

4. Tension the wire tie by twisting loops into the wire. Ensure even alignment of the strain gauge.

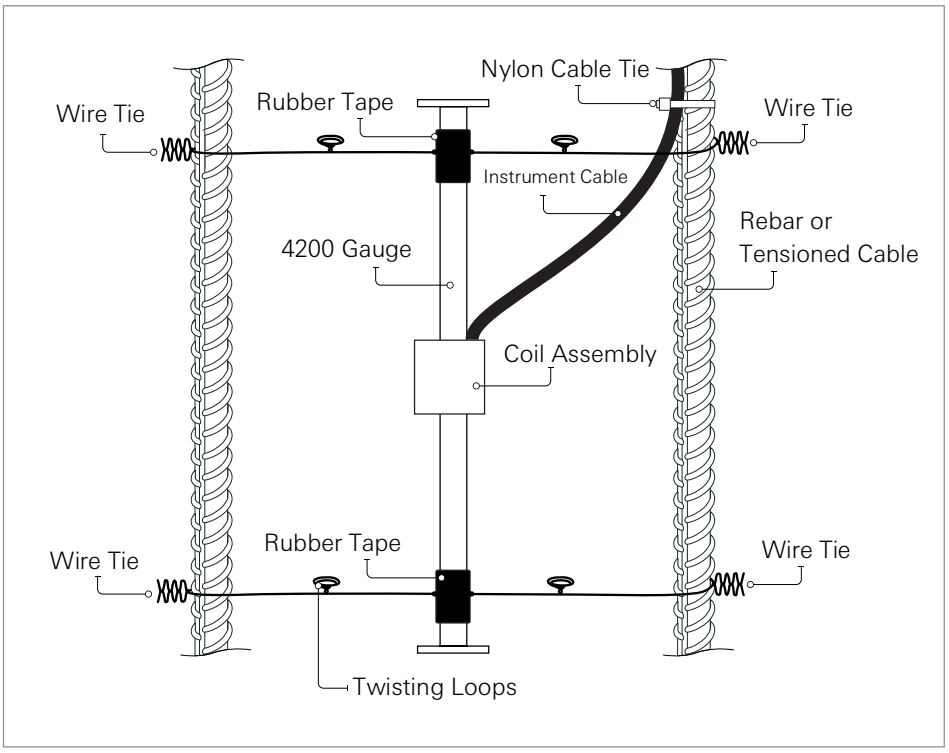


FIGURE 17: *Suspension Method Using Wire Ties*

4.1.3 ALTERNATIVE SUSPENSION METHOD

Note: This method **can not** be used with Model 4202 Series.

Two short pieces of rebar can be used to hang a strain gauge between rebar segments. This method avoids the resonance problems with the wire tie method.

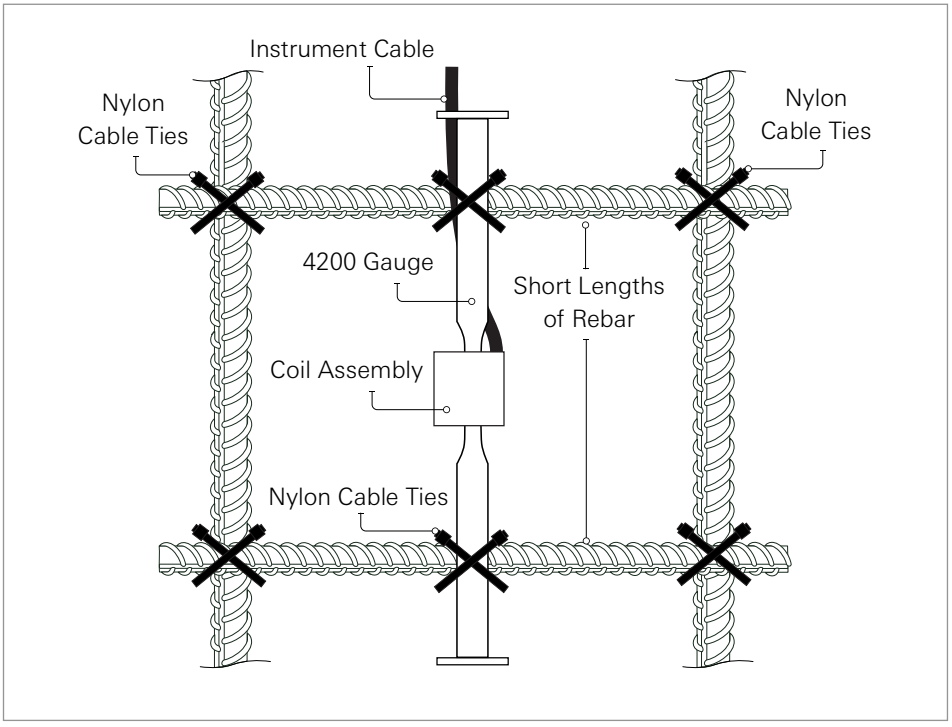


FIGURE 18: *Suspension Method Using Short Rebar Segments*

4.2 USING PRE-CAST BRIQUETTES, SHOTCRETE, OR GROUTING

Strain gauges can be pre-cast into briquettes of the same mix as the mass concrete, then placed within the structure prior to pouring the rest of the structure. These briquettes should be poured no less than one day and no more than three days prior to installation, and should be continuously wetted during curing.

Strain gauges in the Model 4200 family may also be used in shotcrete, or in grouted holes. When using shotcrete, special care should be taken to protect lead wires, especially on the more delicate Model 4202. This is best achieved by packing the area around the strain gauge by hand, then applying shotcrete around the gauge.

4.3 INITIAL ZERO READING

It is imperative that an accurate initial zero reading be obtained for each strain gauge, as this reading will be used for all subsequent data reduction.

Understanding the fundamental behavior of the vibrating wire strain gauge is essential for accurate measurements and analysis. There is no way to know the true strain in any structure, so all measurements are based on changes from a previous state. Once installed, a zero reading must be taken that serves as a reference point from which all future measurements will be compared. It is recommended that this reading is taken in a known load state, typically zero load.

Always allow sufficient time for the gauge temperature to stabilize before taking a reading. Be sure to record the temperature (see Section 6.2) every time a reading is taken, along with notes concerning the construction activity for added context. This data might supply logical reasons for observed changes in the readings. (See Appendix C for additional information about temperature effects.)

5. INSTRUMENT PROTECTION

5.1 CABLE AND CONNECTOR PROTECTION

The cable should be protected from accidental damage caused by moving equipment or debris. This is best accomplished by routing the cable through flexible conduit (available from GEOKON). The conduit can be connected via conduit bulkhead connectors to the cover plates. The GEOKON cover plate has a stamped knockout, which provides a hole for the conduit connector.

Because the vibrating wire output signal is a frequency rather than a current or voltage, cable splicing has no ill effects. The cable used for making splices should be a high-quality twisted pair type, with 100% shielding and an integral shield drain wire. **It is very important that the shield drain wires be spliced together.** Always maintain polarity when possible 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.

Install instrument cables as far away as possible from sources of electrical interference such as power lines, generators, motors, transformers, arc welders, etc. Cables should never be buried or run with AC power lines. Doing so will cause the instrument cables to pick up the frequency noise from the power cable, and this will likely make obtaining a stable reading difficult.

5.2 LIGHTNING PROTECTION

In settings where lightning strikes are a concern, GEOKON offers the Model 4999-12L/LE Surge Protection Module:

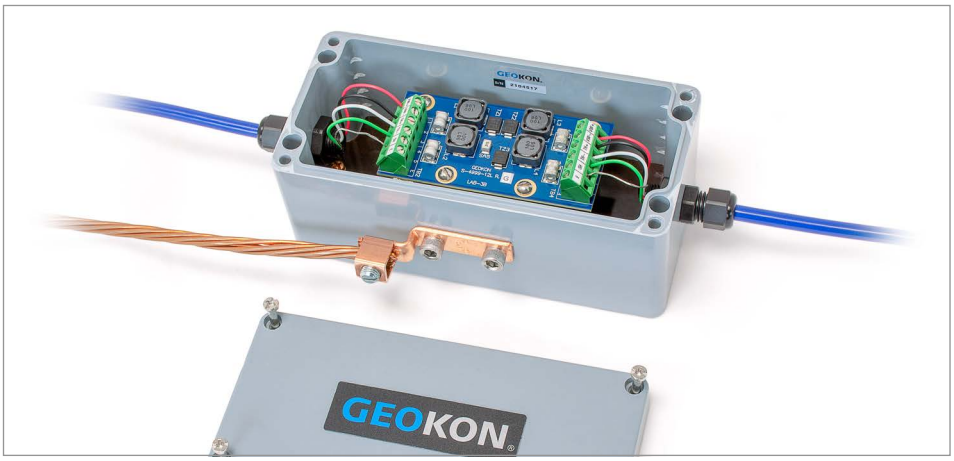


FIGURE 19: *Model 4999-12L/LE*

The module features surge protection circuitry that can be replaced in the event that it is damaged by a lightning strike. The Module is installed between a strain gauge and the data logger or terminal box it is connected to. Consult the Model 4999-12L/LE Instruction Manual (geokon.com/4999-12L/E) for additional information.

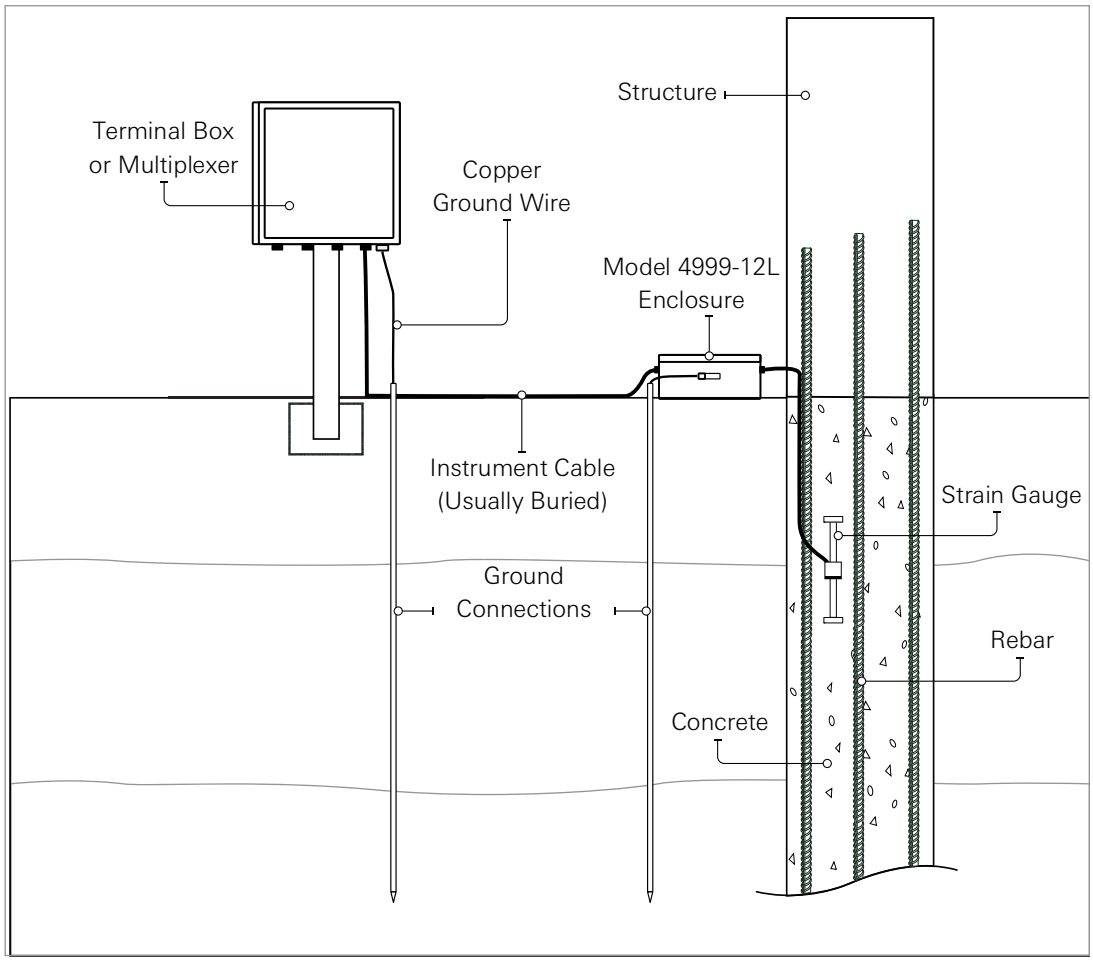


FIGURE 20: *Lightning Protection Scheme*

6. TAKING READINGS

Note: Digital readouts report the uncalibrated output of the strain gauges. For the most accurate results, calibration corrections must be performed (see Section 7).

6.1 COMPATIBLE READOUTS AND DATA LOGGERS

GEOKON can provide several readout and data logger options. Devices compatible with this product are listed below. For further details and instruction consult the corresponding Manual(s) at geokon.com/Readouts and geokon.com/Dataloggers.

DIGITAL READOUTS:

- **GK-404**

  The Model GK-404 VW Readout is a portable, low-power, hand-held unit capable of running for more than 20 hours continuously on two AA batteries. It is designed for the readout of all GEOKON Vibrating Wire (VW) instruments, and can display the reading in digits, frequency (Hz), period (μs), or microstrain (με). The GK-404 displays the temperature of the sensor (embedded thermistor) with a resolution of 0.1 °C.

- **GK-406**

  The Model GK-406 is a field-ready device able to quickly measure a sensor, save data, and communicate results with custom PDF reports and spreadsheet output. Measurements are geo-located with the integrated GPS allowing the GK-406 to verify locations and lead the user to the sensor locations. The large color display and VSPECT™ technology produce the best measurement possible both in the field and in the office.

DATA LOGGERS:

- **GeoNet Series**

  The GeoNet Data Logger series is designed to collect and transfer data from vibrating wire, RS-485, and analog instruments. GeoNet offers a wide range of telemetry options, including LoRa, cellular, Wi-fi, satellite, and local. Data loggers can work together to operate in a network configuration, or be used separately as standalone units. GeoNet devices arrive from the factory ready for deployment and may commence with data acquisition in minutes.

  Data is transferred to a secure cloud-based storage platform where it can be accessed through the GEOKON OpenAPI. Industry leading data visualization software, such as the free GEOKON Agent Software, can be used with the OpenAPI for data viewing and reporting. Data loggers without network capabilities are also available.

- **8600 Series**

  The Model 8600 Series Data Logger is designed to support the reading of a large number of GEOKON instruments for various unattended data collection applications using GEOKON Model 8032 Multiplexers. Weatherproof packaging allows the unit to be installed in field environments where inhospitable conditions prevail. The Nema 4X enclosure also has a provision for locking to limit access to responsible field personnel.

6.2 MODEL 4999 TERMINAL BOXES

Terminal boxes 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, making it easy to manually connect a Readout Box (GK-404 or GK-406) to multiple sensors at one time.

For further details and instruction consult the Model 4999 Instruction Manual (geokon.com/4999).

6.3 MEASURING TEMPERATURES

All GEOKON vibrating wire instruments 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-404 and GK-406 readouts will read the thermistor and display the temperature in degrees Celsius.

Note: With Model 4200HT only an Ohmmeter can be used to measure the temperature.

USING AN OHMMETER TO READ TEMPERATURES:

Connect an ohmmeter to the green and white thermistor leads coming from the instrument. 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 48.5Ω per km (14.7Ω per 1000') at 20 °C. Multiply these factors by two to account for both directions.

Look up the temperature for the measured resistance in Appendix B. Standard thermistors are covered in Section B.1, high temperature (Model 4200HT) thermistors are covered in Section B.2.

7. DATA REDUCTION

The process of turning strain gauge readings into usable, accurate strain measurements depends on how the readings were taken and how the gauges were calibrated. GEOKON strain gauges come with one of two calibration options:

- Batch Calibration: An economical and practical option where a representative sample of gauges in each batch are calibrated, resulting in a single average gauge factor. This option provides adequate accuracy for most applications and results in simple, easy-to-implement calculations. The batch calibration report provides a:
  - **Linear batch factor** that can be used to calculate strains from any gauge within the batch using the linear equation (see Section 7.1).

Note: Large orders may contain strain gauges from multiple batches. When this occurs, calibration reports for each batch will be supplied.

- Individual Calibration: For applications where the maximum possible accuracy is required, individual calibration precisely characterizes the relationship between strain and a particular gauge's output. The individual calibration report provides two types of gauge factors:
  - The **linear gauge factor** is a single number that minimizes calculation complexity while still being unique to each individual gauge (see Section 7.2.1).
  - The **polynomial gauge factor** is a set of coefficients unique to each gauge and requires a more complex calculation, but results in the most precise strain readings possible. For standard models see Section 7.2.2, for extended range models see Section 7.2.3.

Note: For extended-range models (4000-ER) it is recommended that the polynomial equation be used.

The units used to take readings depend on the strain gauge. Typically:

- Batch calibrated gauges can be read in either theoretical microstrain ($\mu\varepsilon$) or digits (dg).
- Standard individually calibrated gauges are read in theoretical microstrain ($\mu\varepsilon$).
- Extended range (4000-ER) models are read in digits (dg).

If utilizing digits in strain measurement, refer to the following equation, which shows the calculation of digits:

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

EQUATION 1: *Digits Calculation*

Refer to Section 7.3 for temperature correction.

7.1 BATCH CALIBRATED GAUGES

If reading the sensor in microstrain **(με)** the following calculation is used:

$$\Delta\mu\varepsilon = (R_1 - R_0)B$$

EQUATION 2: *Linear Strain Calculation for Gauges with Batch Calibration (Using με Readings)*

If reading the sensor in digits (dg) the following calculation is used:

$$\Delta\mu\varepsilon = (R_1 - R_0)B \times G$$

EQUATION 3: *Linear Strain Calculation for Gauges with Batch Calibration (Using Digit Readings)*

Where:
R_1 = The current reading in με or digits.
R_0 = The initial field zero reading in με or digits.
B = The batch factor found on the calibration report.
G = The theoretical gauge factor in με per digit, found on the calibration report.

Take note of the sign of the resulting strain. A positive change is tensile and a negative change is compressive.

EXAMPLE:

Reading Units: digits (dg)

A Model 4200 Strain Gauge is mounted in a bridge pier. After being installed, the initial reading is 710.4 dg. After bridge decks are constructed and placed onto the pier, the new reading is 599.2 dg.

The batch factor (B) found on the calibration report is 0.96.

The linear gauge factor (G) found on the calibration report is 3.179.

Because the readings are taken in digits, Equation 3 is used.

The change in strain is:

$$\Delta\mu\varepsilon = (R_1 - R_0)B \times G$$

$$\Delta\mu\varepsilon = (599.2 - 710.4)0.96 \times 3.179$$

$$\Delta\mu\varepsilon = -339.4\ \mu\varepsilon$$

The resulting change in strain is negative, which means that the pier has experienced a peak change of 339.4 με in **compression** from when the initial reading was taken.

7.2 STRAIN CALCULATION FOR INDIVIDUALLY CALIBRATED GAUGES

7.2.1 LINEAR CALCULATION

To convert microstrain **(με)** or digits (dg) to apparent change in strain ($\Delta\mu\varepsilon$) the following equation applies:

$$\Delta\mu\varepsilon = G(R_1 - R_0)$$

EQUATION 4: *Linear Strain Calculation for Individually Calibrated Gauges*

Where:
G = The gauge factor found on the calibration report.

R_1 = The current reading in $\mu\varepsilon$ for standard models, or digits for extended range (ER) models.

R_0 = The initial field zero reading in $\mu\varepsilon$ for standard models, or digits for extended range (ER) models.

Take note of the sign of the resulting strain. A positive change is tensile and a negative change is compressive.

EXAMPLE:

Reading Units: microstrain($\mu\varepsilon$)

A Model 4200 Strain Gauge is embedded in a bottom chord member of a beam bridge. After being installed, a technician uses a GEOKON readout in position D to record an initial reading of 1995.1 $\mu\varepsilon$. After the road deck is installed, additional load is added to the truss and the bottom chord experiences a tension force. The new reading is 2239.3 $\mu\varepsilon$.

The linear gauge factor (G) for this gauge, found on the calibration report, is 0.9622.

The change in strain is:

$$\Delta\mu\varepsilon = G(R_1 - R_0)$$

$$\Delta\mu\varepsilon = 0.9622(2239.3 - 1995.1)$$

$$\Delta\mu\varepsilon = 235\ \mu\varepsilon$$

The resulting change in strain is positive, which means that the chord member has experienced a change of 235 $\mu\varepsilon$ in **tension** from when the initial reading was taken.

If the two readings in $\mu\varepsilon$ are directly subtracted from each other without calibration corrections (2239.3 - 1995.1 $\mu\varepsilon$), the resulting change in strain is 244.2 $\mu\varepsilon$, which is only 3.9% higher than the calibration-corrected result of 235 $\mu\varepsilon$. For strain gauges with a compatible GEOKON readout position, this allows a technician in the field to take coarse measurements (biased towards over-reporting strain changes rather than under-reporting) with an accuracy of +10% / -0%. This is the advantage of using a GEOKON handheld readout in position D or E.

7.2.2 POLYNOMIAL CALCULATION FOR STANDARD MODELS

To convert digits to strain using the polynomial calculation the following equation applies:

$$\mu\varepsilon = AR_1^2 + BR_1 + C$$

EQUATION 5: *Polynomial Strain Calculation for Standard Gauges*

Where:
R_1 = The current reading in $\mu\varepsilon$.
A, B, C = The polynomial gauge factors found on the calibration report.

Take note of the sign of the resulting strain. A positive change is tensile and a negative change is compressive.

EXAMPLE:

Reading Units: digits (dg)

A Model 4200 Strain Gauge is cast into the bottom side of a floor plate to measure tensile forces. After being installed, the initial reading is 731.8 dg. After additional load is added to the floor plate, it deflects downwards. The new reading is 760.2 dg.

The calibration coefficients, found on the calibration report, are:

A = 2.3656E-06

B = 0.9431

C = -975.6

The initial reading (731.8 digits) is converted into $\mu\varepsilon$:

$$\mu\varepsilon_0 = AR_0^2 + BR_0 + C$$

$$\mu\varepsilon_0 = (2.3656 \times 10^{-6})\ 731.8^2 + (0.9431)731.8 + (-975.6)$$

$$\mu\varepsilon_0 = -284.2\ \mu\varepsilon$$

The same process is used to convert the current reading (760.2 digits) into $\mu\varepsilon$:

$$\mu\varepsilon_1 = AR_1^2 + BR_1 + C$$

$$\mu\varepsilon_0 = (2.3656 \times 10^{-6})\ 760.2^2 + (0.9431)760.2 + (-975.6)$$

$$\mu\varepsilon_1 = -257.3\ \mu\varepsilon$$

The two readings are then used to find the apparent change in strain ($\Delta\mu\varepsilon$):

$$\Delta\mu\varepsilon = \mu\varepsilon_1 - \mu\varepsilon_0$$

$$\Delta\mu\varepsilon = (-257.3\ \mu\varepsilon) - (-284.2\ \mu\varepsilon)$$

$$\Delta\mu\varepsilon = 26.9\ \mu\varepsilon$$

The resulting change in strain is positive, which means that the bottom side of the floor plate has experienced a change of 26.9 $\mu\varepsilon$ in tension from when the initial reading was taken.

7.2.3 POLYNOMIAL CALCULATION FOR EXTENDED RANGE (4000-ER) MODELS

$$\mu\varepsilon = AR_1^3 + BR_1^2 + CR_1 + D$$

EQUATION 6: *Polynomial Strain Calculation for Extended Range (ER) Models*

Where:
R_1 = The current reading in digits.
A, B, C, D = The polynomial gauge factors found on the calibration report.

Take note of the sign of the resulting strain. A positive change is tensile and a negative change is compressive.

EXAMPLE:

Reading Units: digits (dg)

A Model 4200-ER Strain Gauge is cast into the bottom side of a floor plate to measure tensile forces. After being installed, the initial reading is 604.9 dg. After additional load is added to the floor plate, it deflects downwards. The new reading is 761.2 dg.

The calibration coefficients, found on the calibration report, are:

A = -3.440E-08

B = 9.809E-05

C = 3.0949

D = -964.5

The initial reading (604.9 digits) is converted into $\mu\varepsilon$:

$$\mu\varepsilon_0 = AR_0^3 + BR_0^2 + CR_0 + D$$

$$\mu\varepsilon_0 = (-3.440 \times 10^{-8})\ 604.9^3 + (9.809 \times 10^{-5})\ 604.9^2 + (3.0949)\ 604.9 + (-964.5)$$

$$\mu\varepsilon_0 = 935.9\ \mu\varepsilon$$

The same process is used to convert the current reading (761.2 digits) into $\mu\varepsilon$:

$$\mu\varepsilon_1 = AR_1^3 + BR_1^2 + CR_1 + D$$

$$\mu\varepsilon_1 = (-3.440 \times 10^{-8})\ 761.2^3 + (9.809 \times 10^{-5})\ 761.2^2 + (3.0949)\ 761.2 + (-964.5)$$

$$\mu\varepsilon_1 = 1433\ \mu\varepsilon$$

The two readings are then used to find the apparent change in strain ($\Delta\mu\varepsilon$):

$$\Delta\mu\varepsilon = \mu\varepsilon_1 - \mu\varepsilon_0$$

$$\Delta\mu\varepsilon = 935.9\ \mu\varepsilon - 1433\ \mu\varepsilon$$

$$\Delta\mu\varepsilon = 497.1\ \mu\varepsilon$$

The resulting change in strain is positive, which means that the underside of the floor plate (at the depth of the strain gauge) has experienced a change of 497.1 $\mu\varepsilon$ in **tension** from when the initial reading was taken.

7.3 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:

$$(T_1 - T_0)(C_1 - C_2)$$

EQUATION 7: *Combined Temperature and Load Related Stress*

Where:

T_0 = The initial temperature.

T_1 = The current temperature.

C_1 = The coefficient of expansion of the gauge = 12.2 $\mu\varepsilon$ / °C (10.6 for 4200-ER models).

C_2 = The coefficient of expansion of concrete: ~10 $\mu\varepsilon$ /°C. (Users should use their own values if known.)

See the temperature correction equations below. Refer to Appendix C for more information.

7.3.1 LOAD RELATED STRAIN

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

$$\mu\varepsilon_{load} = \Delta\mu\varepsilon + (T_1 - T_0)(C_1 - C_2)$$

EQUATION 8: *True, Load-Related Strain Corrected for Temperature*

Where:

$\Delta\mu\varepsilon$ = The apparent change in strain, calculated using the Linear or Polynomial equation.

T_1 = The current reading.

B = The batch factor found on the calibration report.

T_0 = The initial temperature.

T_1 = The current temperature.

C_1 = The coefficient of expansion of the gauge = 12.2 $\mu\varepsilon$ / °C (10.6 for 4200-ER models).

C_2 = The coefficient of expansion of concrete: ~10 $\mu\varepsilon$ /°C. (Users should use their own values if known.)

EXAMPLE:

$\Delta\mu\varepsilon$ = -339.4 $\mu\varepsilon$ (Calculated using the Linear or Polynomial equation), this is the **apparent strain**.

T_1 = 30 °C

T_0 = 20 °C

C_1 = 12.2 $\mu\varepsilon$ / °C

C_2 = 10 $\mu\varepsilon$ / °C

Calculating Load Related Strain:

$$\mu\varepsilon_{load} = \Delta\mu\varepsilon + (T_1 - T_0)(C_1 - C_2)$$

$$\mu\varepsilon_{load} = -339.4 + (30 - 20)(12.2 - 10)$$

$$\mu\varepsilon_{load} = -317.4$$

7.3.2 ACTUAL STRAIN

The actual strain undergone by the concrete, (i.e., that which would be measured by a measuring scale) is given by:

$$\mu\varepsilon_{actual} = \Delta\mu\varepsilon + (T_1 - T_0)C_1$$

EQUATION 9: *Actual Strain*

Where:

$\Delta\mu\varepsilon$ = The apparent change in strain, calculated using the Linear or Polynomial equation.

T_1 = The current reading.

T_0 = The initial temperature.

T_1 = The current temperature.

C_1 = The coefficient of expansion of the gauge = 12.2 $\mu\varepsilon$ / °C (10.6 for 4200-ER models).

EXAMPLE:

$\Delta\mu\varepsilon$ = -339.4 $\mu\varepsilon$ (Calculated using the Linear or Polynomial equation), this is the **apparent strain**.

T_1 = 30 °C

T_0 = 20 °C

C_1 = 12.2 $\mu\varepsilon$ / °C

Calculating Actual Strain:

$$\mu\varepsilon_{actual} = \Delta\mu\varepsilon + (T_1 - T_0)C_1$$

$$\mu\varepsilon_{actual} = -339.4 + (30 - 20)12.2$$

$$\mu\varepsilon_{actual} = -217.4$$

7.4 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.

7.5 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.

7.6 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.

7.7 CONVERTING STRAIN TO LOAD

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

$$L = E\mu\varepsilon A$$

EQUATION 10: *Strain to Load Formula*

Where:
L = The load.

E = The elastic modulus of the structural element in the appropriate units.
$\mu\varepsilon$ = The strain in microstrain.

A = The cross-sectional area in the appropriate units.

Caution! 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.

7.8 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:

Model	E, approximate
4200	596,000 psi
4200L	56,500 psi
4200-ER	N/A
4200HT	596,000 psi
4202	610,000 psi
4204	596,000 psi
4204L	56,500 psi
4210	2,350,000 psi

TABLE 2: *Effective Modulus*

8. TROUBLESHOOTING

Maintenance and troubleshooting is confined to periodic checks of the cable connections and maintenance of terminals. Once installed, the gauges are usually inaccessible and remedial action is limited.

Should difficulties arise, consult the list of possible solutions shown below. Do not attempt to repair or open gauges in the field, return any faulty gauges to GEOKON. Visit geokon.com/Technical-Support for additional troubleshooting help.

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 5.

SYMPTOM: THERMISTOR RESISTANCE IS TOO LOW

☐ Check all connections, terminals, and plugs for a short-circuit. If a short is located in the cable, splice according to instructions in Section 5.

☐ Water may have penetrated the interior of the strain gauge. There is no remedial action.

SYMPTOM: STRAIN GAUGE READINGS ARE UNSTABLE

☐ Ensure correct readout settings, including excitation voltage, excitation sweep range, and position (if using GEOKON Model GK-404 or similar readouts).

☐ Make sure the shield wire is connected to ground.

☐ Check if the readout or data logger produces stable readings with a different strain gauge. If not, it may have a depleted battery, incorrect settings, or otherwise be malfunctioning.

☐ Try a different plucking coil: Remove the hose clamp from the plucking coil and try a different coil. If the new plucking coil can successfully read the gauge, discard the faulty one.

☐ Consider if there is a source of electrical noise nearby. Common sources include generators, motors, welding equipment, and high-voltage electrical lines. If possible, turn off or move the source and check the strain gauge again. If this is found to be the cause but the source cannot be removed, install electronic filtering.

☐ Determine if the strain gauge is within its operating range. Consult Appendix A, Table 5 and compare the gauge's reading to its range. If the reading is outside of the output range, loosen the set screws in the mounting block with two set screws to allow the gauge to return to its midpoint reading. The set screw in the other mounting block can be left in place.

Note: Adjusting the strain gauge in this way will make it lose any correlation to the original setpoint/zero reading. Data taken after adjusting the gauge cannot be correlated to data taken before.

SYMPTOM: STRAIN GAUGE FAILS TO READ

☐ Ensure correct readout settings, including excitation voltage, excitation sweep range, and position (if using GEOKON Model GK-404 or similar readouts).

☐ Check if the readout or data logger produces readings with a different strain gauge. If not, it may have a depleted battery, incorrect settings, or otherwise be malfunctioning.

☐ Try a different plucking coil: Remove the hose clamp from the plucking coil and try a different coil. If the new plucking coil can successfully read the gauge, discard the faulty one.

☐ Examine the instrument cable for mechanical damage. Check the resistance of the cable by connecting an ohmmeter to the sensor leads. Table 3 shows the expected resistance for the various wire combinations; you can use Table 4 to fill in the actual resistance found. Cable resistance is approximately 48.5 Ω per km (14.7 Ω per 1000') of 22 AWG wire. Cable damage can cause both infinite resistance (broken cable) or very low resistance (shorted cable). If either condition is present but damage cannot be found, cut and re-test the cable at closer and closer points to the gauge. If a break or short is present, splice according to the instructions in Section 5. If the problem persists all the way to the gauge, replace the entire plucking coil and cable.

Strain Gauge Resistance Values

Red/Black coil resistance values vary for different model gauges:

- 4200HT: ≅120 Ω
- 4202: ≅50 Ω
- All Other Models: ≅180 Ω

Green/White: 3000 Ω at 25 °C

Any other wire combination will result in a measurement of infinite resistance.

Note: Tests should be performed with a quality multimeter to accurately show possibilities of shorts. Sensors should be disconnected from other equipment while performing resistance tests, this includes surge modules, terminals, multiplexers, and data loggers. Fingers cannot be touching the multimeter leads or sensor wires while testing.

Table 3 shows the expected resistance for the various wire combinations.

Table 4 is provided for the customer to fill in the actual resistance found.

Vibrating Wire Sensor Lead Grid - SAMPLE VALUES					
	Red	**Black**	**White**	**Green**	**Shield**
Red					
Black	**≅180 Ω**				
White	Infinite	Infinite			
Green	Infinite	Infinite	**3000 Ω at 25°C**		
Shield	Infinite	Infinite	Infinite	Infinite	

TABLE 3: *Sample Resistance*

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

TABLE 4: *Resistance Worksheet*

APPENDIX A. SPECIFICATIONS

A.1 VIBRATING WIRE STRAIN GAUGE

The table below lists the specifications for strain gauge models.

Model	4200 / 4200L	4200-ER-5	4200-ER-10	4200HT	4200ROS
Range (F.S.), (nominal)[1]	3000 με	5000 με	10000 με	3000 με	3000 με
Batch Accuracy[2]	Calibration: ±0.5% F.S.	Individual Calibration Only	Individual Calibration Only	Calibration: ±0.5% F.S.	Calibration: ±0.5% F.S.
Individual Accuracy[2]	Calibration: ±0.1% F.S.				
Zero Stability	0.02% F.S./yr				
Linearity	±0.5% F.S.	±2.5% F.S.	±4.0% F.S.	±0.5% F.S.	±0.5% F.S.
Thermal Coefficient	12.2 με / °C	10.6 με / °C	10.6 με / °C	Model 4200HT: 12.2 με / °C	12.2 με / °C
Active Gage Length[3]	153 mm			148 mm	153 mm
Frequency Range	550 – 1200 Hz				
Coil Resistance	180 Ω			Model 4200HT: 120 Ω	180 Ω
Temperature Range[4]	-20 to +80 °C			Model 4200HT: -20 to +200 °C	-20 to +80 °C

Model	4202	4202-ER-5	4202-ER-10	4204 / 4204L	4210
Range (F.S.), (nominal)[1]	3000 με	5000 με	10000 με	3000 με	3000 με
Batch Accuracy[2]	Calibration: ±0.5% F.S.	Individual Calibration Only	Individual Calibration Only	Calibration: ±0.5% F.S.	Individual Calibration Only
Individual Accuracy[2]	Calibration: ±0.1% F.S.				
Zero Stability	0.02% F.S./yr				
Linearity	±0.5% F.S.	±2.5% F.S.	±4.0% F.S.	±0.5% F.S.	
Thermal Coefficient	12.2 με / °C				
Active Gage Length[3]	51 mm			101 mm	254 – 610 mm
Frequency Range	1600 – 3500 Hz			800-1600 Hz	1500 – 3500 Hz
Coil Resistance	50 Ω			180 Ω	
Temperature Range[4]	-20 to +80 °C				

TABLE 5: *Strain Gauge Specifications*

Note:

[1] Represents entire range of gauge, including compressive and tensile directions. Usable microstrain range in either direction will be less.

[2] Using curve fitting techniques, (second order polynomial) a representative sample of gauges are calibrated. One calibration factor is supplied that can be used with all gauges in that batch.

[3] Other lengths available on request

[4] Other ranges available on request

A.2 THERMISTOR

See Appendix B for more information.

Standard Range: -80 to +150 °C

High Temperature (HT) Range: -55 to +300 °C

Accuracy: ±0.5 °C

A.3 STRAIN GAUGE DIMENSIONS

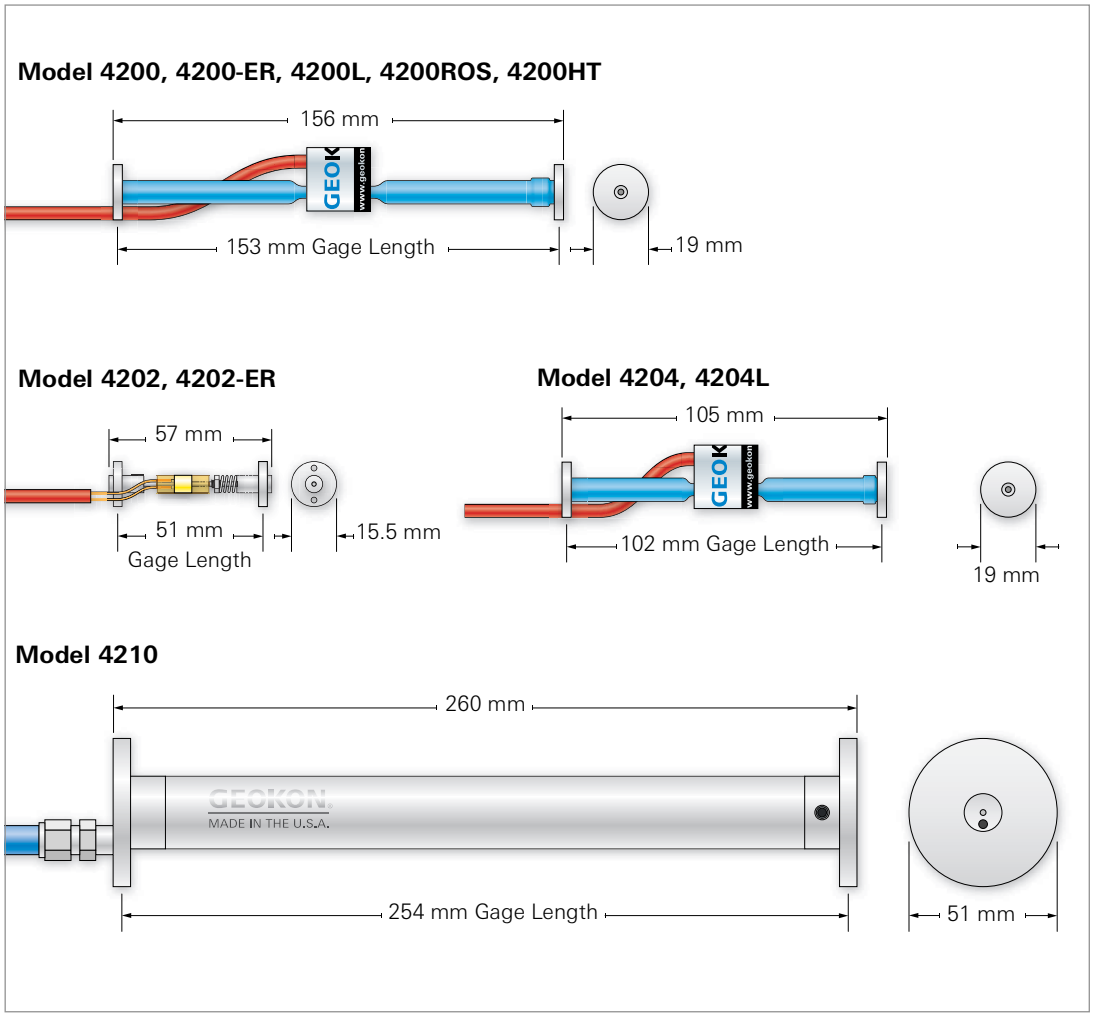


FIGURE 21: *Strain Gauge Dimensions*

A.4 ACCESSORIES

Part Number	Description
4000-1	Plucking coil (includes thermistor) with varied length cable, with hose clamp
4000-3	Plucking coil (includes thermistor) with 3 m (10') cable, with hose clamp
4200-SPACER	Pair of mounting brackets for attaching strain gauges to #4 through #11 reinforcing bar. Includes two 254 mm (10") cable ties.
4200-3	Strain gauge Rosette Mount for Model 4200ROS, 4 attachment rods included. Specify method of attachment to rosette.
4210-1	Strain gauge Rosette Mount for Model 4210 (strain gauge must be modified for use with Rosette Mount), 4 attachment rods included. Specify method of attachment to rosette.
4210-2	No-stress strain enclosure for 254 mm (10") strain gauge. Allows a strain gauge to be isolated from the stress field in concrete.

TABLE 6: *Strain Gauge Accessories*

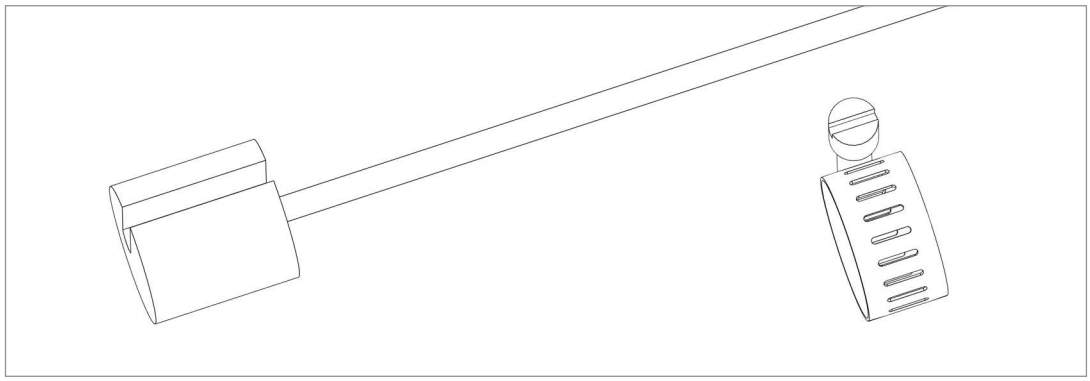


FIGURE 23: *Model 4000-1 and 4000-3 Plucking Coil and Hose Clamp*

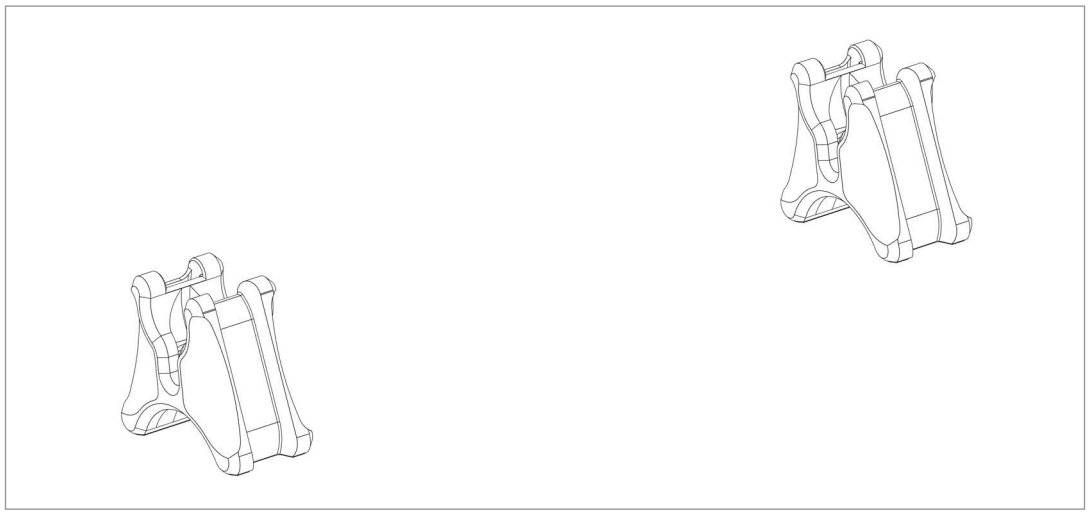


FIGURE 24: *Model 4200-SPACER Mounting Brackets (Zip Ties Not Shown)*

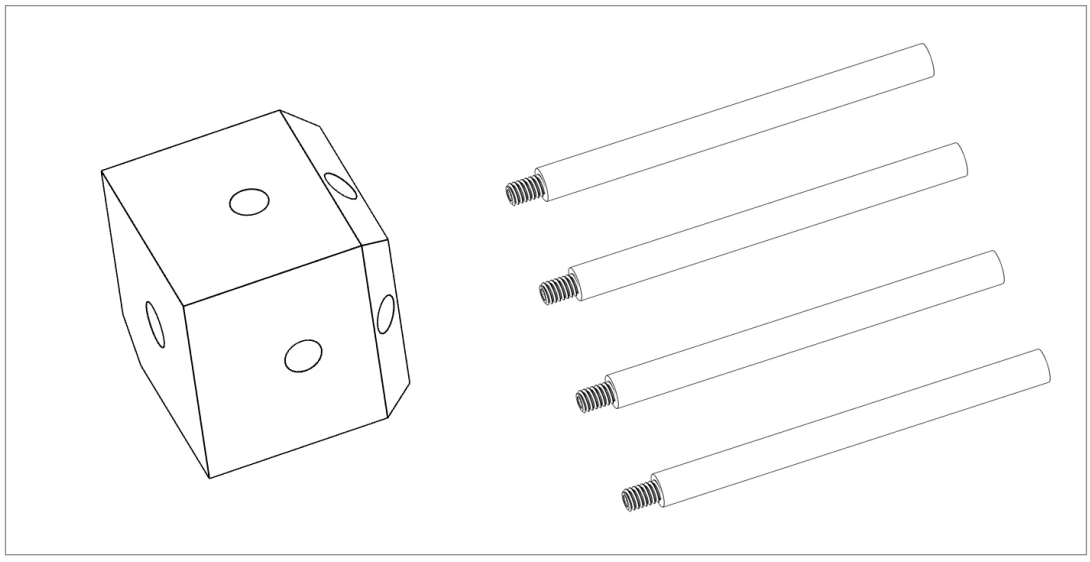


FIGURE 25: *Model 4200-3 and 4210-1 Strain Gauge Rosette Mounts*

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

B.1 3KΩ THERMISTOR RESISTANCE (STANDARD)

Thermistor Types include YSI 44005, Dale #1C3001–B3, Alpha #13A3001–B3, and Honeywell 192–302LET–A01.

Resistance to Temperature Equation:

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

EQUATION 11: *3KΩ Thermistor Resistance*

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

TABLE 7: *3KΩ Thermistor Resistance*

B.2 10KΩ THERMISTOR RESISTANCE (HIGH TEMP)

Thermistor Type: US Sensor 103JL1A

Resistance to Temperature Equation:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3 + D(LnR)^5} - 273.15$$

EQUATION 12: *10KΩ Thermistor Resistance*

Where:
T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
A = 1.127670×10^{-3}
B = 2.344442×10^{-4}
C = 8.476921×10^{-8}
D = 1.175122×10^{-11}
Note: Coefficients optimized for a curve **J** Thermistor over the temperature range of 0 °C to +250 °C.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
32,650	0	7,402	32	2,157	64	763.5	96	316.6	128	148.4	160	76.5	192	42.8	224
31,029	1	7,098	33	2,083	65	741.2	97	308.7	129	145.1	161	75.0	193	42.1	225
29,498	2	6,808	34	2,011	66	719.6	98	301.0	130	142.0	162	73.6	194	41.4	226
28,052	3	6,531	35	1,942	67	698.7	99	293.5	131	138.9	163	72.2	195	40.7	227
26,685	4	6,267	36	1,876	68	678.6	100	286.3	132	135.9	164	70.8	196	40.0	228
25,392	5	6,015	37	1,813	69	659.1	101	279.2	133	133.0	165	69.5	197	39.3	229
24,170	6	5,775	38	1,752	70	640.3	102	272.4	134	130.1	166	68.2	198	38.7	230
23,013	7	5,545	39	1,693	71	622.2	103	265.8	135	127.3	167	66.9	199	38.0	231
21,918	8	5,326	40	1,637	72	604.6	104	259.3	136	124.6	168	65.7	200	37.4	232
20,882	9	5,117	41	1,582	73	587.6	105	253.1	137	122.0	169	64.4	201	36.8	233
19,901	10	4,917	42	1,530	74	571.2	106	247.0	138	119.4	170	63.3	202	36.2	234
18,971	11	4,725	43	1,480	75	555.3	107	241.1	139	116.9	171	62.1	203	35.6	235
18,090	12	4,543	44	1,432	76	539.9	108	235.3	140	114.5	172	61.0	204	35.1	236
17,255	13	4,368	45	1,385	77	525.0	109	229.7	141	112.1	173	59.9	205	34.5	237
16,463	14	4,201	46	1,340	78	510.6	110	224.3	142	109.8	174	58.8	206	33.9	238
15,712	15	4,041	47	1,297	79	496.7	111	219.0	143	107.5	175	57.7	207	33.4	239
14,999	16	3,888	48	1,255	80	483.2	112	213.9	144	105.3	176	56.7	208	32.9	240
14,323	17	3,742	49	1,215	81	470.1	113	208.9	145	103.2	177	55.7	209	32.3	241
13,681	18	3,602	50	1,177	82	457.5	114	204.1	146	101.1	178	54.7	210	31.8	242
13,072	19	3,468	51	1,140	83	445.3	115	199.4	147	99.0	179	53.7	211	31.3	243
12,493	20	3,340	52	1,104	84	433.4	116	194.8	148	97.0	180	52.7	212	30.8	244
11,942	21	3,217	53	1,070	85	421.9	117	190.3	149	95.1	181	51.8	213	30.4	245
11,419	22	3,099	54	1,037	86	410.8	118	186.1	150	93.2	182	50.9	214	29.9	246
10,922	23	2,986	55	1,005	87	400.0	119	181.9	151	91.3	183	50.0	215	29.4	247
10,450	24	2,878	56	973.8	88	389.6	120	177.7	152	89.5	184	49.1	216	29.0	248
10,000	25	2,774	57	944.1	89	379.4	121	173.7	153	87.7	185	48.3	217	28.5	249
9,572	26	2,675	58	915.5	90	369.6	122	169.8	154	86.0	186	47.4	218	28.1	250
9,165	27	2,579	59	887.8	91	360.1	123	166.0	155	84.3	187	46.6	219		
8,777	28	2,488	60	861.2	92	350.9	124	162.3	156	82.7	188	45.8	220		
8,408	29	2,400	61	835.4	93	341.9	125	158.6	157	81.1	189	45.0	221		
8,057	30	2,316	62	810.6	94	333.2	126	155.1	158	79.5	190	44.3	222		
7,722	31	2,235	63	786.6	95	324.8	127	151.7	159	78.0	191	43.5	223		

TABLE 8: *10KΩ Thermistor Resistance*

APPENDIX C. TEMPERATURE EFFECTS

If the ends of the structural member are free to expand or contract without restraint, strain changes can occur without any change in the stress reading. However, if the ends of a steel structural member are restrained by some semirigid 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 strain gauge would accurately measure the magnitude of this temperature induced, compressive stress increase because the vibrating wire is not restrained from expansion, even though the member is restrained. Expansion would be indicated on the readout box by a decrease in the strain reading equal to the temperature-induced increase in compressive stress in the member.

These temperature-induced stresses can be separated from any external load-induced stresses by reading both the strain and the temperature of the gauge at frequent intervals. Take these readings when the external loading from construction activity remains constant. When these strain changes are plotted against the corresponding temperature changes, the resulting graph shows a straight-line relationship, the slope of which yields a factor K_T. This factor can be used to calculate the temperature induced stress:

$$\sigma_{thermal} = K_T(T_1 - T_0)E$$

EQUATION 13: *Temperature Induced Stress*

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

$$\sigma_{combined\ temp\ and\ load\ related} = [\Delta\mu\varepsilon + (T_1 - T_0)(C_1 - C_2)]E$$

EQUATION 14: *Combined Temperature and Load Related Stress*

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

$$\sigma_{external\ load} = [\Delta\mu\varepsilon + (T_1 - T_0)(C_1 - C_2) - K_T(T_1 - T_0)]E$$

EQUATION 15: *External Load Stress*

The correction factor, K_T, may change with time and with construction activity, as the rigidity of the restraint may change. It would then be advised to repeat the above procedure to calculate a new temperature correction factor.

If the **actual** strain of the steel member is required, (i.e., the change of unit length that would be measured by a dial gauge attached to the surface):

$$\mu\varepsilon_{actual} = \Delta\mu\varepsilon + (T_1 - T_0)C_1$$

EQUATION 16: *Actual Strain*

C_1 is the coefficient of expansion of the gauge = 12.2 $\mu\varepsilon$ / °C (10.6 for 4200-ER models).

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 1 °C, then the vibrating wire undergoes an expansion of 12.2 $\mu\varepsilon$ and $(R_1 - R_0)B$ would be -12.2 $\mu\varepsilon$, therefore the result of 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 $\mu\varepsilon$, while the vibrating wire would expand 12.2 $\mu\varepsilon$. The value of $(R_1 - R_0)B$ would then be -2.2 $\mu\varepsilon$ (the vibrating wire would slacken slightly), yielding a value of 10 $\mu\varepsilon$.

APPENDIX D. TYPICAL CALIBRATION REPORTS

D.1 BATCH CALIBRATION REPORT

GEOKON®

Vibrating Wire Strain Gauge Batch Calibration Report

Batch Number 50131352 Calibration Date: 7/15/2024

Calibration Instruction: CI-VW Strain Gauge Technician:

Strain Gauge Type	Batch Factor, B	Theoretical Gauge Factor, G (με/ digit)
4200	0.97	3.304

Calculations

Geokon Readout Boxes (GK-403, GK-404, GK-405)

$$\Delta\mu\varepsilon = (R_1 - R_0)\, B$$

Where:

$\Delta\mu\varepsilon$ is the apparent change in microstrain
R_0 is the initial reading in microstrain on Channel D
R_1 is a subsequent reading

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

Dataloggers

$$\Delta\mu\varepsilon = (R_1 - R_0)\, B * G$$

Where:

$\Delta\mu\varepsilon$ is the apparent change in microstrain
R_0 is the initial reading in digits
R_1 is a subsequent reading

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

The above instruments were found to be in tolerance in all operating ranges.
The above named instruments have been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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FIGURE 26: *Batch Calibration Report*

D.2 INDIVIDUAL CALIBRATION REPORT

GEOKON®

Vibrating Wire Strain Gauge Calibration Report

Model: 4200

Calibration Date: December 12, 2023

This calibration has been verified/validated as of 09/18/2024

Serial Number: 2319775

Temperature: 21.6 °C

Calibration Instruction: CI-VW Strain Gage

Technician:

GK-401 Reading Position D (readings in microstrain)

Actual Strain 1st Cycle (microstrain)	Gauge Reading, R 1st Cycle (microstrain)	Actual Strain 2nd Cycle (microstrain)	Gauge Reading, R 2nd Cycle (microstrain)	Average Actual Strain (microstrain)	Average Gauge Reading (microstrain)	Calculated Strain Linear (microstrain)	Error Linear (%FS)	Calculated Strain Polynomial (microstrain)	Error Polynomial (%FS)
0	1031	-1	1030	-1	1030	-6	-0.19	-1	-0.03
615	1682	618	1684	616	1683	618	0.04	618	0.06
1201	2295	1206	2300	1204	2297	1205	0.05	1204	-0.01
1812	2934	1818	2940	1815	2937	1816	0.04	1814	-0.03
2419	3568	2414	3562	2417	3565	2417	0.03	2417	0.00
3022	4196	3019	4192	3021	4194	3018	-0.07	3021	0.01

Linear Gauge Factor (G): 0.9562 **Regression Zero** 1037

Calculated Strain: **Linear, Strain = G (R_1 - R_0)**

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

Polynomial Gauge Factors: **A:** 2.3656E-06 **B:** 0.9431 **C:** -975.6

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.

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FIGURE 27: *Individual Calibration Report*

APPENDIX E. NO STRESS STRAIN ENCLOSURE

The GEOKON Model 4210-2 No Stress Strain Enclosure is a double-walled, foam-filled polyethylene container. A mounting flange with four mounting holes allows the enclosure to be secured to a wall or cage. Each unit is supplied with 22 feet (6.7 m) of stainless steel bend-and-stay wire. Figure 29 shows a standard installation.



FIGURE 28: *No Stress Strain Enclosure and Wire*

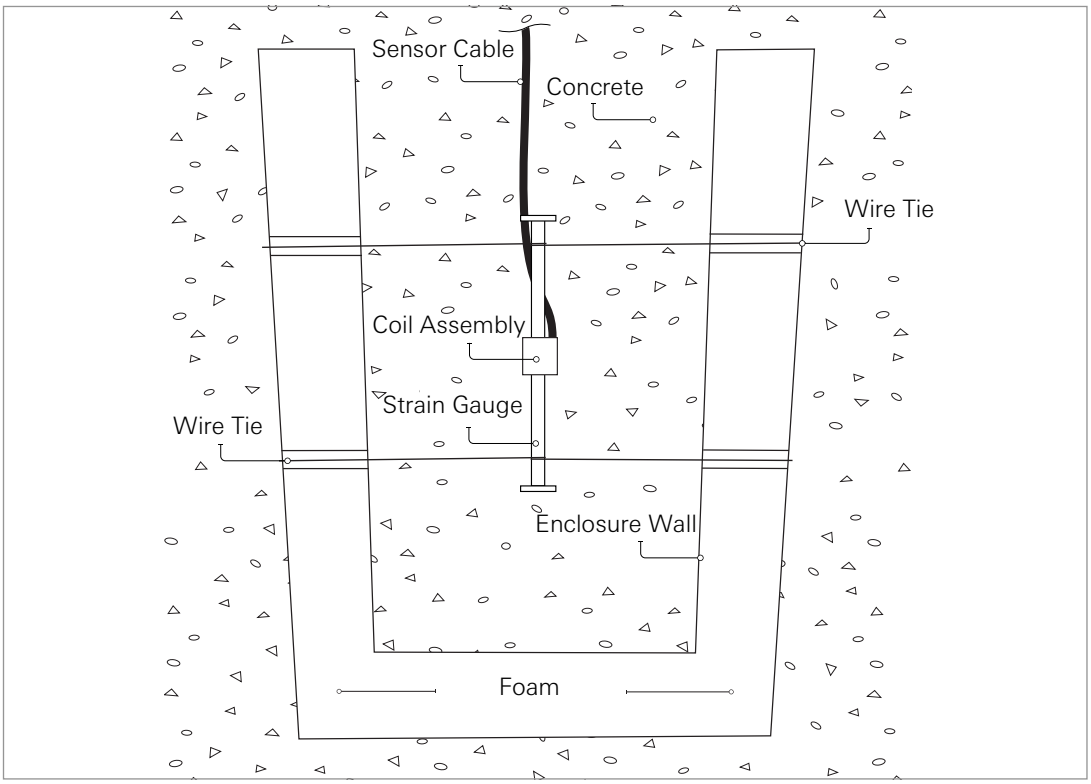


FIGURE 29: *Strain Gauge Installation*

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.

1. Position the enclosure inside the concrete mass with the top open so that it can be easily filled with concrete. (Often the enclosure will be placed next to a strain gauge rosette mount, see Appendix F.)
2. Mount the strain gauge by wrapping two turns of the supplied 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 wire around the outside of the enclosure and tie together.
4. Use a wire tightening tool or similar device to tighten the wire.
5. Repeat this procedure, using another 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. ROSETTE MOUNT

GEOKON Model 4200-3 and 4210-1 Rosette Mounts are used to measure strain in multiple orientations at the same approximate location. Strain gauges can be mounted in a total of 6 orientations, including vertical, horizontal, longitudinal, or 45 degree positioning.

Four rods are supplied with the rosette mount (additional rods are available for purchase through GEOKON).

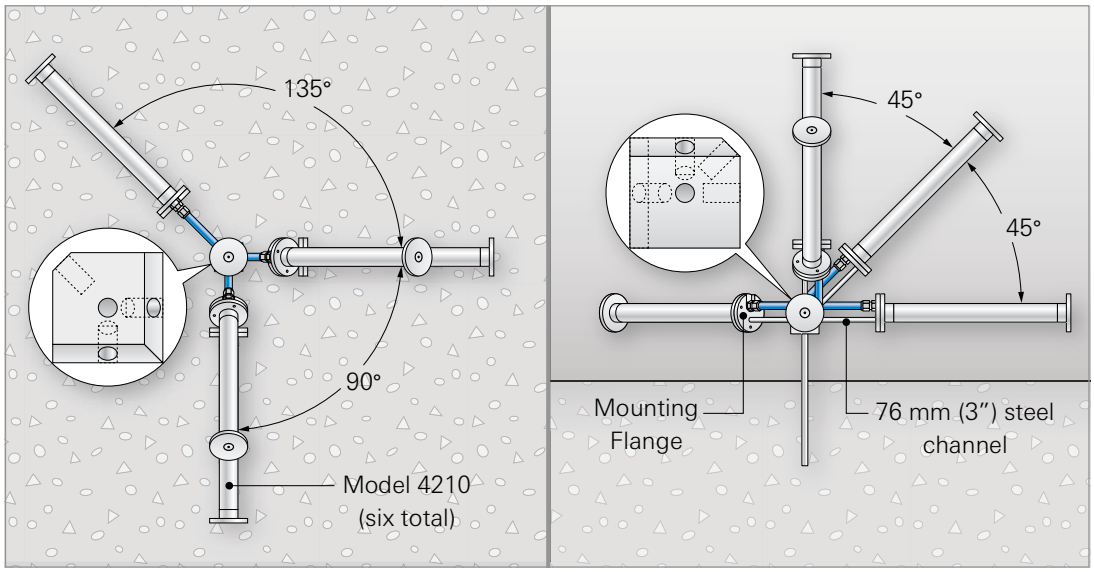


FIGURE 30: *Rosette Mount Installed with Six Strain Gauges, Top View (Left), Front View (Right)*

1. Secure the rosette mount at the mounting location. The rosette mount has an 8 mm (0.316") diameter x 12.7 mm (0.5") deep drilled hole. This allows for the rosette mount to be secured to a rod (obtained locally) via gluing or welding.
2. Install the rods to the rosette mount in the desired positioning.

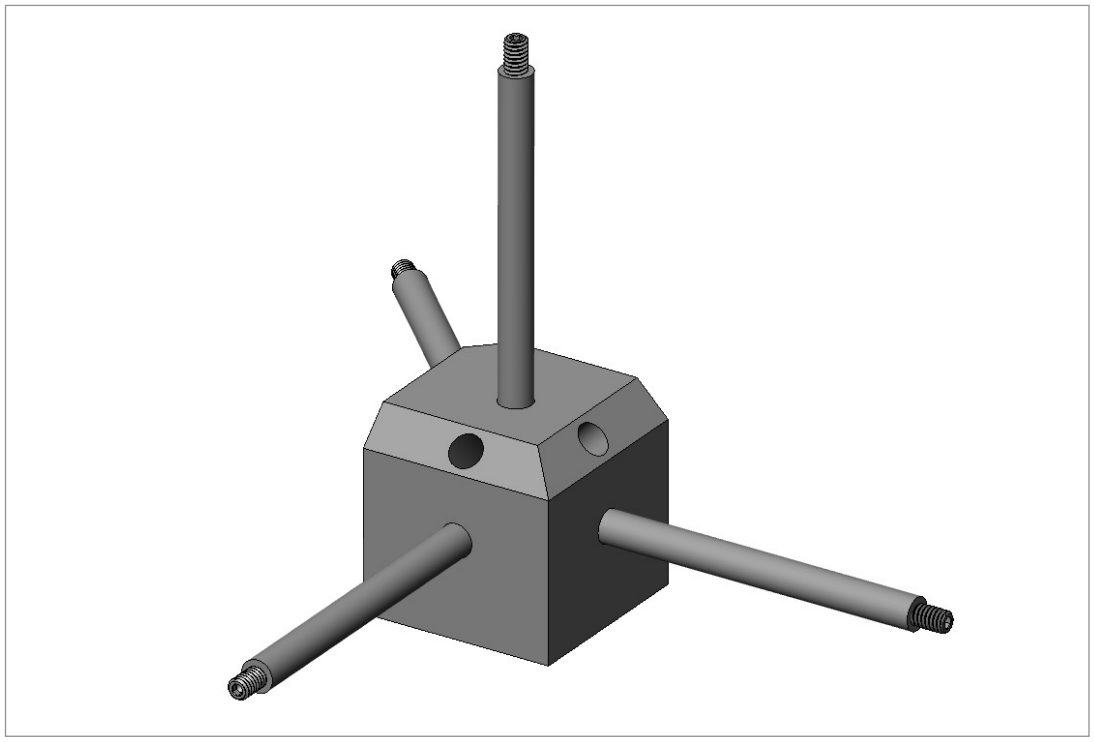


FIGURE 31: *Rosette Mount with Rods Installed, Example Orientation*

3. Thread the strain gauges onto the rods. Model 4200ROS Series and modified Model 4210 Series Strain Gauges have a female thread designed for this purpose.

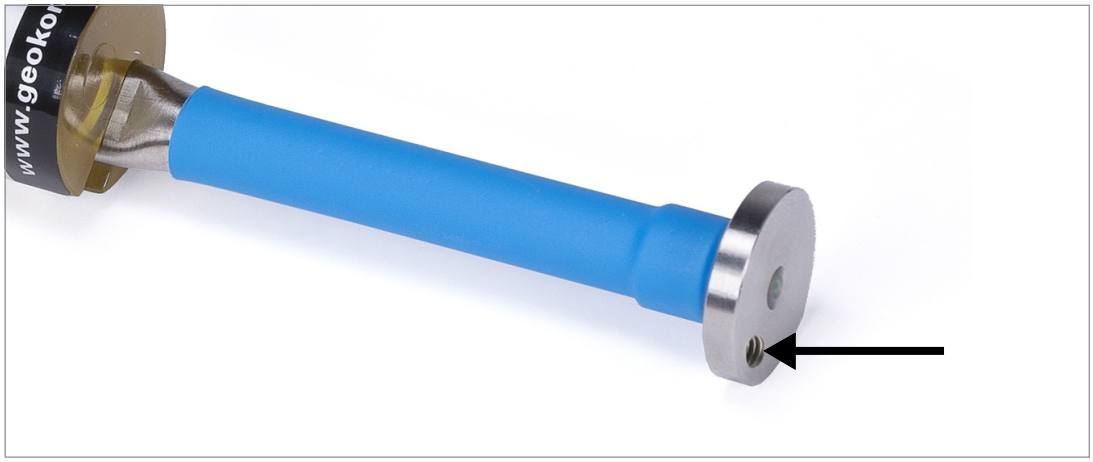


FIGURE 32: *Model 4500ROS Strain Gauge Female Thread Location*

4. When pouring concrete, remove aggregate that is too large. Be careful not to disturb the gauges during the filling process.

APPENDIX G. THEORY OF OPERATION

The knowledge and equations below are for informational purposes only.

When a strain gauge is attached to a body, any deformations in the body that align with the strain gauge's primary axis will also affect the strain gauge. Inside any vibrating wire strain gauge is a segment of music wire, tensioned between two end blocks, such that changes in the length of the gauge add or release tension from the wire. This change in tension alters the resonant frequency of the wire, which is read via an electromagnetic coil. This results in a highly sensitive, highly stable strain gauge that is resistant or immune to effects in temperature or cable resistance.

The relationship that describes the vibrating wire behavior, calculated using the 4200 gauge parameters, is shown below. Substitute the values from Table 9 for Models 4202 and 4204.

Note: These equations do not apply to Model 4210.

Model	4200 / 4200L / 4200ROS / 4200HT (Including Extended Ranges)	4202 (Including Extended Ranges)	4204 / 4204L
Gauge Length (L_g)	6 inches	2 inches	4 inches
Wire Length (L_w)	5.875 inches	2 inches	3.875 inches
Gauge Factor	3.304	0.391	1.422

TABLE 9: *Embedment Strain Gauge Theoretical Parameters*

1. The fundamental frequency (resonant frequency) of a vibrating wire is a function of its length, tension, and density:

$$f = \frac{1}{2L_w}\sqrt{\frac{T}{\rho\iota}}$$

EQUATION 17: *Fundamental Frequency*

Where:

f = Frequency (Hz)

L_w = Length of the wire (inches)

T = Tension in the wire ($\mathrm{pounds-force}$)

$\rho\iota$ = Density per unit length ($\frac{\mathrm{pounds-mass}}{\mathrm{inch}}$)

2. Tension (T) in the wire can be expressed in terms of strain in the wire (ε_w) and substituted into Equation 17:

$$f = \frac{1}{2L_w}\sqrt{\frac{\varepsilon_w Ea}{\rho\iota}}$$

EQUATION 18: *Fundamental Frequency with Strain*

Where:

ε_w = Strain in the wire

E = Modulus of elasticity, steel ($29.7 \times 10^6\left(\frac{\mathrm{pounds-force}}{\mathrm{inch}^2}\right)$)

a = Cross-section area of the wire (inch^2)

GEOKON®

GEOKON
48 Spencer Street
Lebanon, New Hampshire
03766, USA

Phone: +1 (603) 448-1562
Email: teamsales@geokon.com
Website: www.geokon.com

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