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Instruction Manual

Model 4200 Series

Vibrating Wire Strain Gages

(Doc Rev S, 8/15)

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TABLE of CONTENTS

LIST of FIGURES, TABLES and EQUATIONS

1. INTRODUCTION

The Geokon Model 4200 and 4200L Vibrating Wire Strain Gage is designed primarily for long-term strain measurements in mass concrete, in structures such as foundations, piles, bridges, dams, containment vessels, tunnel liners, etc. See Figure 1. The 4200L is a low modulus variety designed to enable early curing strains to be measured.

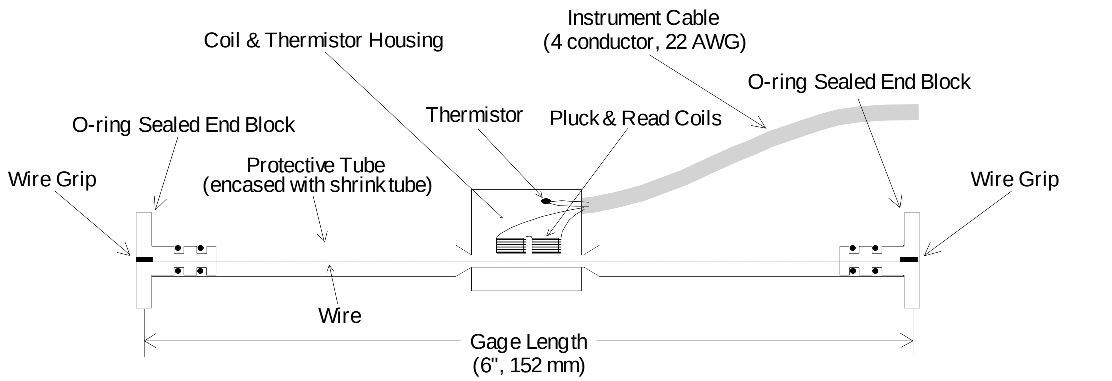


Figure 1 - Model 4200 and 4200L Vibrating Wire Strain Gage

The Model 4202 Vibrating Wire Strain Gage is designed for direct embedment in grout, mortar and small aggregate concrete. See Figure 2. It is also useful for model studies.

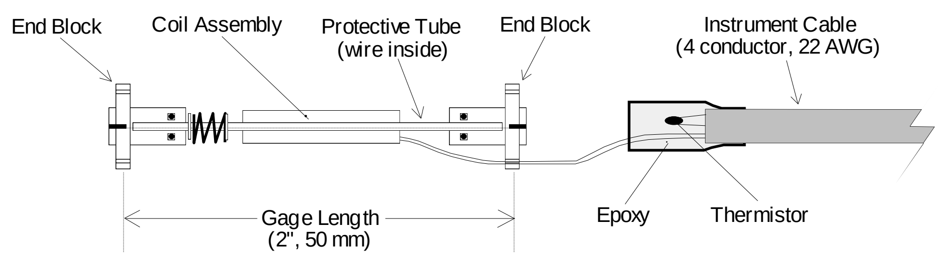


Figure 2 - Model 4202 Vibrating Wire Strain Gage

The Model 4210 Vibrating Wire Strain Gage is designed for embedment in large aggregate concrete (greater than ¾ inch). The standard gage length for the Model 4210 is 10 inches; other gage lengths are available (Model 4212 = 12 inches, Model 4214 = 14 inches, etc.). See Figure 3.

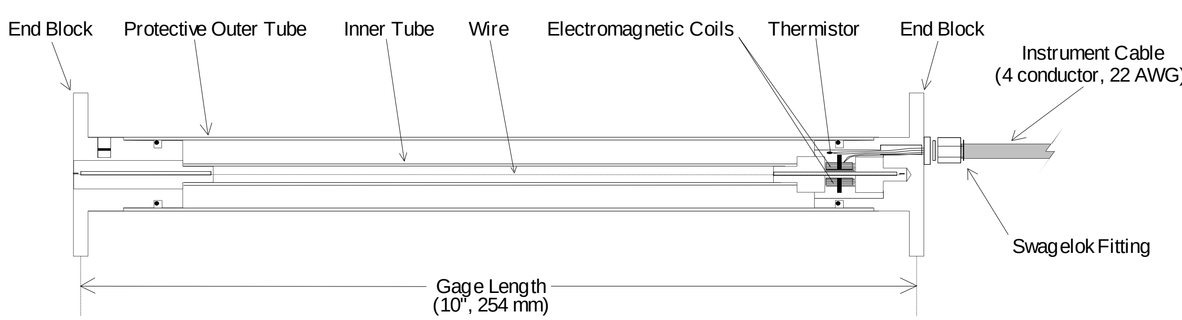


Figure 3 - Model 4210 Vibrating Wire Strain Gage

The primary means of gage placement is direct embedment in concrete by pre-attaching the gage to rebar or tensioning cables, pre-casting the gage into a concrete briquette which is subsequently cast into the structure, or grouting 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 relative to one another, 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. Electromagnetic coils that are located close to the wire accomplish excitation and readout of the gage frequency.

Portable readouts or dataloggers available from Geokon, such as the model GK-403, GK-404 or MICRO-10, used in conjunction with any of these vibrating wire strain gages, will provide the necessary voltage pulses to pluck the wire and convert the measured frequencies so as to display the reading directly in microstrain units.

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

PLEASE NOTE THE FOLLOWING:

- ***Do not rotate or pull on the gage end blocks as this may cause permanent damage.***

2. GAGE INSTALLATION

The Models 4200/4200L/4202/4210 strain gages are supplied fully sealed and pre-tensioned. The coil housing should be slotted over the flat part at the center of the gage and held in place by means of the hose clamp provided. Alternatively the coil housing can be glued in place using cyano-acrylate glue, but if this is done it will no longer be possible to remove the gage from the coil housing.

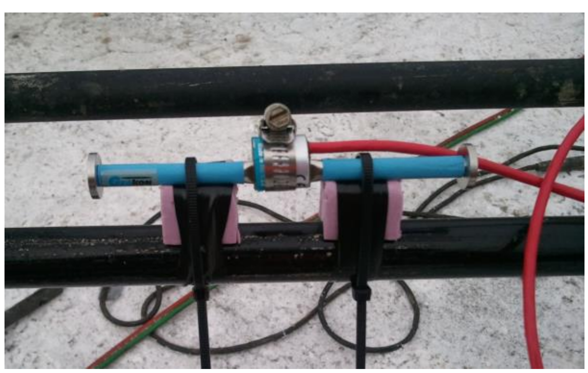


Figure 3A showing the hose clamp

A preliminary check is advisable and this is made by connecting to the readout box and observing the displayed readout (see readout instructions, Section 3). The observed reading should be around the mid-range position (see Table 1, Page 7). Pressure on the gage ends should make this reading decrease.

Check the resistance between the two lead wires (usually red and black). For the model 4200 and 4200L it should be around 180 ohms. For the model 4202 it should be around 50 ohms. For the model 4210 it should be around 180 ohms. Remember to add the cable resistance at approximately 14.7Ω/1000' or 48.5Ω/km (at 20°C, multiply by 2 for both directions). If the gage contains a thermistor, check its resistance (usually the white and green lead wires) with an ohmmeter. Check the reading against that which should be obtained at the existing ambient temperature. See Appendix C for the resistance to temperature conversion and resistance v. temperature table. See Appendix D for Res/Temp conversion table used with Model 4200HT high temperature strain gage. (See Appendix F)

Return any faulty gages to the factory. Gages should not be opened in the field.

2.1. Placing the Gage in Concrete

The Models 4200/4200L/4200HT/4202/4210 strain gages are normally set into the concrete structure in one of two ways: either by casting the unit(s) into the concrete mix directly or by pre-casting the unit(s) into briquettes that are subsequently cast into the structure.

The 4200L strain gage is designed specifically to allow strains to be measure in curing concrete. Unlike the Model 4200 strain gage, which has a modulus similar to that of cured concrete, the 4200L has a low modulus to match the curing concrete and because of this it is easily compressed so that it cannot be buried more than 1 meter deep in the wet concrete.

When casting the gage directly into the structure care must be taken to avoid applying any large forces to the end blocks during installation. This is most imperative when installing the Model 4202. The models 4200, 4200L, 4200HT and 4210 can be wired into position by wiring directly to the tube (see Figure 4). The wires should not be tied too tightly since rebar and/or tension cables tend to move during concrete placement and vibration. Care should be taken not to damage the cable with the vibrator. The gage can also be placed directly into the mix if it can be assured that the orientation will be correct after the gage placement.

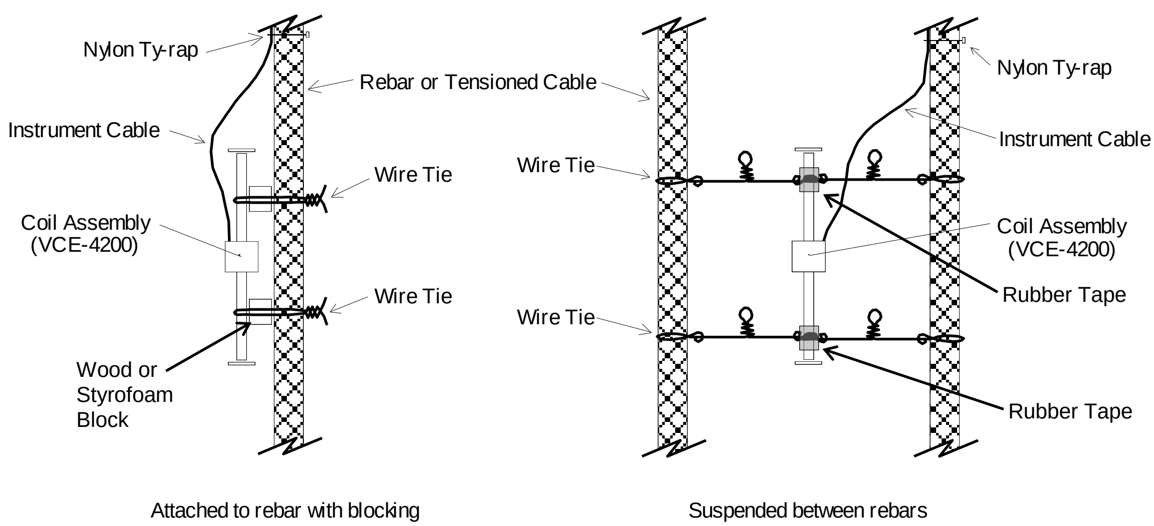


Figure 4 - Attaching Model 4200/4200L/4200HT Strain Gages to Rebar

Note the following instructions to suspend the model VCE-4200 strain gage between rebar:

1. **Wrap a layer of self-vulcanizing rubber tape around the gage in the two places shown in Figure 4 (around the tie points). The rubber layer serves as a shock absorber, dampening any vibrations of the suspension system. Sometimes, without the rubber layers, as the tie wires are tightened the resonant frequency of the tie wires interferes with the resonant frequency of the gage. This results in unstable readings or no readings at all. This effect disappears once the concrete has been placed.**
2. Select a length of soft iron tie wire, the kind normally used for tying rebar cages together. Twist it 2 times around the body of the strain gage, over the rubber strips, about 3 cm from the gage ends.
3. Twist two loops in the wire, one on either side of the gage, at a distance of about 3cm from the gage body. Repeat this process at the other end of the gage.
4. Position the gage between the rebar and twist the wire ends twice around the rebar, then around itself.
5. Tighten the wire and orient the gage by twisting on the loops.
6. Slip on the plucking coil and affix using a hose clamp. Tie the instrument cable off to one of the rebar using nylon Ty-Raps™.

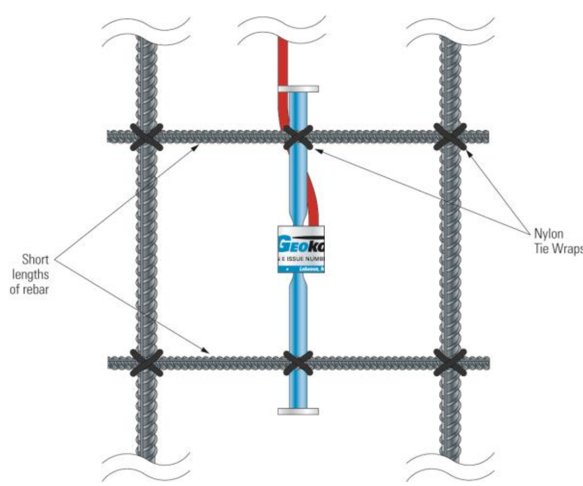
Note these special instructions for attaching the Model 4202 or Model 4210 to rebar;

- When installing the Model 4202 do not wrap the iron tie wire around the body of the gage. The gage could be damaged due to its delicate construction. Use the holes in the end blocks to affix the gage to the rebar, being sure that the gage is not tensioned or compressed in the longitudinal direction.

- When installing the Model 4210 it is not necessary to wrap the tie points on the gage body with self-vulcanizing tape.

<u>Alternative Method</u>

Tie two short pieces of steel rebar to the existing rebar using nylon Tie-wraps, as shown in Figure 4B *(see page 7)*. Then tie the strain gage to the short pieces of rebar again using nylon tie wraps. This method avoids the resonance problems associated with the previous method.



<u>Figure 4B - Alternative Method for attaching Model 4200/4200HT straingages to rebar.</u>

2.2. Using Pre-cast Briquettes or Grouting

An alternate method to the above is to pre-cast the gages into briquettes of the same mix as the mass concrete and then place these in the structure prior to concrete placement. The briquettes should be constructed not more than 3 days and not less than 1 day prior to installation. The briquettes should be continuously cured with water prior to placement in the mass concrete.

Embedment gages can also be used in shotcrete and in drilled holes in rock or concrete that are subsequently grouted. When used in shotcrete special care should be taken to protect the lead wires. Encasing them in conduit or heavy tubing has been used effectively to protect the cable. The gages can be placed by packing the immediate area around the gage by hand and then proceeding with the shotcrete operation.

2.3. Cable Protection and Termination

The cable from the strain gages can be protected by the use of flexible conduit, which can be supplied by Geokon.

Terminal boxes with sealed cable entries and covers are also available, allowing many gages to be terminated at one location with complete protection of the lead wires. The panel can have built-in jacks or a single connection with a rotary position selector switch.

Cables may be spliced to lengthen them, without affecting the gage readings. Always maintain polarity by connecting color to color. Always waterproof the splice completely, preferably using a splice kit (epoxy based) such as the 3M Scotchcast™ kit, model 82-A1.

Cables may be terminated by stripping and tinning and connected by clipping to the patch cord from the readout box. Alternatively, a plug may be used which will connect directly into the readout box or to a receptacle on a special patch cord.

2.4. Lightning Protection

The Models 4200/4202/4210 Embedment Strain Gages, unlike numerous other types of instrumentation available from Geokon, do not have any integral lightning protection components, i.e. transzorbs or plasma surge arrestors. Usually this is not a problem as the gages are installed within concrete or grout and somewhat isolated from potentially damaging electrical transients. However, there may be occasions where some sort of lightning protection is desirable, for example where the gage is in contact with rebar that may be exposed to direct or indirect lightning strikes. Also, if the instrument cable is exposed, it may be appropriate to install lightning protection components, as the transient could travel down the cable to the gage and possibly destroy it.

Note the following suggestions:

- If the gage is connected to a terminal box or multiplexer components such as plasma surge arrestors (spark gaps) may be installed in the terminal box/multiplexer to provide a measure of transient protection. Terminal boxes and multiplexers available from Geokon provide locations for installation of these components.
- Lighting arrestor boards and enclosures are available from Geokon that install at the exit point of the instrument cable from the structure being monitored. The enclosure has a removable top so, in the event the protection board (LAB-3) is damaged, the user may

service the components (or replace the board). A connection is made between this enclosure and earth ground to facilitate the passing of transients away from the gage. See Figure 3. Consult the factory for additional information on these or alternate lightning protection schemes.

- Plasma surge arrestors can be epoxy potted into the gage cable close to the sensor. A ground strap would connect the surge arrestor to earth ground, either a grounding stake or the rebar itself.

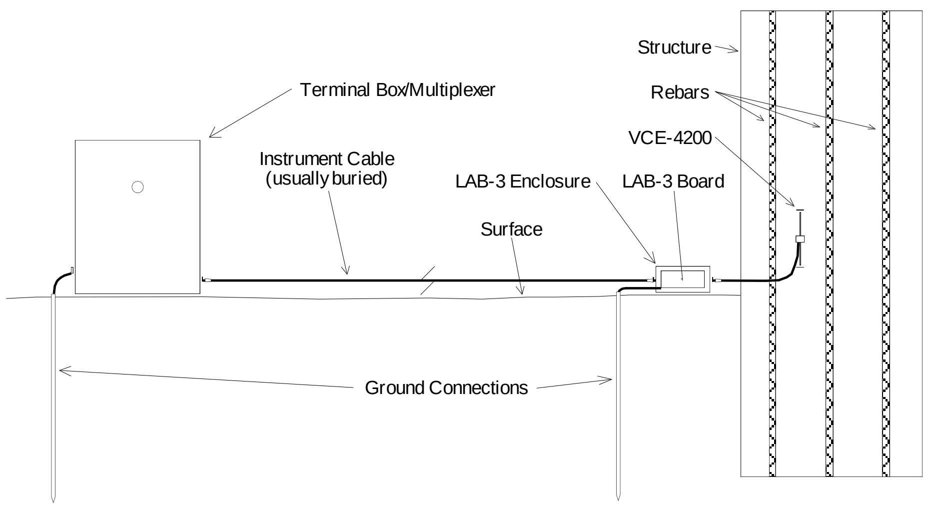


Figure 5 - Lightning Protection Scheme

3. TAKING READINGS

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

Model:	4200/4200HT	4202	4204	4210/4212/4214
Readout Position:	D	E	A	B
Display Units:	microstrain ($\mu\varepsilon$)	microstrain ($\mu\varepsilon$)	period ($1/f \times 10^6$)	digits ($f^2 \times 10^{-3}$)
Frequency Range:	450-1200 Hz	1400-3500 Hz	800-1600 Hz	1400-3500 Hz
Mid-Range Reading:	2500 $\mu\varepsilon$	2500 $\mu\varepsilon$	833 μseconds	6000 digits
Minimum Reading:	1000 $\mu\varepsilon$	1000 $\mu\varepsilon$	1250 μseconds	2000 digits
Maximum Reading:	4000 $\mu\varepsilon$	4000 $\mu\varepsilon$	625 μseconds	10000 digits

Table 1 - Embedment Strain Gage Readout Positions

3.1. Operation of the GK-403 Readout Box

The GK-403 can store gage readings and also apply calibration factors to convert readings to engineering units. Consult the GK-403 Instruction Manual for additional information on Mode "G" of the Readout. The GK-403 reads out the thermistor temperature directly in degrees C.

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

1. Turn the display selector to position "A", "B", "D" or "E". See Table 1 for correct position.

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Press the "Store" button to record the value displayed. If the no reading displays or the reading is unstable see section 5 for troubleshooting suggestions. The thermistor will be read and displayed on the screen above the gage reading in degrees centigrade.
3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.2 Operation of the GK-404 Readout Box

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

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

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

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

3.3 Operation of the GK-405 Readout Box

The GK-405 Vibrating Wire Readout is made up of two components:

- the Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout Application
- the GK-405 Remote Module which is housed in a weather-proof enclosure and connects to the vibrating wire sensor by means of:

1) Flying leads with alligator type clips when the sensor cable terminates in bare wires or,
2) by means of a 10 pin connector..

The two components communicate wirelessly using Bluetooth®, a reliable digital communications protocol. The Readout Unit can operate from the cradle of the Remote Module (see Figure 6) or, if more convenient, can be removed and operated up to 20 meters from the Remote Module

Figure 6   GK405 Readout Unit

For further details consult the GK405 Instruction Manual.

3.4. MICRO-10 Datalogger

The following parameters are recommended when using the strain gages with the MICRO-10 datalogger or any other CR10 based datalogger:

See Table 2 for the recommended Gage Type selection and Gage Factor entry to convert to microstrain when using the embedment strain gages with the MICRO-10 Datalogger Configuration Software. Table 2 also lists the starting and ending frequency settings for the excitation sweep when writing a program for the CR10 using the P28 vibrating wire measurement instruction. Alternately, if a calibration sheet is supplied with the strain gage the exact values can be calculated from the start and end frequencies of the calibration. To maximize the stability and resolution of the sensor a relatively narrow band of excitation frequency should be selected. One could calculate these settings by taking an initial reading and then setting the starting frequency to 200 Hz below and the ending frequency 200 Hz above.

Model:	**4200**	**4202**	**4204**	**4210**	**4212**	**4214**
MICRO-10 Gage Type:	4200	4100	4360	4100	4100	4100
Gage Factor:	3.304	0.391	1.422	0.3568	0.3624	0.3665
Start Frequency (P28):	4 (450 Hz)	14 (1400 Hz)	8 (800 Hz)	14 (1400 Hz)	14 (1400 Hz)	14 (1400 Hz)
End Frequency (P28):	12 (1200 Hz)	35 (3500 Hz)	16 (1600 Hz)	35 (3500 Hz)	35 (3500 Hz)	35 (3500 Hz)

Table 2 - Embedment Strain Gage Datalogger Parameters

Note: Batch factors and/or actual gage factors should be used when supplied.

3.5 Measuring Temperatures

All Vibrating Wire Strain Gages are equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor.

The GK-403 and GK-404 readout boxes will read the thermistor and display temperature in degrees C. [Except when using the 4200HT strain gage which uses a high temperature thermistor and which must be read using an ohmmeter]

Temperatures can also be read using an ohmmeter.

1. Connect an ohmmeter to the green and white thermistor leads coming from the strain gage. (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 Appendix C Table C-1. For the 4200HT use the table in Appendix D.

4. <u>DATA REDUCTION USING THE GK-403, GK-404 OR GK-405, POSITIONS D OR E</u>

Readings on Channel D or E of either the GK-403, GK-404 or GK-405 Readout Box are displayed directly in microstrain based on the theoretical equation for the *Model 4200 (Channel D)* and *4202 (Channel E)*. Other models are read in positions A or B.

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

<u>Equation 1 - Theoretical Strain</u>

G, the theoretical gage factor for the 4200 gage is 3.304 and for the 4202 gage is 0.3910.

In practice the method of wire clamping shortens the vibrating wire slightly causing it to over-register the strain. This effect is removed by applying a batch gage factor (B) supplied with each gage. Then the apparent change in strain shown on the readout box equall to

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

<u>Equation 2 – Apparent Strain</u>

Where R_0 and R_1 are the readout box readings in Pos D or E. (Note: when $(R_1 - R_0)$ is positive, the strain is tensile).

4.1 Readout Box Position B

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

The table below shows the different Model numbers along with readout position, theoretical gage factors and some experimental data (derived from batch calibrations).

Model:	4200	4202	4202X	4204	4210	4212	4214
Readout Pos:	D	E	B	A*	B	B	B
Theoretical GageFactor:	3.304	0.391	1.1 **	1.422	0.3568	0.3624	0.3665
Typical Batch Factor:	0.97 to 0.98	0.91	1.04 to 1.14		0.95		

Table 3 - Embedment Strain Gage Factors

**The Model 4204 must be read in position A which will then require a manual calculation of the frequency to be made. ** The model 4202X is calibrated individually*

4.2. Strain Resolution

When using the GK-403 Readout on channel setting "D" (4200/4200HT) or "E" (Model 4202) the strain resolution is ±0.1 microstrain throughout the range of the gage.

For Models 4210, 4212 and 4214, (channel B), the resolution is 0.1 times the supplied gage factor. However, for some gages the reading may fluctuate + or – one digit so this resolution may not be useful.

4.3. 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 of stress in the concrete if the concrete is restrained in any way, and these stresses are superimposed on any other load related stresses.

Temperature can also affect the strain gage itself since increasing temperatures will cause the vibrating wire to elongate and thus to 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 in which the gage is embedded or to which the gage is attached. If the concrete expanded by exactly the same amount as the wire then the wire tension would remain constant and no correction would be necessary. However the coefficient of expansion of steel, C_1, is 12.2 microstrain/°C (17.3 microstrain/°C for the model 4200HT), whereas the coefficient of expansion of concrete, C_2, is approximately 10 microstrain/°C so that a correction for temperature is required equal to

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

Equation 3 – Correction for Temperature Effects on the Gage

And the **load related** strain in the 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 4 – True, Load Related Strain corrected for temperature

Note: Users should use their own values of C_2 if known.

Example:

R_0 = 3000 on channel D
R_1 = 2900 on channel D
T_0 = 20°C
T_1 = 30°C
B = 0.975 (Batch calibration factor)

The **apparent strain** =

(2900 – 3000) 0.975 = –97.5 μstrain (compression)

The **load related** strain, corrected for temperature effects on the gage, =

(2900 – 3000) 0.975 + (30 – 20) (12.2 – 10) = –75.5 μstrain (compression)

Please note that the **actual** strain, i.e the actual strain undergone by the concrete, (i.e.what would be measured by, say, a measuring scale), is given by the formula

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

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

See Appendix G for further information.

4.4. Shrinkage Effects

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

It is difficult to compensate for these unwanted strains. An attempt may be made, or it may occur naturally, to keep the concrete under a constant condition of water content. But this is frequently impossible on concrete structures exposed to varying weather conditions. Sometimes an attempt is made to measure the shrinkage and/or swelling effect by casting a strain gage inside a concrete block that remains unloaded but exposed to the same moisture conditions as the active gages. Strains measured on this gage may be used as a correction.

4.5. 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, in fact, be strain due to creeping under a constant sustained load.

On some projects, gages have been cast into concrete blocks in the laboratory and then kept loaded by means of springs inside a load frame so that the creep phenomenon can be quantified.

4.6. Effect of Autogenous Growth

In some old concrete, with a particular combination of aggregates and alkaline cements, the concrete may expand with time as it undergoes a chemical change and recrystallization. This expansion is rather like creep but in the opposite direction. It is difficult to account for.

4.7. Converting Strains to Loads

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

$$L = E \mu A$$

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

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

5. TROUBLESHOOTING

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

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

Symptom: Strain Gage 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 range (either compressive or tensile) of the instrument?

✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Move the equipment away from the installation or install electronic filtering. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger.

✓ Does the readout work with another gage? If not, the readout may have a low battery or be malfunctioning.

Symptom: Strain Gage Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gage leads (usually red and black leads) is 180Ω, ±10Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). If the resistance reads infinite, or very high (megohms), a cut wire must be suspected. If the resistance reads very low (<100Ω) a short in the cable is likely. Splicing kits and instructions are available from the factory to repair broken or shorted cables. Consult the factory for additional information.

- ✓ Does the readout or datalogger work with another strain gage? If not, the readout or datalogger may be malfunctioning.

APPENDIX A - SPECIFICATIONS

A.1 Strain Gage

Model:	4200/4200HT	4202	4204	4210	4212	4214
Range (nominal):	3000 $\mu\varepsilon$					
Resolution:	1.0 $\mu\varepsilon$[1]	0.4 $\mu\varepsilon$[1]	1.0 $\mu\varepsilon$[1]	0.4 $\mu\varepsilon$[1]	0.4 $\mu\varepsilon$[1]	0.4 $\mu\varepsilon$[1]
Calibration Accuracy	0.1%FSR					
Typical Batch Factor	0.98	0.91		0.95		
Batch Factor Accuracy	0.5%FSR					
Sytem Accuracy:	2.0% FSR[2]					
Stability:	0.1%FS/yr					
Linearity:	2.0% FSR					
Thermal Coefficient:	12.2 $\mu\varepsilon$/°C [3]					
Frequency Range Hz:	450-1200	1400-3500	800-1600	1400-3500	1400-3500	1400-3500
Dimensions (gage): (Length × Diameter)	6.125 × 0.750" 155 × 19 mm	2.250 × 0.625" 57 × 16 mm	4.125 × 0.750" 105 × 19 mm	10.250 × 2" 260 × 50 mm	12.250 × 2" 311 × 50 mm	14.250 × 2" 362 × 50 mm
Dimensions (coil):	0.875 × 0.875" 22 × 22 mm	NA				
Coil Resistance:	180 Ω	50 Ω	50 Ω	180 Ω	180 Ω	180 Ω
Temperature Range:	-20 to +80° C					

Table A-1 Strain Gage Specifications

Notes:
[1] Depends on the readout; figures in Table A-1 pertain to the GK-401 Readout.
[2] System Accuracy takes into account hysteresis, non-linearity, 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 gage.
[3] The Model 4200HT high temperature strain gage has a Thermal Coefficient of 17.3 $\mu\varepsilon$/°C

A.2 Thermistor (see Appendix C also)

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 like manner. The deformations alter the tension of the wire and hence also it's natural frequency of vibration (resonance). The relationship between frequency (period) and deformation (strain) is described as follows:

Model:	4200/4200HT	4202	4204
Gage Length (L_g):	6.000 inches	2 inches	4.000 inches
Wire Length (L_W):	5.875 inches	2 inches	3.875 inches
Gage Factor:	3.304	0.391	1.422

Table B-1 - Embedment Strain Gage Theoretical Parameters

Note: The examples below are calculated using the Model 4200 gage parameters. Substitute the values from Table B-1 for the Models 4202/4204 strain gages. **These equations do not apply to the Models-4202X/4210/4212/4214 strain gages.**

1. The fundamental frequency (resonant frequency) of vibration of a wire is related to its tension, length and mass 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, sec.^{2}/in.^{2}).

2. Note that: $m = \frac{W}{L_w g}$

Where;
W is the weight of L_W inches of wire (pounds).
g is the acceleration of gravity (386 in./sec.^{2}).

3. and: $W = \rho a L_w$

Where;
ρ is the wire material density (0.283 lb./in.^{3}).
a is the cross sectional area of the wire (in.^{2}).

4. Combining equations 1, 2 and 3 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 (in./in.).
E is the Young's Modulus of the wire (30 x 10^6 Psi).

6. Combining equations 4 and 5 gives:

$$f = \frac{1}{2L_w}\sqrt{\frac{\varepsilon_w E g}{\rho}}$$

7. Substituting the given values for E, g and ρ yields:

$$f = \frac{101142}{L_w}\sqrt{\varepsilon_w}$$

8. On channel 'A', which displays the period of vibration, T, multiplied by a factor of 10^6:

$$T = \frac{10^6}{f}$$

9. Combining equations 7 and 8 gives:

$$\varepsilon_w = \frac{97.75 L_w{}^2}{T^2}$$

10. Equation 9 must now be expressed in terms of the strain in the surface of the body to which the gage 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.
Lg is the gage length (in inches).

11. Combining equations 9 and 10 gives:

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

Where; (for the VCE-4200 Strain Gage)
L_W is 5.875 inches.
Lg is 6.000 inches.

12. Therefore: $\varepsilon = 3.304 \times 10^3 [\frac{1}{T^2}]$

(Note that T is in seconds x 10^6 and ε is in inches per inch)

13. The display on position "D" of the GK-401/403 Readout is based on the equation:

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

Note that in this formula ε is in micro inches per inch and T is in seconds x 10^6

Alternatively $\varepsilon = 3.304 \times 10^{-3} f^2$ microstrain. Where f is the frequency in Hz

The squaring, inverting and multiplication by the factor, 3.304×10^9, is all done internally by the microprocessor so that the displayed reading on Channel D is given in terms of microinches per inch (ε).

APPENDIX C - THERMISTOR TEMPERATURE DERIVATION

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

Resistance to Temperature Equation:

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

Equation C-1 Convert Thermistor Resistance to Temperature

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

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

Table C-1 Thermistor Resistance versus Temperature

APPENDIX D - HIGH-TEMPERATURE THERMISTOR LINEARIZATION

High Temperature Thermistor Linearization using SteinHart-Hart Log Equation

Thermistor Type: Thermometrics BR55KA822J

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

Where: T = Temperature in °C
LnR = Natural Log of Thermistor Resistance
$A = 1.02569 \times 10^{-3}$
$B = 2.478265 \times 10^{-4}$
$C = 1.289498 \times 10^{-7}$

Note: Coefficients calculated over -30° to +260° C. span.

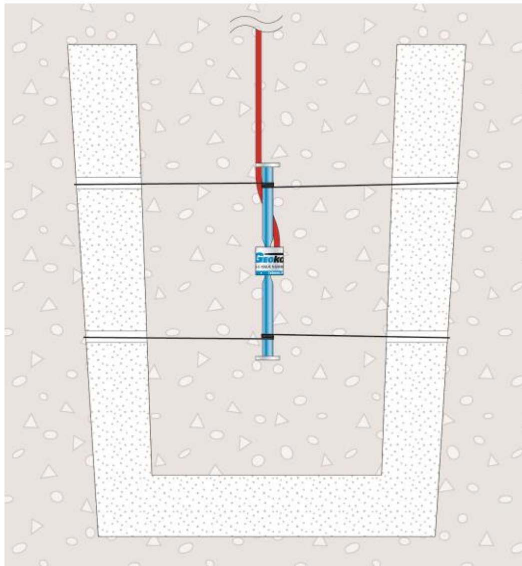
Temperature Calculation and Error Table

Temp	R (ohms)	LnR	LnR^3	Calculated Temp	Diff	FS Error	Temp	R (ohms)	LnR	LnR^3	Calculated Temp	Diff	FS Error
-30	113898	11.643	1578.342	-30.17	0.17	0.06	120	407.62	6.010	217.118	120.00	0.00	0.00
.-25	86182	11.364	1467.637	-25.14	0.14	0.05	125	360.8	5.888	204.162	125.00	0.00	0.00
-20	65805	11.094	1365.581	-20.12	0.12	0.04	130	320.21	5.769	191.998	130.00	0.00	0.00
-15	50684.2	10.833	1271.425	-15.10	0.10	0.03	135	284.95	5.652	180.584	135.00	0.00	0.00
-10	39360	10.581	1184.457	-10.08	0.08	0.03	140	254.2	5.538	169.859	140.01	-0.01	0.00
-5	30807.4	10.336	1104.068	-5.07	0.07	0.02	145	227.3	5.426	159.773	145.02	-0.02	-0.01
0	24288.4	10.098	1029.614	-0.05	0.05	0.02	150	203.77	5.317	150.314	150.03	-0.03	-0.01
5	19294.6	9.868	960.798	4.96	0.04	0.01	155	183.11	5.210	141.428	155.04	-0.04	-0.01
10	15424.2	9.644	896.871	9.98	0.02	0.01	160	164.9	5.105	133.068	160.06	-0.06	-0.02
15	12423	9.427	837.843	14.98	0.02	0.01	165	148.83	5.003	125.210	165.08	-0.08	-0.03
20	10061.4	9.216	782.875	19.99	0.01	0.00	170	134.64	4.903	117.837	170.09	-0.09	-0.03
25	8200	9.012	731.893	25.00	0.00	0.00	175	122.1	4.805	110.927	175.08	-0.08	-0.03
30	6721.54	8.813	684.514	30.01	-0.01	0.00	180	110.95	4.709	104.426	180.07	-0.07	-0.02
35	5540.74	8.620	640.478	35.01	-0.01	0.00	185	100.94	4.615	98.261	185.10	-0.10	-0.04
40	4592	8.432	599.519	40.02	-0.02	-0.01	190	92.086	4.523	92.512	190.09	-0.09	-0.03
45	3825.3	8.249	561.392	45.02	-0.02	-0.01	195	84.214	4.433	87.136	195.05	-0.05	-0.02
50	3202.92	8.072	525.913	50.01	-0.01	-0.01	200	77.088	4.345	82.026	200.05	-0.05	-0.02
55	2693.7	7.899	492.790	55.02	-0.02	-0.01	205	70.717	4.259	77.237	205.02	-0.02	-0.01
60	2276.32	7.730	461.946	60.02	-0.02	-0.01	210	64.985	4.174	72.729	210.00	0.00	0.00
65	1931.92	7.566	433.157	65.02	-0.02	-0.01	215	59.819	4.091	68.484	214.97	0.03	0.01
70	1646.56	7.406	406.283	70.02	-0.02	-0.01	220	55.161	4.010	64.494	219.93	0.07	0.02
75	1409.58	7.251	381.243	75.01	-0.01	0.00	225	50.955	3.931	60.742	224.88	0.12	0.04
80	1211.14	7.099	357.808	80.00	0.00	0.00	230	47.142	3.853	57.207	229.82	0.18	0.06
85	1044.68	6.951	335.915	85.00	0.00	0.00	235	43.673	3.777	53.870	234.77	0.23	0.08
90	903.64	6.806	315.325	90.02	-0.02	-0.01	240	40.533	3.702	50.740	239.69	0.31	0.11
95	785.15	6.666	296.191	95.01	-0.01	0.00	245	37.671	3.629	47.788	244.62	0.38	0.13
100	684.37	6.528	278.253	100.00	0.00	0.00	250	35.055	3.557	45.001	249.54	0.46	0.16
105	598.44	6.394	261.447	105.00	0.00	0.00	255	32.677	3.487	42.387	254.44	0.56	0.19
110	524.96	6.263	245.705	110.00	0.00	0.00	260	30.496	3.418	39.917	259.34	0.66	0.23
115	461.91	6.135	230.952	115.00	0.00	0.00							

<u>Table B-2: High Temperature Thermistor Resistance versus Temperature</u>.

APPENDIX E – NO-STRESS /STRAIN ENCLOSURE.

The No-Stress/Strain Enclosure is a double walled enclosure made of pvc filled with styrofoam as shown in the figure below:



Its purpose is to position an internal strain gage so that it is not subject to changes in strain in the mass concrete surrounding it but does remain subject to changes caused by the changes in moisture content, temperature, alkali/aggregate reaction experienced by the mass concrete surrounding it. The intention is to use the data gleaned from the no-stress strain gage to apply corrections for these phenomena to the other active strain gages in the mass concrete so that the strains due only to stress changes can be quantified.

The cell is positioned inside the mass concrete, (often next to a strain-gage rosette), with the top open so that it can easily be filled with concrete.The no-stress strain gage is held by steel tie wire in the center of the enclosure using two sets of holes that are pre-drilled through the walls of the enclosure. To mount the strain gage wrap two turns of wire around the gage and then feed the ends of the wire out through opposite holes in the side of the enclosure wrapping the ends around the outside of the enclosure and tie them off together use a tie-wire tightening tool or similar to tighten the wire. Repeat this with a second tie-wire in the other set of holes 5 inches above the last set. Arrange the cable to the sensor so that it comes out the top of the enclosure.When pouring concrete into the enclosure remove aggregate that is too large and be careful not to disturb the gages during the filling process.

APPENDIX F – MODEL 4200HT High Temperature Strain Gage

The Model 4200HT High Temperature Embedment Strain Gage is similar to the standard Model 4200 but is constructed using components that can be used at temperatures up to 200°C. It is particularly useful for measurements in autoclaved spun concrete piles.

Data Interpretation is the same as that outlined in Section 4 with the exception that the Temperature Coefficient is 17.3$\mu\varepsilon$/°C

Note also that the thermistor included with the gage is the high temperature thermistor that uses the resistance/temperature conversion table shown in Appendix D. If the high temperature strain gages are being read by the GK-403 or GK-404 readout box, do **not connect the green and white wires to the readout box.** The temperature shown on the readout box would not be useable because they only apply when the standard thermistor is being read. So to read temperatures use a digital ohmmeter.

APPENDIX G - MEASUREMENT OF, AND CORRECTION FOR, TEMPERATURE EFFECTS

If the ends of the structural member were free to expand or contract without restraint then strain changes could take place without any change in stress. On the other hand, if the ends of the structural member were restrained by some semi-rigid medium, then any increase in temperature of the structural member would result in a build-up of compressive load-related strain in the member. (Even though the actual strain would be tensile!) The magnitude of this temperature-induced compressive strain increase would be measured accurately by the strain gage. Because, while the member is restrained from expansion, the vibrating wire is not restrained and the thermal expansion of the vibrating wire would cause a reduction in wire tension and a resulting decrease in the vibrational frequency. This would be indicated by a compressive strain reading, whose magnitude would be given by equation 4 page 10.

The temperature-induced stresses can be separated from any external load-induced stresses by reading both the strain and temperature of the strain gages at frequent intervals over a period of time in which the external loading from construction activity can be assumed to remain constant. When these strain changes are plotted against the corresponding temperature changes, the resulting graph would 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

$$\sigma_{\textit{temperature induced}} = K_T (T_1-T_0)E \text{...G1}$$

Which if desired can be subtracted from the combined load related stress change

$$\sigma_{\textit{combined temp and load-related}} = [(R_1-R_0)B + (T_1-T_0)(C_1-C_2)]E \text{.......................G2}$$

to give that part of the stress change due to construction activity loads only

$$\sigma_{\textit{external load}} = [(R_1-R_0)B + (T_1-T_0)(C_1-C_2) - K_T (T_1-T_0)]E \text{..................G3}$$

Note that the correction factor, K_T, may change with time and with construction activity due to the fact that the rigidity of the restraint may change. It would then be a good idea to repeat the above procedure in order to calculate a new temperature correction factor.

If, for whatever reason, the <u>actual</u> strain of the concrete member is required, that is, the change of unit length that would be measured by, say, a dial gage attached to the surface, this is given by the equation

$$\mu\varepsilon_{\textit{actual}} = (R_1-R_0)B + (T_1-T_0)C_1 \text{..G4}$$

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

Equation 4 may seem less than intuitive and requires some explanation: As an example assume first that the strain gage is inside a concrete slab that is perfectly restrained at its ends. If the temperature rises by, say 1 degree C then the vibrating wire undergoes an expansion of +12.2 microstrain and $(R_1-R_0)B$ would be -12.2 microstrains so that equation 4 would result in zero actual strain in the concrete slab.

On the otherhand – suppose that the concrete slab is free of all restraint and experiences a temperature change of + 1degree C. The concrete would expand 10 microstrains while the vibrating wire would expand 12.2 microstrans. The value of $R_1-R_0)B$ woulld be - 2.2 microstrians (the vibrating wire would slacken slightly), and equation 4 would yield a value of + 10 microstrains.