Model 4200 Series

Vibrating Wire Strain Gauges

Instruction Manual

GEOKON®

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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.
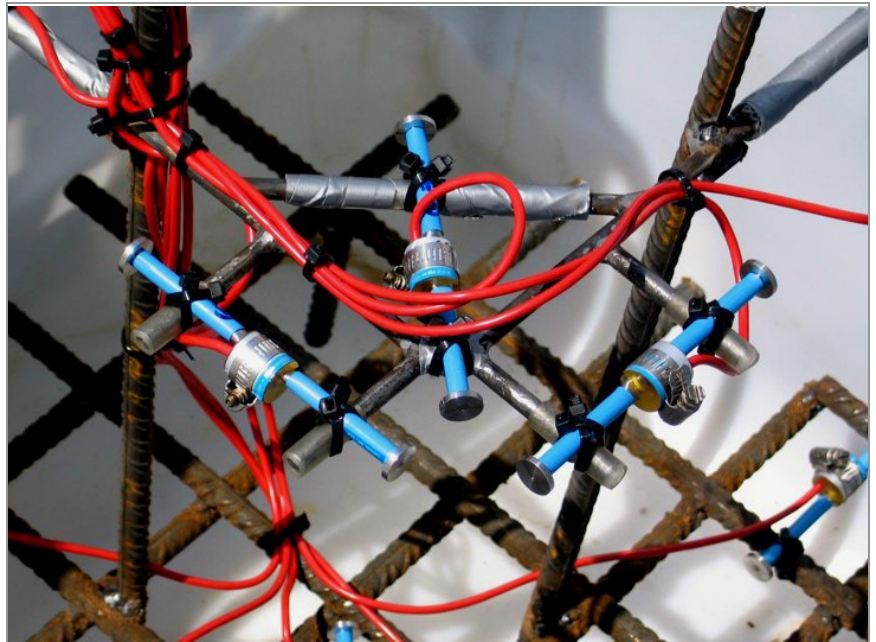
FIGURE 1: On-site Installation Photo

2. MODELS

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

2.1 MODELS 4200 AND 4200L

Model 4200 is designed primarily for long-term strain measurements inside mass concrete, in structures such as foundations, piles, bridges, dams, containment vessels, tunnel liners, etc. This strain gauge features a 3,000 microstrain range, with a length of 152 mm (6").

The 4200L is a low-modulus version, designed to enable early curing strains to be measured.
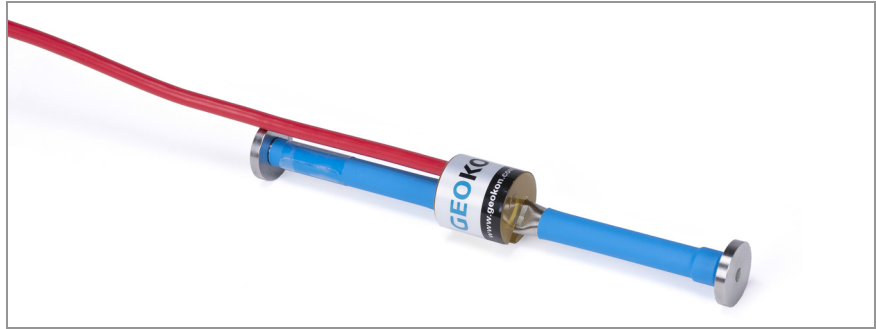
FIGURE 2: Model 4200 Vibrating Wire Strain Gauge

FIGURE 3: Model 4200L Vibrating Wire Strain Gauge

2.2 MODELS 4200-6 AND 4200-7

GEOKON Models 4200-6 and 4200-7 are extended range strain gauges. The Model 4200-6 features a 5,000 microstrain range, while the Model 4200-7 features a 10,000 microstrain range. The length of both gauges is 152 mm (6").

FIGURE 4: Model 4200-6 Vibrating Wire Strain Gauge

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

2.3   MODEL 4202

Model 4202 is designed for 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').
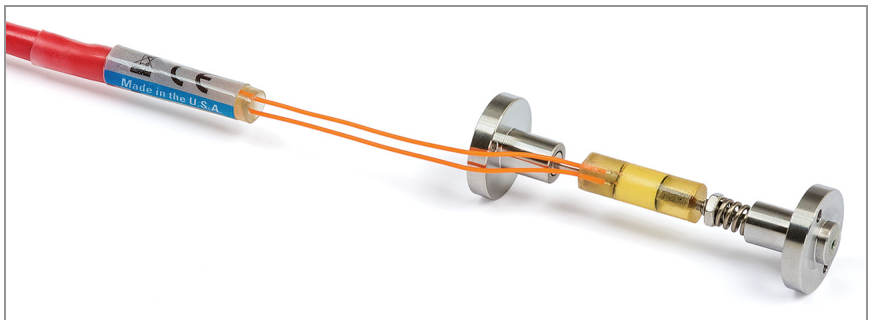
FIGURE 6: *Model 4202 Vibrating Wire Strain Gauge*

2.4   MODEL 4204

Model 4204 is designed to be embedded in concrete where space may be limited. The length of the gauge is 101 mm (4").

FIGURE 7: *Model 4204 Vibrating Wire Strain Gauge*

2.5 MODEL 4210

Model 4210 is designed for embedment in large aggregate concrete, greater than 19 mm (¾"). 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 8: *Model 4210 Vibrating Wire Strain Gauge*

3. PRIOR TO INSTALLATION

3.1 ADJUSTING GAUGE TO THE DESIRED RANGE

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 using the steps below:

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
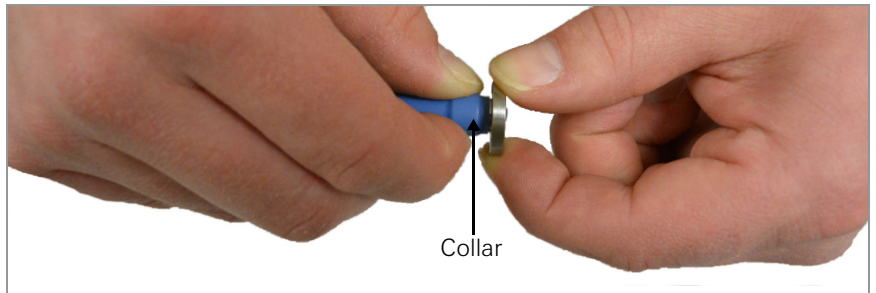
FIGURE 9: *Adjusting the Range of the Strain Gauge*

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.

3.1.1 ADJUSTING THE RANGE OF MODEL 4202

Model 4202 gauges are supplied with an initial reading of approximately 2500 microstrain. This gives a range of ±1500 microstrain. This range is usually adequate for most purposes and should not be altered except in unusual circumstances.

If the strain directions are known, the wire tension can be adjusted for greater range in either compression or tension using the steps below:

1. Attach the red and black leads to the readout box pre-set to position E.

2. Grasp the gauge at the center to prevent it from turning in the next step.

Coil   Tensioning Nut
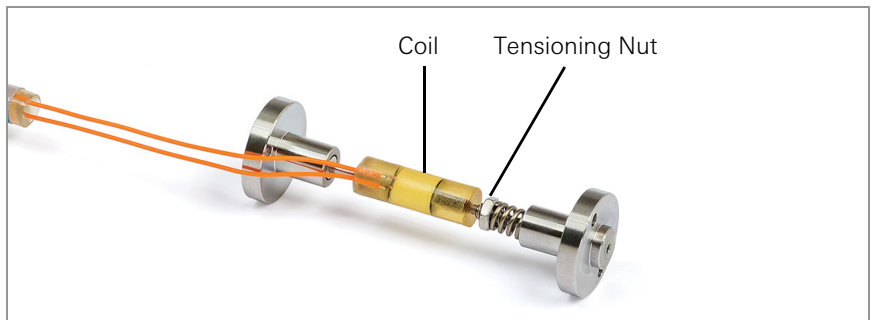
FIGURE 10: *Model 4202 VW Strain Gauge*

3. Using a mini-wrench, rotate the tensioning nut. The position of the nut controls the spring tension.

   ■ To accommodate more compressive strain, increase the range of measurement by turning the nut in a clockwise direction to set the initial reading between 2500 and 3000 microstrain.

   ■ To accommodate more tensile strain, increase the range of measurement by turning the nut in a counter-clockwise direction to set the initial reading between 1500 and 2000 microstrain. A rotation of ½ turn will give a change of about 600 microstrain. The following table shows various tension settings.

Setting Range	Strain Reading	Available Strain Range	
		Tension	Compression
Midrange	2500	1500	1500
Tension (67% of range)	2000	2000	1000
Compression (67% of range)	3000	1000	2000

TABLE 1: *Guide to 4202 Initial Tension Settings*

4. The gauge end block will often turn with the tensioning nut. After making the adjustment, grasp the end block and rotate it back to its original position, so that the flats of the two end blocks are aligned. Remember to hold the tube/coil assembly while doing this.

5. Check the reading. If okay, apply a spot of thread locking cement to preserve the nut position and the tension.

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.
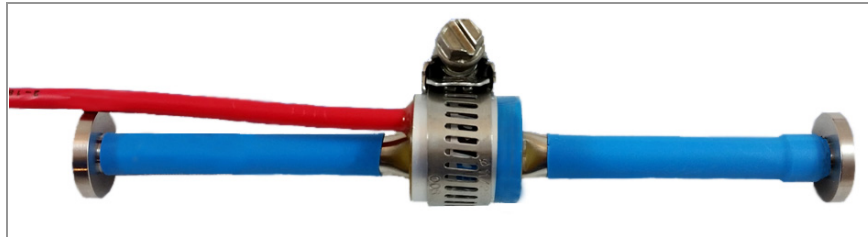
FIGURE 11: *Assembled Gauge and Coil Housing*

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 7, convert the resistance to temperature. Compare the result to the current ambient temperature. (For Model 4200HT see Table 8.)

3. Connect the gauge to a readout box. (See readout instructions, Section 6.) Observe the displayed readout. The reading should be about the midrange position as defined in Table 2.

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. INSTRUMENT PROTECTION

4.1 CABLE SPLICING AND TERMINATION

Terminal boxes with sealed cable entries are available from GEOKON for all types of applications. These allow many instruments 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 instrument readings; therefore, splicing of cables has no ill effects, and in some cases may in fact be beneficial. The cable used for making splices should be a high quality twisted pair type, with 100% shielding and an integral shield drain wire. **When splicing, it is very important that the shield drain wires be spliced together**. Always maintain polarity by connecting color to color.

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

Terminate a cable by stripping and tinning the individual conductors and then connecting them to the patch cord of a readout box. Alternatively, use a connector to plug directly into the readout box or to a receptacle on a special patch cord.

4.2 PROTECTION FROM ELECTRICAL NOISE

Be sure to 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.

4.3 LIGHTNING PROTECTION

Unlike numerous other types of instrumentation available from GEOKON, vibrating wire strain instruments do not have any integral lightning protection components, such as transorbs or plasma surge arrestors.

SUGGESTED LIGHTNING PROTECTION OPTIONS:

■ Lighting arrestor boards and enclosures are 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 instruments. See the figure below.

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

Consult the factory for additional information on available lightning protection.
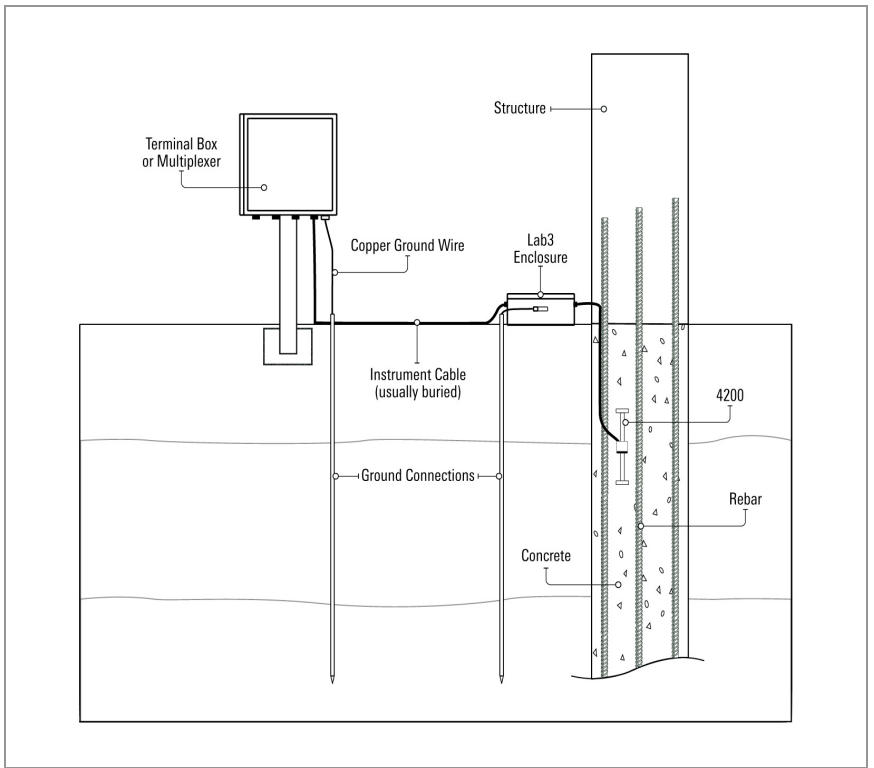
FIGURE 12: *Lightning Protection Scheme*

5. 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 Section 5.1 through 5.4)

2. Cast them into briquettes that are subsequently cast into the concrete structure (see Section 5.5).

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.

5.1 DIRECT ATTACHMENT USING MODEL 4200-SPACER

1. Insert a cable tie into the slot in each spacer.
2. Place one spacer on each end of the 4200 gauge.
3. Place the spacers against the rebar as shown in Figure 13.
4. Wrap each cable tie over the body of the gauge and around the rebar.
5. Tighten the cable tie until the gauge is held securely in place.
6. Trim the ends of the cable ties if desired.

5.2 ALTERNATIVE DIRECT ATTACHMENT METHOD

1. Place two pieces of wood or polystyrene foam between the gauge and the rebar as shown in Figure 14.

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.
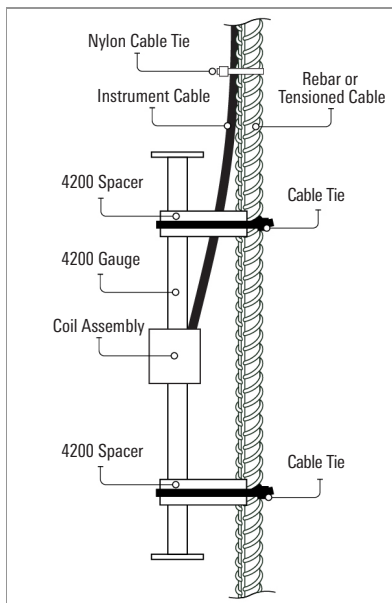
FIGURE 13: Attaching Gauges to Rebar
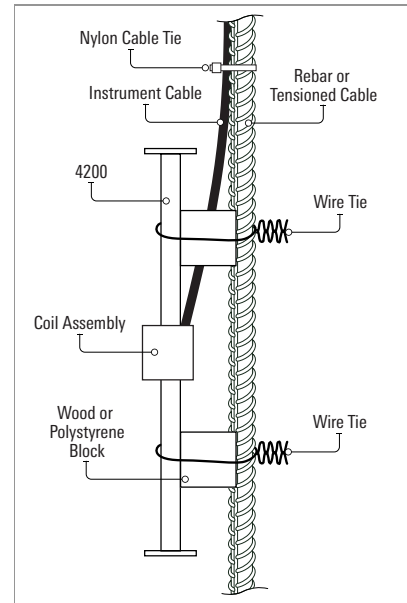
FIGURE 14: Alternative Method

5.3 SUSPENSION METHOD

1. Wrap a layer of self-vulcanizing rubber tape 3 cm from each gauge end, as shown in Figure 15.

    Model 4210 Note: This step is not necessary

    The layers of rubber serve as a shock absorber, dampening any vibration of the suspension system. Without the rubber layers, the resonant frequency of the tie wires might interfere with the resonant frequency of the gauge when the tie wires are tightened. This can result in unstable readings, or in no readings at all. However, this problem disappears once the concrete has been placed.

    For a method that avoids this potential problem, see Section 5.4.

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.

6. Attach the plucking coil using a hose clamp. Tie the instrument cable off to one of the rebar using nylon cable ties.
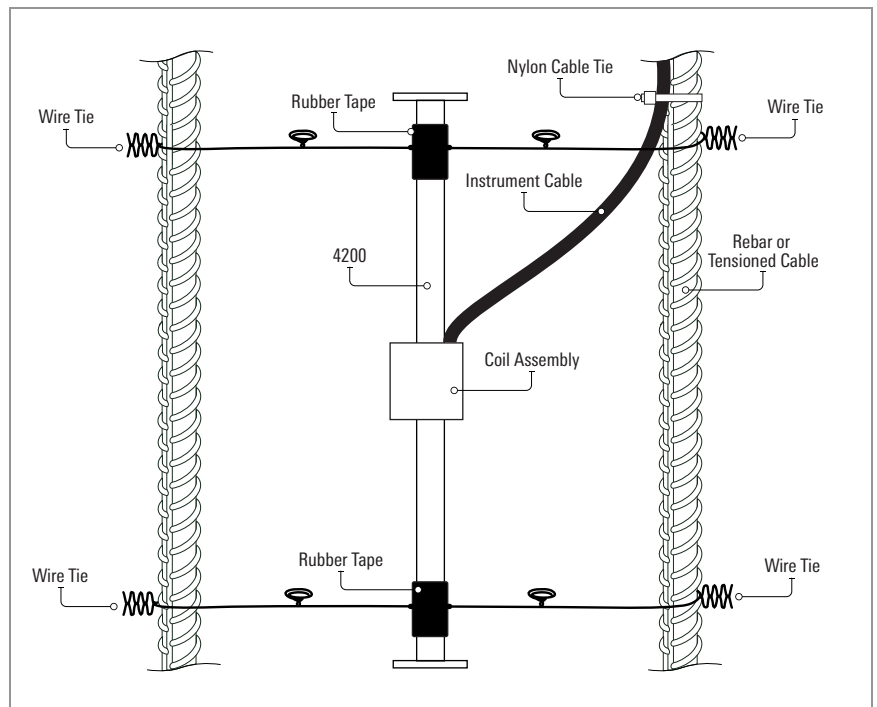
FIGURE 15: *Suspending Model 4200/4200L Strain Gauges Between Rebar*

5.4 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.
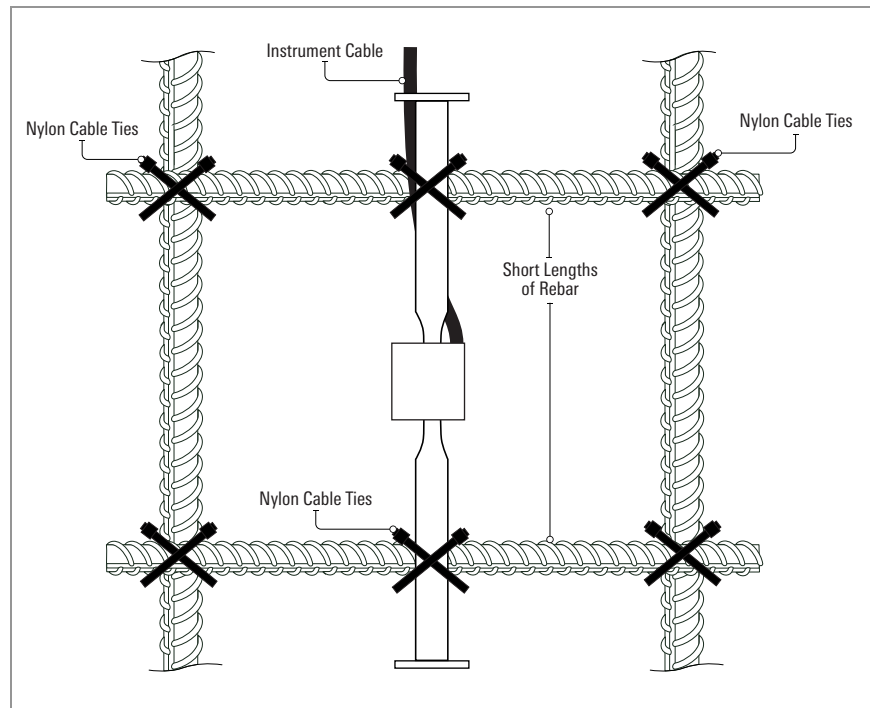
FIGURE 16: *Alternative Method for Attaching Model 4200 Strain Gauges to Rebar*

5.5 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.

6. TAKING READINGS

6.1 EMBEDMENT STRAIN GAUGE READOUT POSITIONS

The table below indicates the GK-404 / 405 readout position for each model of strain gauge.

Model	4200/4200HT	4200-6/7	4202	4204	4210/4212/4214
Readout Position	D	D	E	A (Mode: digits)	B
Display Units	microstrain ($\mu\varepsilon$)	readout units	microstrain ($\mu\varepsilon$)	digits (f^210^{-3})	digits (f^210^{-3})
Frequency Range	450–1200 Hz	450–1200 Hz	1400–3500 Hz	800–1600 Hz	1400–3500 Hz
Mid-Range Reading	2500 $\mu\varepsilon$	2000 $\mu\varepsilon$	2500 $\mu\varepsilon$	1700 digits	6000 digits
Minimum Reading	1000 $\mu\varepsilon$	1000 $\mu\varepsilon$	1000 $\mu\varepsilon$	650 digits	2000 digits
Maximum Reading	4000 $\mu\varepsilon$	3000 $\mu\varepsilon$	4000 $\mu\varepsilon$	2750 digits	10000 digits

TABLE 2: *Readout Positions*

6.2 GK-404 VIBRATING WIRE READOUT

The Model GK-404 VW 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 digits, frequency (Hz), period (μs), or microstrain ($\mu\varepsilon$). The GK-404 also displays the temperature of the transducer (embedded thermistor) with a resolution of 0.1 °C.

FIGURE 17: *GK-404 Readout*

6.2.1 OPERATING THE GK-404

1. Attach the flying leads by aligning the red circle on the silver Lemo connector with the red line on the top of the GK-404 (see Figure 18). 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.

FIGURE 18: *Lemo Connector to GK-404*

- 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.

6.3 GK-405 VIBRATING WIRE READOUT

The GK-405 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.

FIGURE 19: GK-405 Readout

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.

6.3.1 CONNECTING SENSORS WITH 10-PIN BULKHEAD CONNECTORS ATTACHED

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

6.3.2 CONNECTING SENSORS WITH BARE LEADS

Attach the 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).

6.3.3 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.

6.4 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-405 readouts will read the thermistor and display the temperature in degrees Celsius.

TO READ TEMPERATURES USING AN OHMMETER:

1. 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.

2. Look up the temperature for the measured resistance in Appendix C. For the 4200HT use Appendix E.

7. 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.)

Model	Readout Position	Theoretical Gauge Factor
4200/4200L/ 4200HT	D	3.304
4200-6	D	N/A
4200-7	D	N/A
4202	E	0.391
4204/4204L	A	N/A
4210	B	N/A
4212	B	N/A
4214	B	N/A

TABLE 3: *Embedment Strain Gauge Factors*

7.1 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*

7.2 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.

7.3 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:

$$\mu\varepsilon_{\text{theory}} = G(\Delta f^2 \text{x} 10^{-3})$$

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:

$$\mu\varepsilon_{\text{apparent}} = (R_1 - R_0)B$$

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 suppled with each gauge.

7.4 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 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 microstrain/°C.

(C_1 for Model 4200HT gauges is 17.3 microstrain/°C.)

C_2 is the coefficient of expansion of concrete: ~10 microstrain/°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:

$$\mu_{load} = (R_1 - R_0)B + (T_1 - T_0)(C_1 - C_2)$$

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 suppled with each gauge.

$T_0,$ $T_1,$ $C_1,$ and C_2 are the same values as shown in Equation 4 above.

A theoretical example of the above is shown below.

EXAMPLE:

If:

R_0 = 3000 in position D

R_1 = 2900 in position D

T_0 = 20 °C

T_1 = 30 °C

B = 0.975 (batch calibration factor)

Then:

The **apparent strain** = (2900 – 3000) 0.975 = –97.5 μstrain (compression).
The **load-related strain**, corrected for temperature effects on the gauge =
(2900 – 3000) 0.975 + (30 – 20) (12.2 – 10) = –75.5 mstrain (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:

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

EQUATION 6: Actual Strain

Which in the current example = (2900 – 3000) 0.975 + (30 – 20) (12.2) = 24.5
μstrain (expansion).

See Appendix G for further information.

7.4.1 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 με 4200-7 model is as follows:

Temperature Correction Factor = $(0.000401 * R_1 - 1.067)(T_1 - T_0)$

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:
$R_1 + (0.000401 * R_1 - 1.067) \times (T_1 - T_0)$

7.5 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.

7.6 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.

7.7 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.

7.8 CONVERTING STRAIN TO LOAD

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

$$L = E\mu A$$

EQUATION 7: *Strain to Load Formula*

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

When installing strain 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.

7.9 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
4200-6 / 4200-7	N/A
4200HT	596,000 psi
4200HT-T	11,950,000 psi
4202	610,000 psi
4204	596,000 psi
4204L	56,500 psi
4210 / 4212 / 4214	2,350,000 psi

TABLE 4: *Effective Modulus*

8. 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 faulty gauges to GEOKON. 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 4.1.

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 4.1.

☐ 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. Cable resistance is approximately 14.7Ω per 1000 ft (48.5Ω per km) of 22 AWG wire.

☐ 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 4.1.

☐ Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.

Refer to the expected resistance for the various wire combinations below.

Vibrating Wire Sensor Lead Resistance Levels

Red/Black $\cong$180Ω **(**$\cong$50Ω for Models 4202 & 4200HT-T, $\cong$120Ω for Model 4200HT**)**

Green/White   3000Ω at 25 °C

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

APPENDIX A.   SPECIFICATIONS

A.1 STRAIN GAUGE

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

Model	4200/4200L	4200-6	4200-7	4202	4204
Range (Nominal)	3000 με	5,000 με	10,000 με	3000 με	
Resolution	1.0 με[1]	2 – 5 με[1]		0.4 με[1]	1.0 με[1]
Calibration Accuracy	±0.5% Full Scale Reading (FSR)				
Batch Factor Accuracy	±0.5% FSR	2.5 – 4% FSR		±0.5% FSR	
System Accuracy	±2.0% FSR[2]				
Stability	0.1% Full Scale (FS)/yr				
Linearity	0.5% FSR	2.5 – 4% FSR		0.5% FSR	
Thermal Coefficient	12.2 ppm/°C				
Frequency Range (Hz)	450–1200	450–1200		1400–3500	800–1600
Dimensions (gauge) (LxD)	6.125 x 0.750" 155 x 19 mm	6.00 x 0.750" 153 x 19 mm		2.250 x 0.625" 57 x 16 mm	4.125 x 0.750" 105 x 19 mm
Dimensions (coil)	0.875 x 0.875" 22 x 22 mm	0.875 x0.875" 22 x 22 mm		N/A	
Coil Resistance	180Ω	180Ω		50Ω	180Ω
Temperature Range	−20 to +80 °C				

Model	4210	4212	4214	4200HT / 4200HT-T
Range (Nominal)	3000 με			
Resolution	0.4 με[1]	0.4 με[1]	0.4 με[1]	1.0 με[1]
Calibration Accuracy	±0.5% Full Scale Reading (FSR)			
Batch Factor Accuracy	±0.5% FSR			
System Accuracy	±2.0% FSR[2]			
Stability	0.1% Full Scale (FS)/yr			
Linearity	0.5% FSR			
Thermal Coefficient	12.2 ppm/°C			12.2 ppm °C / 17.3 ppm °C
Frequency Range (Hz)	1400–3500	1400–3500	1400–3500	450–1200
Dimensions (gauge) (LxD)	10.250 x 2" 260 x 50 mm	12.250 x 2" 311 x 50 mm	14.250 x 2" 362 x 50 mm	6.125 x 0.750" 155 x 19 mm
Dimensions (coil)	N/A			0.875 x 0.875" 22 x 22 mm
Coil Resistance	180Ω	180Ω	180Ω	120Ω / 50Ω
Temperature Range	−20 to +80 °C			−20 to +200 °C / −20 to +220 °C

TABLE 5: *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.

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.

Model:	4200/4200HT/4200HT-T	4202	4204
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 6: 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:
    ρ 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:

$$f = \frac{1}{2L_W} \sqrt{\frac{Fg}{\rho a}}$$

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

$$F = \varepsilon_W E a$$

    Where:
    ε_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:

$$f = \frac{1}{2L_W}\sqrt{\frac{\varepsilon_W Eg}{\rho}}$$

7. Substituting the given values for E, g, and ρ 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:
    ε is the strain in the body.
    L_g is the gauge length in inches.
11. Combining the equations from steps nine and ten gives:

$$\varepsilon = \frac{97.75}{T^2} \cdot \frac{{L_W}^3}{L_g}$$

    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 3.304×10^9 is all done internally by the microprocessor of the readout so that the displayed reading in position D is given in microinches per inch (ε).

Note: In the previous steps, T is seconds x 10^6 and ε 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

C.1   3KΩ THERMISTOR RESISTANCE

Thermistor Types:

■   YSI 44005, Dale #1C3001–B3, Alpha #13A3001–B3

■   Honeywell 192–302LET–A01

Resistance to Temperature Equation:

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

EQUATION 8: *3kΩ Thermistor Resistance*

Where:
T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
A = 1.4051 x 10^{-3}
B = 2.369 x 10^{-4}
C = 1.019 x 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*

C.2 10KΩ THERMISTOR RESISTANCE

Thermistor Type: US Sensor 103JL1A

Resistance to Temperature Equation:

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

EQUATION 9: *10KΩ Thermistor Resistance*

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

A = 1.127670 x 10^{-3}

B = 2.344442 x 10^{-4}

C = 8.476921 x 10^{-8}

D = 1.175122 x 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 D.   NO STRESS STRAIN ENCLOSURE

GEOKON's Model 4200-4 No Stress Strain Enclosure is a double walled PVC cylinder with the wall cavity filled with polystyrene foam. The figure below shows a standard 4200-4 installation.
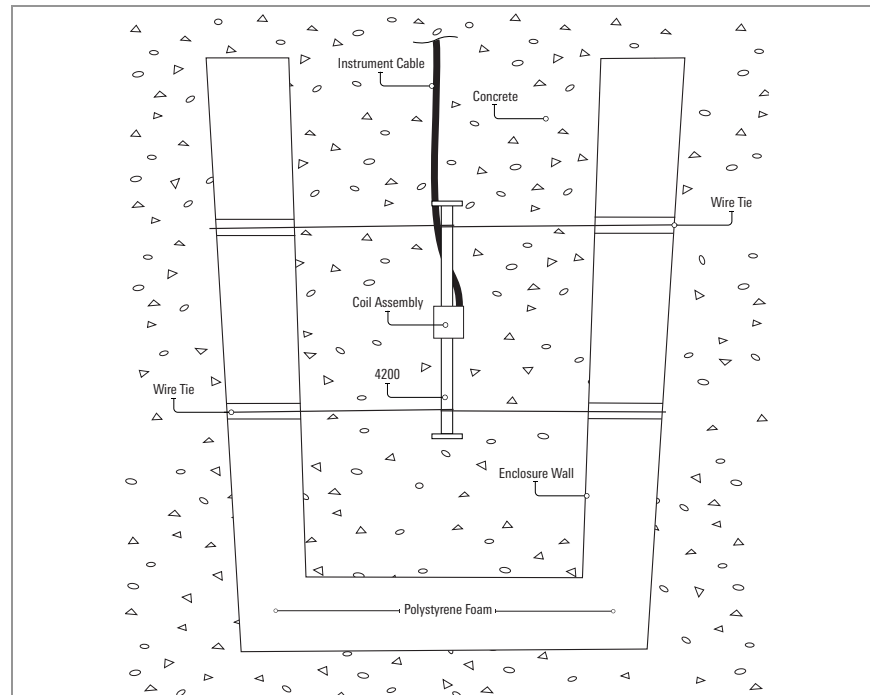
FIGURE 20: *No Stress Strain Enclosure*

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 E.   MODEL 4200HT / 4200HT–T HIGH-TEMPERATURE STRAIN GAUGES

GEOKON Model 4200HT and 4200HT-T High-Temperature Embedment Strain Gauges are similar to the Model 4200, but are constructed using components that can withstand temperatures up to 200 °C (4200HT) and 220 °C (4200HT-T). They are particularly useful for measurements in autoclaved spun concrete piles.

FIGURE 21: *Model 4200HT*

FIGURE 22: *Model 4200HT-T*

Data interpretation is the same as that outlined in Section 7, with the exception of the Temperature Coefficient for the Model 4200HT-T, which is 17.3 $\mu\varepsilon$ / °C. Coil resistance for Model 4200HT is 120 ohms, and is 50 ohms for the 4200HT-T.

The thermistor included with the gauge is a high-temperature thermistor, which uses the resistance to temperature conversion table shown in Table 8. 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 8.

GEOKON.

Vibrating Wire Strain Gauge Calibration Report

Model: 4200

Calibration Date: February 05, 2020

This calibration has been verified/validated as of 09/15/2020

Serial Number: 2003764

Temperature: 22.5 °C

Calibration Instruction: CI-VW Strain Gage

Technician: _Kathy Rogers_

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	1006	0	1005	0	1006	4	0.15	0	0.00
600	1611	600	1612	600	1612	599	-0.02	600	0.00
1202	2222	1202	2223	1202	2223	1199	-0.08	1202	0.02
1800	2829	1800	2831	1800	2830	1796	-0.15	1799	-0.05
2403	3449	2402	3449	2403	3449	2403	0.02	2404	0.04
3000	4061	3000	4062	3000	4062	3004	0.15	3000	-0.01

Linear Gauge Factor (G): 0.9817

Regression Zero 1001

Calculated Strain:

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

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

Polynomial Gauge Factors: A: -3.4656E-06   B: 0.9991   C: -1001

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 23: *Sample Calibration Report*

FIGURE 24: *Sample Batch Calibration Sheet*

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.

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:

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

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 microstrain and $(R_1-R_0)B$ would be -12.2 microstrain, therefore the result of Equation 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 microstrain, while the vibrating wire would expand 12.2 microstrain. The value of $(R_1-R_0)B$ would then be -2.2 microstrain (the vibrating wire would slacken slightly), and Equation 5 would yield a value of 10 microstrain.