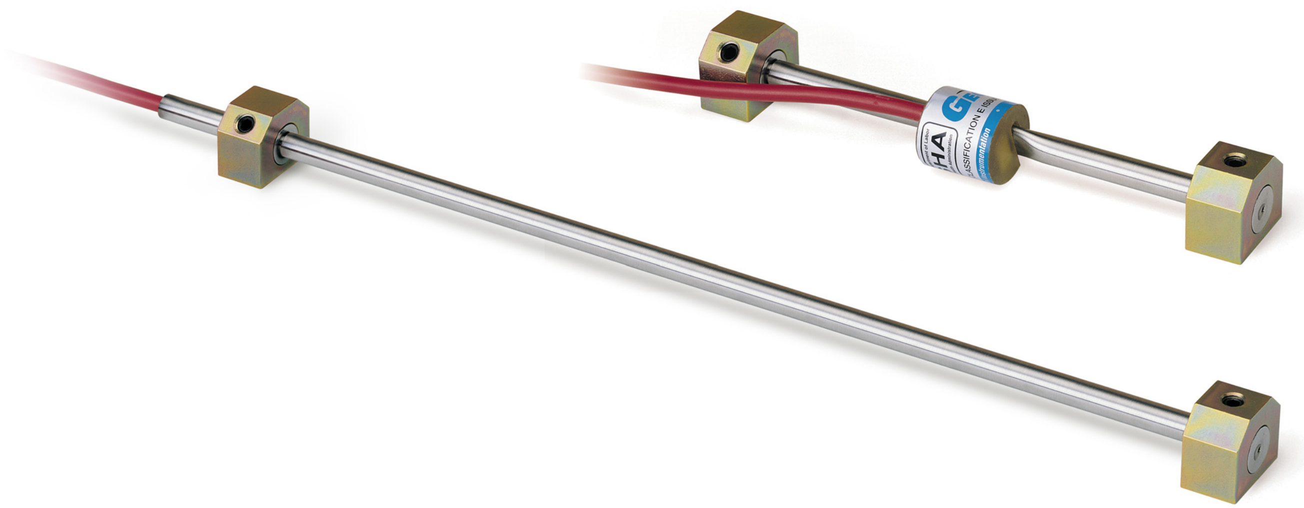
Model 4000 Series (4050 included)

Vibrating Wire Strain Gauges

Instruction Manual



GEOKON®

Document Revision: GG.2 | Release date: 10/31/24

WARRANTY STATEMENT

GEOKON warrants its products to be free of defects in materials and workmanship, under normal use and service for a period of 13 months from date of purchase. If the unit should malfunction, it must be returned to the factory for evaluation, freight prepaid. Upon examination by GEOKON, if the unit is found to be defective, it will be repaired or replaced at no charge. However, the WARRANTY IS VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion or current, heat, moisture or vibration, improper specification, misapplication, misuse or other operating conditions outside of GEOKON's control. Components that wear or are damaged by misuse are not warranted. This includes fuses and batteries.

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

Every precaution for accuracy has been taken in the preparation of manuals and/or software, however, GEOKON neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damages or losses that result from the use of the products in accordance with the information contained in the manual or software.

TABLE OF CONTENTS

FIGURES

TABLES

EQUATIONS

1. INTRODUCTION

GEOKON Model 4000 vibrating wire strain gauges are intended primarily for measuring strain on structural steel members such as tunnel linings, arches, struts, piles, sheet piling, etc. They may also be used to monitor strain changes on concrete or rock surfaces. Attachment to steel surfaces is accomplished by arc welding the mounting blocks to the surface; other surfaces require special mounting blocks with rebar anchors that are grouted into boreholes.

Strain is measured using the vibrating wire principle. A length of steel wire is tensioned between two mounting blocks that are welded to the steel surface being studied. Deformations of the surface will cause the two mounting blocks to move in relation to each other, altering the tension in the steel wire. This change in tension is measure□d as a change in the resonant frequency of vibration of the wire.

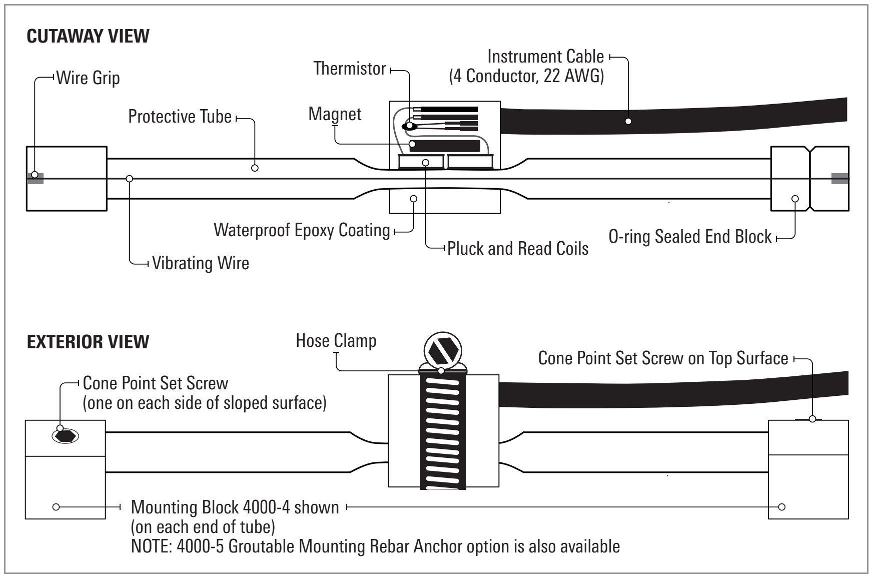


FIGURE 1: *Model 4000 Vibrating Wire Strain Gauge*

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 instructions, recommended maintenance, and troubleshooting procedures. The theory of the gauge is also given, along with some suggestions for data interpretation.

2. PRELIMINARY CHECKS

Perform a preliminary check before installing the gauge in the field. To perform the preliminary check, complete the following steps according to the instruction in Section 6.2:

1. Connect the gauge to a readout box.
2. Observe the displayed readout. The reading should be around the midrange position as defined in Table 1 on page 16. The temperature reading should match the ambient temperature.
3. Gently pull on the gauge end blocks; confirm that numbers on the readout rise as the tension increases. **Do not apply excessive tension (greater than 9 kg / 20 lb), as this may break the vibrating wire!**

Check electrical continuity using an ohmmeter. Resistance between the gauge leads (usually red and black) should be approximately 180 ohms (50 ohms for model 4050 gauges.) Remember to add cable resistance, which is approximately 14.7Ω per 1000 feet (48.5Ω per km) of 22 AWG stranded copper leads at 20 °C. Multiply this factor by two to account for both directions. Resistance between thermistor leads (usually green and white) will vary based on temperature; see Table 5. Resistance between any conductor and the shield should exceed two megohms.

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

3. GAUGE INSTALLATION

3.1 CONNECTING THE MOUNTING BLOCKS

GEOKON vibrating wire strain gauges are held in place by two mounting blocks. GEOKON can provide mounting blocks, spacer bars, and spacing jigs for different gauge types and installations.

Assemble the mounting blocks onto the spacer bar as follows:

1. Fit the two mounting blocks over the ends of the spacer bar.
2. Position the mounting blocks and spacer bar onto the spacing jig.

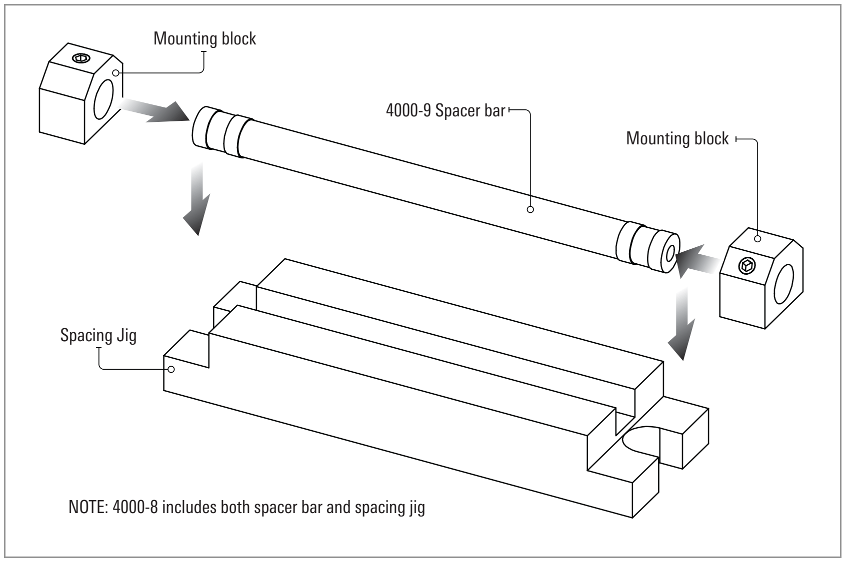


FIGURE 2: *Spacing Jig*

3. Tighten the setscrews in the mounting blocks down onto the spacer bar so that it will not slide. Avoid tightening excessively, since this could damage the spacer bar.
4. Remove the completed mounting block and spacer bar assembly from the spacing jig.

3.2 INSTALLATION ON STEEL SURFACES

3.2.1 WELDING

Once the correct spacing of the mounting blocks has been set using the spacing jig, the mounting blocks may be welded to the steel surface as follows:

1. Clean the steel using a wire brush; remove all scale, rust, dirt, and oil.
2. Using the spacer bar as a handle, press the mounting blocks firmly against the steel surface.
3. Weld the edges of the mounting blocks in the order shown in the following figure.

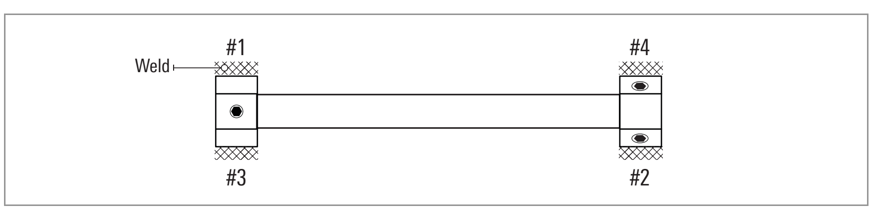


FIGURE 3: *Welding Sequence for the Mounting Blocks*

Avoid excessive heat while welding. **Do not weld the end surfaces of the mounting blocks**; this would prevent removal of the spacer bar. Avoid welding splatter, which could stick to the spacer bar. When many gauges are being installed, it is advantageous to have more than one spacer bar available.

After welding, cool the mounting blocks with a water-soaked rag, then slacken the setscrews and slide out the spacer bar. Clean away all welding slag using a chipping hammer and wire brush.

Optional: Paint over the surface to provide some protection against corrosion.

Continue with the installation by proceeding to Section 3.5.

3.2.2 INSTALLATION ON DRIVEN STEEL PILES

Strain gauges mounted on steel piles need to be protected from being scraped off as the pile is driven into the ground. This can be accomplished by welding 101 x 38 mm (4" x 1.5") channel iron or 64 mm (2.5") or larger angle iron over the top of the gauges and cables. For more, see Section 3.5.

To avoid burning the cables, the protection should be welded on before the gauges and cables are installed. To accomplish this, leave windows in the steel over the gauge locations. It is not necessary to use continuous welds; tack welding is sufficient so long as it holds the angles or channels firmly in place. Cables must be restrained by welding studs at three-meter intervals, to which the cables can then be tied.

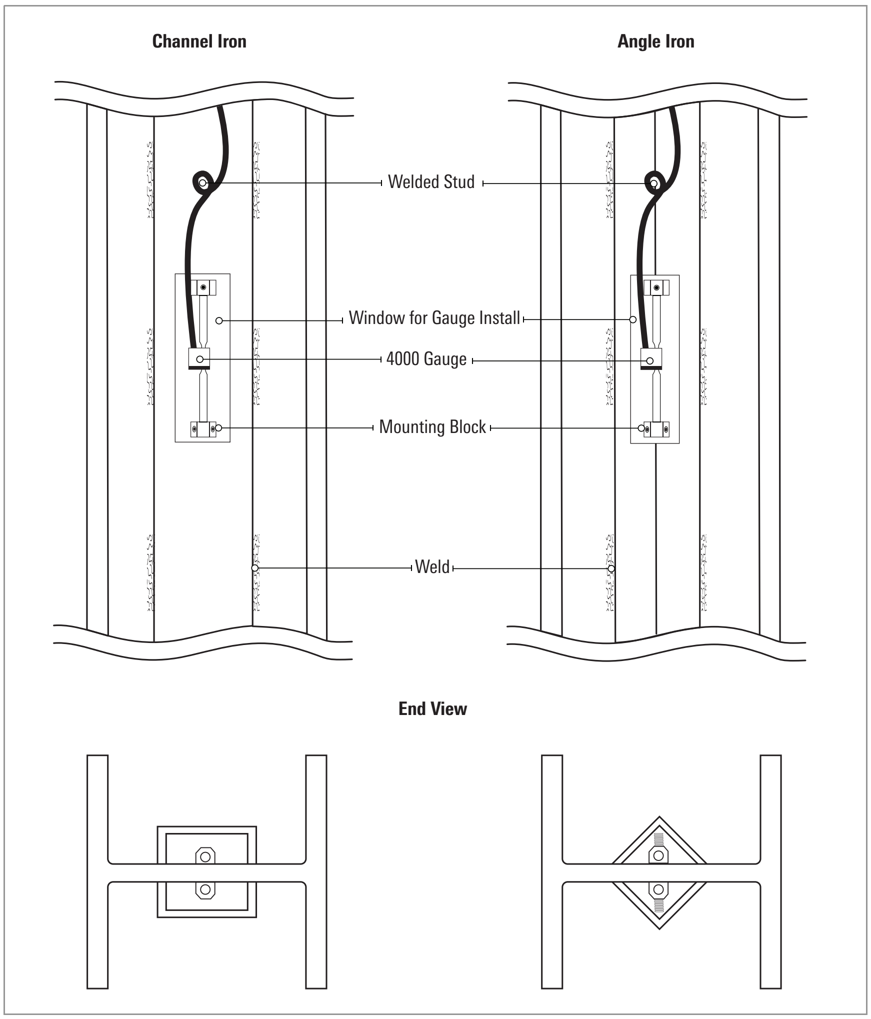


FIGURE 4: *Protection on Driven Piles*

To prevent shock damage during driving, please observe these additional precautions:

- ☐ Install the mounting block that possesses the single setscrew in the upper position.
- ☐ Tighten hard the setscrews that hold the gauge in the mounting blocks. Use Loctite on the threads.
- ☐ Glue the coil onto the flat area of the gauge tube. (Use any cyanoacrylate product such as Eastman 910 or Crazy Glue.) Make sure that the cable side of the coil points towards the top of the pile, i.e., towards the end of the gauge with the V-groove.
- ☐ As an added precaution, tighten hard when installing the hose clamp that holds the coil on the gauge, and tighten using a nut driver.
- ☐ When setting the gauges make sure they are reading around 3500 on position C. **This is very important.**

Continue with the installation by proceeding to Section 3.5. After the gauges are installed, seal the windows by welding a section of the appropriate material over the window.

3.3 INSTALLATION USING EPOXY CEMENTS

GEOKON strain gauges can be epoxied to steel or concrete surfaces provided these two factors are strictly observed:

1. Proper care must be taken to clean the surfaces to be bonded.
2. Sufficient time must be allowed for the epoxy to cure before the gauges are attached to the mounting blocks.

Note: Due to the large number of variables associated with adhesive use (thermal cycles, UV exposure, vibration, impact, moisture, corrosion of base steel, etc.,) epoxy cement is recommended for short term monitoring only.

3.3.1 CONCRETE SURFACES

Materials needed:

- Devcon Underwater Putty, Mfg. Part# 11800 — GEOKON Part# 6201-2
- Loctite 410 Instant Adhesive, Mfg. Part# 41045 — GEOKON Part# 4000-15

1. Mix a quantity of the two-part underwater putty. The mix ratio is 1/1.
2. Grind and/or sand the surfaces to be bonded. (This includes both the concrete and the end block surfaces.)
3. Clean surfaces with compressed air or aerosol cleaner.
4. Attach the mounting blocks to the spacer bar, per the instructions in Section 3.1.
5. Apply a thin layer of mixed underwater putty to the center two-thirds of the mounting block, and a thin layer of 410 instant adhesive to the outside edges of the mounting blocks (see the figure below).

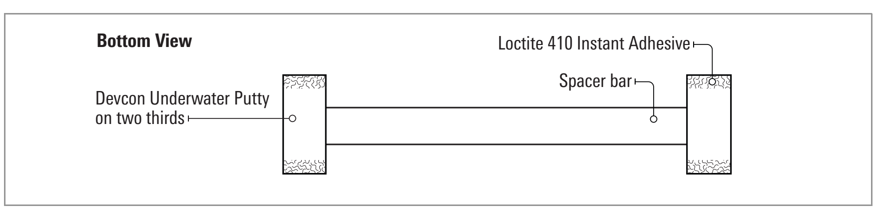


FIGURE 5: *Installation Using Epoxy*

6. Press the assembly firmly against the surface and hold in place for two minutes.
7. Carefully remove the spacing bar from the mounting blocks.
8. Allow 24 hours curing time before the gauges are installed.
9. Continue with the installation by proceeding to Section 3.5.

3.3.2 STEEL SURFACES

Use Loctite Speedbonder H4500. This can be purchased in a cartridge which automatically dispenses the two-part adhesive in its correct 10/1 mixture. (Adhesive, dispenser, and nozzles are available from GEOKON.)

Follow the instructions provided and then continue with the installation by proceeding to Section 3.5.

3.4 INSTALLING ON CONCRETE SURFACES USING ANCHOR STUDS

Strains in the surface of concrete can be measured by utilizing special mounting blocks that have reinforcing bar welded to them (GEOKON model 4000-5). Attach the strain gauge to the concrete surface as follows:

1. Drill two 64 mm (2.5") deep holes in the concrete at the proper spacing, using a minimum 13 mm (1/2") drill bit. (A template is available, GEOKON model 4000-11.)
2. Connect the mounting blocks to the spacer bar using the spacer block (see Section 3.1).
3. Grout the rebar studs into the holes using fast-setting hydraulic cement or a high strength epoxy. Redhead epoxy, type Epcon Ceramic 6 works well.
4. Once the grout has cured, continue with the installation by proceeding to Section 3.5.

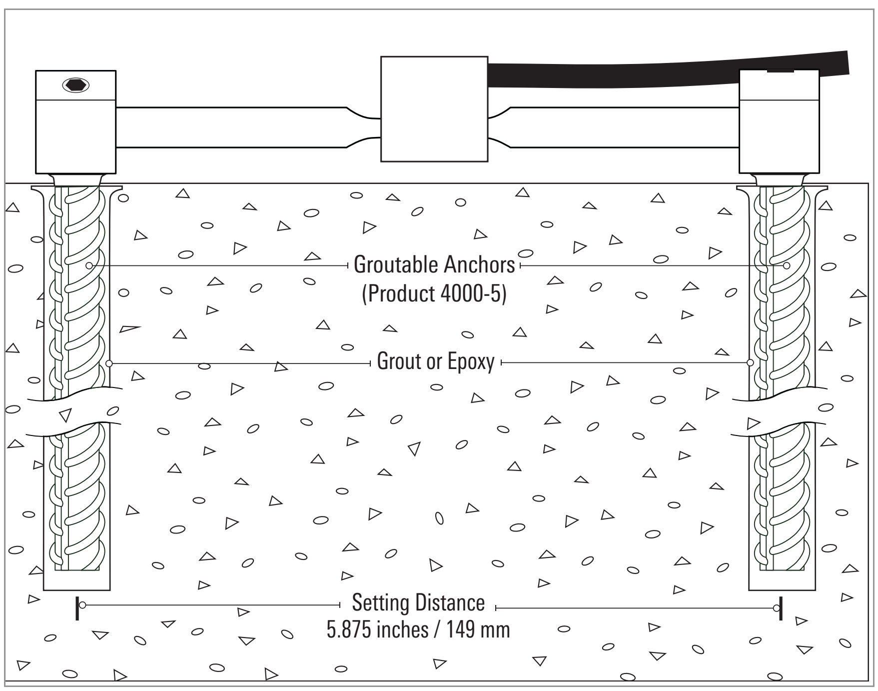


FIGURE 6: *Installation on Concrete Using Groutable Anchors*

3.5 SETTING THE STRAIN GAUGE

Mount the strain gauge as follows:

1. Slide the strain gauge through the mounting blocks. The end of the gauge that has the V-groove goes inside the mounting block that has only one setscrew; the smooth end goes inside the mounting block with two setscrews.
2. Tighten hard the setscrew in the mounting block with only one screw.
3. Slide the slot in the coil assembly (located at the end of the instrument cable) over the narrow center of the gauge.
4. Connect the gauge to the readout box using the instructions in Section 6.2
5. Adjust the reading by pulling or pushing on the free end of the strain gauge.
6. Set the initial reading on the gauge to the correct level depending on whether compressive or tensile strains are anticipated. Strain gauges are shipped with a reading of approximately 3000 to 3500 microstrain. This level is okay for compressive strains. If tensile strains are to be measured, set the initial reading to around 1500 microstrain. The usable range of the strain gauge runs from around 1000 to 4000 microstrain. The midrange reading is 2500 microstrain.
7. When the desired reading has been achieved, tighten hard the setscrews in the mounting block with two setscrews.
8. Install the hose clamp over the assembly and tighten using a nut driver.
9. In order to remove any installation strains and stabilize the initial reading, tap on the mounting blocks with a hard plastic tool, e.g., the handle of a screwdriver. Continue tapping until the reading remains stable.

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

It is preferable to install gauges on steel members while they are still in an unloaded condition, i.e., prior to their assembly into the structure. When the initial zero is established in this manner, the initial readings correspond to **zero load**, otherwise, if the member is under load the initial readings will correspond to some unknown load level.

Avoid excessive handling of the gauge prior to taking zero readings. Always allow sufficient time for the gauge temperature to stabilize before taking a reading. Be sure to record the temperature every time a reading is taken, along with notes concerning the construction activity that is taking place. This data might supply logical reasons for observed changes in the readings. (See also Appendix E and F.)

Each strain gauge has a thermistor encapsulated along with the plucking coil. GEOKON readout boxes display the temperature directly in degrees Celsius. An ohmmeter can also be used. (The relationship between resistance and temperature is shown in Appendix C.)

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 MECHANICAL DAMAGE

4.2.1 COVER PLATES

Gauges can be further protected by welding cover plates composed of 101 x 38 mm (4" x 1.5") channel iron or 64 mm (2.5") or larger angle iron over the top of the gauges.

To avoid damaging the cables, the protection should be welded on before the gauges and cables are installed. To accomplish this, leave windows in the steel over the gauge locations.

Note: It is not necessary to use continuous welds; tack welding is sufficient as long as it holds the angles or channels firmly in place. Cables must be restrained using welding studs, to which the cables can be tied at three-meter intervals.

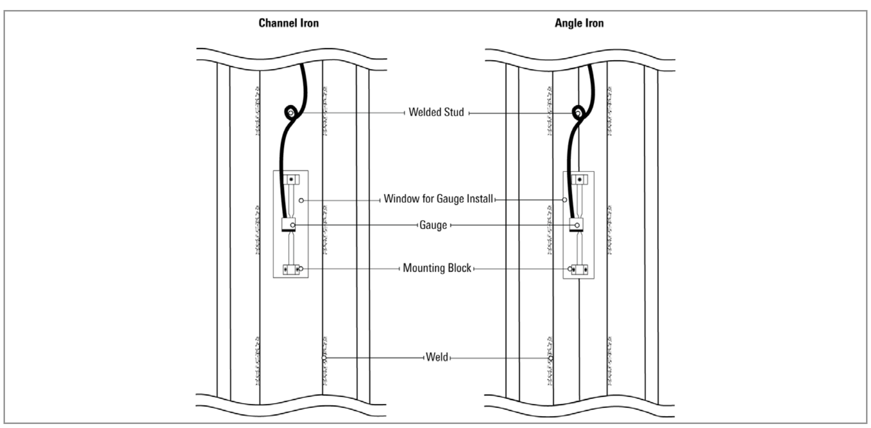


FIGURE 7: *Cover Plate - Top View*

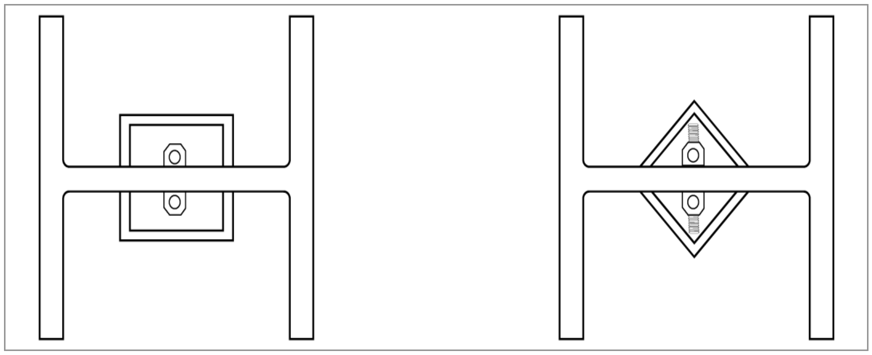


FIGURE 8: *Cover Plate - End View*

INSTALL THE COVER PLATES AS FOLLOWS:

1. Weld the two 9.5 x 51 mm (3/8 x 2") long hex bolts in place head down. The bolts should be spaced at a nominal 530 mm (21") apart. A spacer jig is available from GEOKON, or the cover plate can be flipped onto its back and the holes in the cover plate can be used to mark the bolt locations. One hole in the cover plate is slotted, so the spacing is not critical. Avoid welding anywhere near the gauge as this will cause large local distortions in the metal. Use either a special stud welder or an arc welder to weld the head of the bolt to the surface.
2. Place the cover plate over the welded bolts.
3. Install washers, then nuts. Avoid excessive force while tightening the cover retaining nuts, as this will distort the underlying steel surface and can give rise to spurious strain readings.

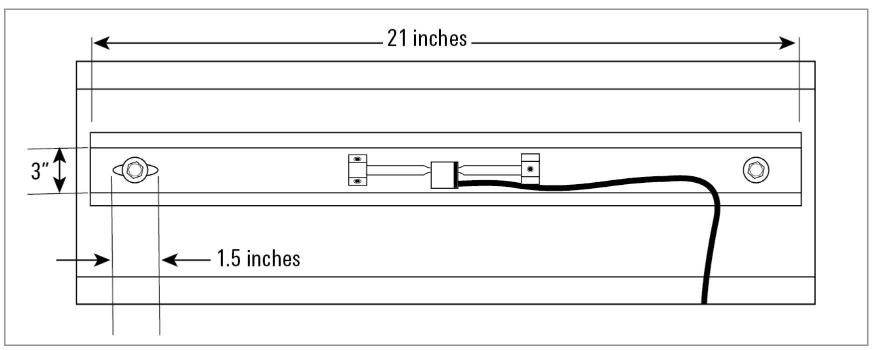


FIGURE 9: *Cover Plate Installation, Top View*

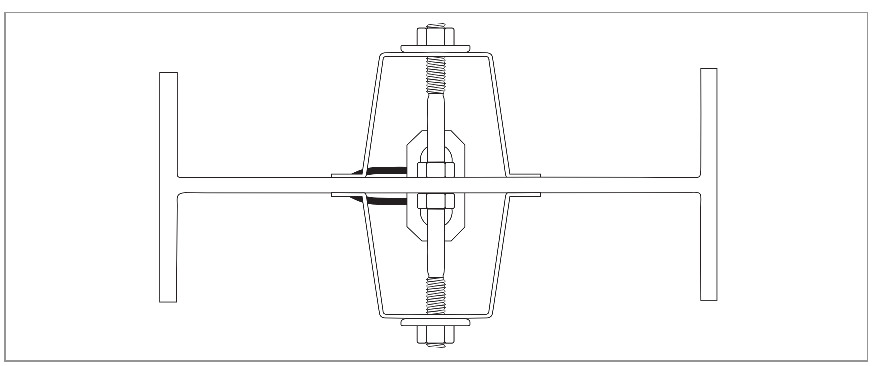


FIGURE 10: *Cover Plate Installation, Side View*

4.3 CABLE AND CONNECTOR PROTECTION

The cable should be protected from accidental damage caused by moving equipment or fly rock. This is best accomplished by putting the cable inside flexible conduit and positioning the conduit in as safe a place as possible. (Flexible conduit is available from GEOKON.) The conduit can be connected via conduit bulkhead connectors to the cover plates. (The GEOKON cover plate has a stamped knockout which, when removed, provides a hole for connecting the conduit connector.)

4.4 PROTECTION FROM CORROSION

It is imperative that installation weld points, if any, be protected from corrosion. Stainless steel instruments will not corrode, but the substrate can corrode, especially at weld points, unless they are covered by a waterproofing layer. GEOKON recommends you follow this procedure:

1. Apply several drops of cyanoacrylate adhesive to the edge of all spot welded mounting tabs. The glue will wick into the gap between the mounting tabs and the substrate and provide the first line of defense.
2. Mask off the areas where spot welds are needed.
3. Spray self-etching primer (available locally) over mounting tab areas and all exposed bare metal areas. The idea is to protect substrate weld points. It is important to completely cover mounting tab edges, paying attention to where the tab is under the instrument. Be sure to spray beneath the coil housing, if applicable; do not worry if the primer also coats the instrument.
4. Apply a coat of paint over the primed areas.

4.5 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.

4.6 PROTECTION FROM SUNLIGHT AND TEMPERATURE CHANGES

If attached to a steel structure, the thermal coefficient of expansion of the steel vibrating wire inside the instrument is the same as that for the structure. This means that no temperature correction for the measured strain is required when calculating load-induced strains. However, this is only true if the wire and the underlying steel structure are at the same temperature. If sunlight is allowed to impinge directly onto the gauge, it could elevate the temperature of the wire above the surrounding steel and cause large changes in apparent strain. Therefore, always shield strain gauges from direct sunlight. Protection from thermal effects is best provided by covering the gauges with a layer of insulating material such as Polystyrene foam or fiberglass.

4.7 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.

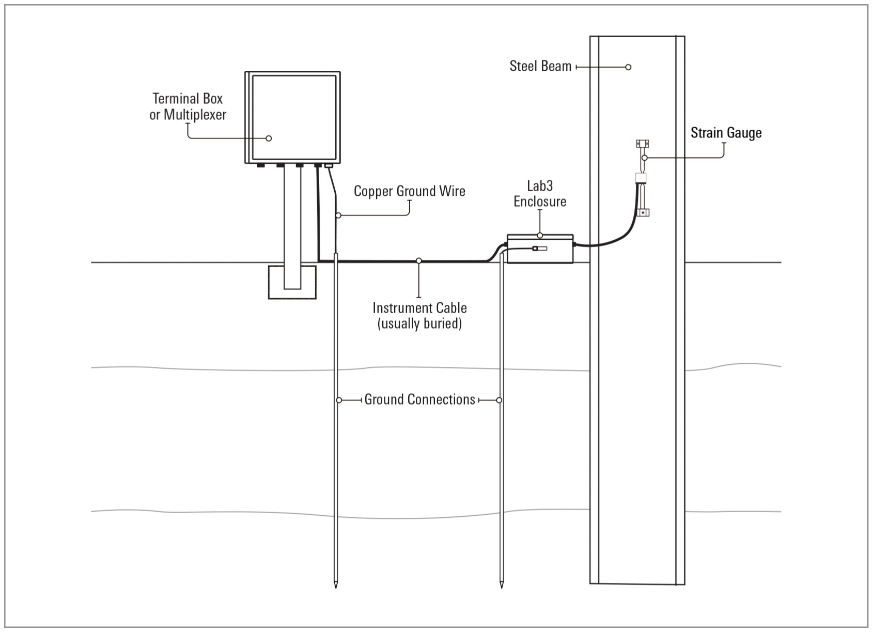


FIGURE 11: *Lightning Protection Scheme*

5. GAUGE LOCATION

5.1 END EFFECTS

To avoid end effects, strain gauges should be placed away from the ends of struts where they may be influenced by localized clamping or bolting distortions. For most structural members a distance of five feet is sufficient. Alternatively, end effects may be of some interest because they add to the load-induced effects, and may be large enough to initiate failure at the ends of the structural member, rather than in the middle.

5.2 WELDING EFFECTS

Arc welding close to the gauges can cause very large localized strains in the steel member. Welding studs onto soldier piles to support lagging, shotcrete reinforcing mesh, etc., can cause big strain changes. This is also true of welding cover plates, protective channels, etc., over the gauges and cables. Always take gauge readings before and after any arc welding on the steel structure so that corrections can be applied to any apparent strain shifts**.**

5.3 BENDING MOMENTS

In the case of a steel structure, a strain gauge measures the strain at one point on the surface, and this would be sufficient if it could be guaranteed that no bending was occurring in the member. In practice, this will only occur near the center of long thin members subjected to tensile loads. Elsewhere, **bending moments are the rule rather than the exception**, and there will be a neutral axis around which bending takes place.

Since bending effects must be taken into account, more than one strain gauge is required at each cross section of the structural member. For a complete analysis at least three gauges are required, and very often more than that are needed. On a circular pipe strut, three gauges spaced 120 degrees apart around the periphery of the strut would suffice (see Appendix G). On an H pile or I-beam, at least four strain gauges would be required. On sheet piling, two gauges back to back on either side of the pile would be sufficient. Where a member is subjected to bending and **only the front surface is accessible**, e.g., a steel tunnel lining or the outside of sheet pilings, the bending moments can be measured by installing two vibrating wire gauges at different distances from the neutral axis (see Appendix H).

Consider the example of an I-beam, as shown in the figure below.

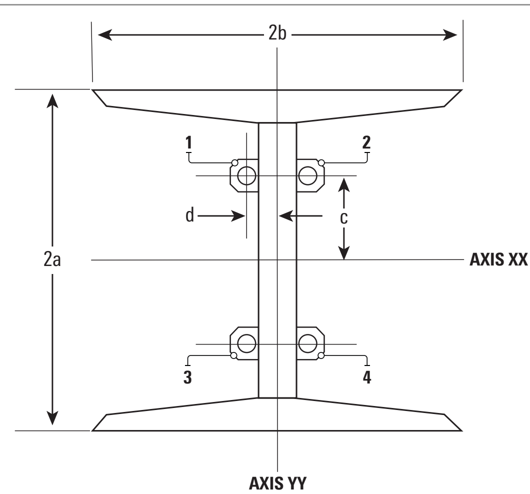


FIGURE 12: *Strain Gauges Mounted on Central Web*

It is always best to locate gauges in pairs, one on each side of the neutral axis corresponding to the section of the I-beam to which the gauge is attached. This, along with locating the gauges on the web making them easy to protect from accidental damage, is why the configuration shown above is preferable.

Note: This configuration is not recommended for tunnel arches.

Strain gauges mounted on the central web can measure axial strain as well as bending moments around both XX and YY axis. In this configuration, four strain gauges (1, 2, 3, and 4 in the previous figure) are welded back to back in pairs on the central web. The gauges are at a height (d) above the center of the web (Axis YY) and at a distance (c). The width of the I-beam flange is represented by 2b and the depth of the web by 2a.

The axial stress is given by averaging the strain reading from all four strain gauges and multiplying by the modulus, as shown in the equation below.

$$\sigma_{axial} = \frac{(\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4)}{4} \text{ x E}$$

EQUATION 1: *Axial Stress Calculation*

The stress due to bending is calculated by looking at the difference between pairs of gauges mounted on opposite sides of the neutral axis. Thus, the maximum stress due to bending about Axis YY is given by:

$$\sigma_{yy} = \frac{(\varepsilon_1+\varepsilon_3) - (\varepsilon_2+\varepsilon_4)}{4} \text{ x } \frac{b}{d} \text{ x E}$$

EQUATION 2: *Stress Due to Bending About Axis YY*

The maximum stress due to bending about Axis XX is given by:

$$\sigma_{xx} = \frac{(\varepsilon_1+\varepsilon_2) - (\varepsilon_3+\varepsilon_4)}{4} \text{ x } \frac{a}{c} \text{ x E}$$

EQUATION 3: *Stress Due to Bending About Axis XX*

$$\sigma_{maximum} = \sigma_{axial} + \sigma_{xx} + \sigma_{yy}$$

EQUATION 4: *Maximum Stress*

In all of the above calculations, pay strict regard to the sign of the strain. A positive change is tensile and a negative change is compressive.

Note that the total strain, at any point in the cross section, is the algebraic sum of the bending strains and the axial strain. The **strains in the outer corners of the flange can be much higher than the strains measured on the web**, and that failure of the section can be initiated at these points, hence the importance of analyzing the bending moments.

The above consideration would seem to lead to the conclusion (from the point of view of obtaining the best measurement of the maximum strains) that the ideal location for the strain gauges would be on the outer corners of the flanges, as shown in the figure below. However, this configuration makes it difficult to protect the gauges and cables from accidental damage. In addition, a serious problem can arise from the fact that **each of the four gauges can be subjected to localized bending forces, which affect only one gauge, but not the others**. For example, it is not uncommon for welding to take place at points close to a strain gauge; this often produces large strain changes in the gauge. It is also not uncommon for local blocking (e.g., tunnel arch supports) and the addition of struts, to cause strain changes on a single nearby gauge.

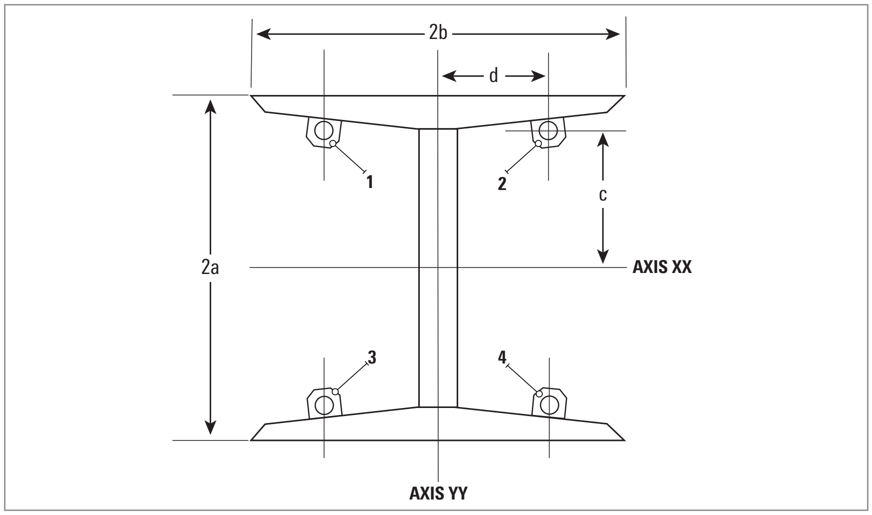


FIGURE 13: *Strain Gauges Mounted on Flanges*

For reasons of economy, if it is decided that only two strain gauges per cross-section are to be used, then the configuration shown in the figure below may be used. This configuration will give the axial strains and the bending moment around **the minor YY axis only**.

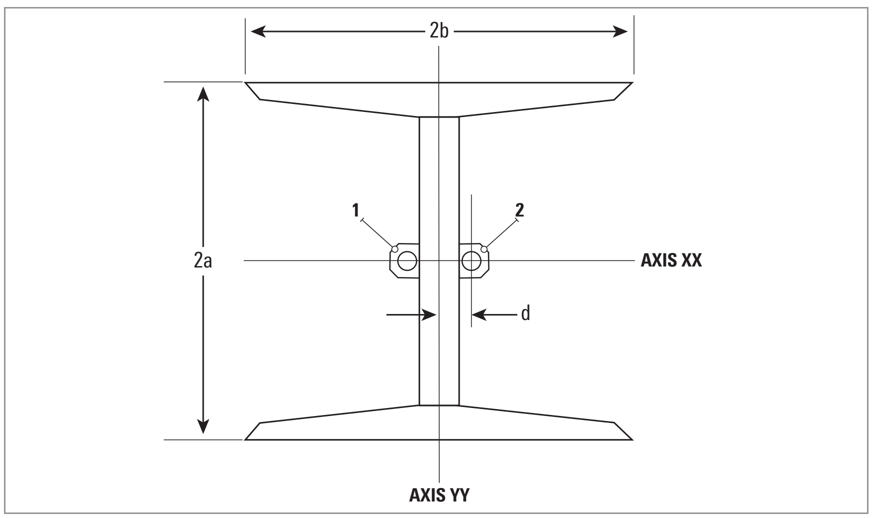


FIGURE 14: *Axial Strain Measurement/Bending Moment About YY Axis*

This configuration allows for easy protection of the instruments and their cables. If desired a hole may be drilled in the web so that the cable from one gauge may be passed through to the other side, allowing both cables to be protected by a single conduit.

Another possible two-gauge configuration is shown in Figure 15.

This configuration allows the calculation of the axial strains and the bending moment around the major XX axis. A disadvantage lies in that the exposed position of the gauges on the outside of the flanges requires a greater degree of protection. Also, local bending at one gauge may not be felt by the other gauge. A real world example of this was seen when welding on the exposed flange of a soldier pile close to one gauge produced large strain changes which were not felt by the other gauge on the back side of the pile.

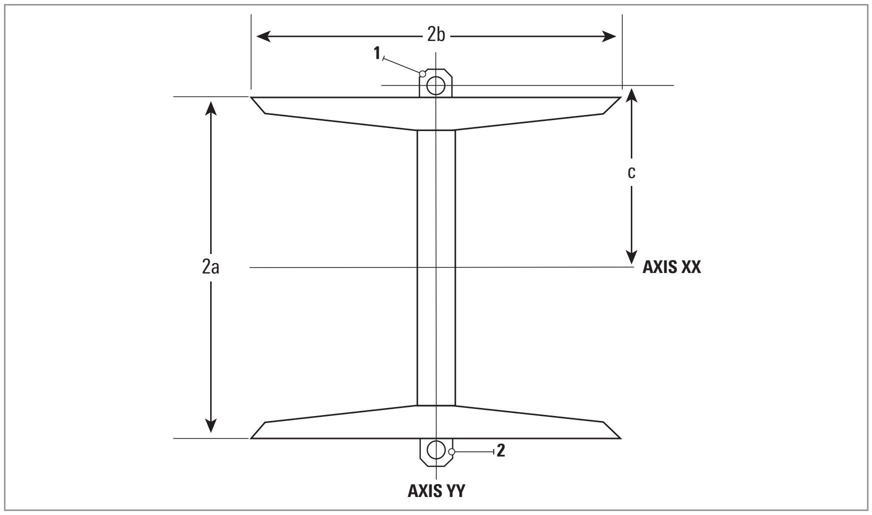


FIGURE 15: *Axial Strain and Bending Moment About XX Axis*

The configuration shown in the figure below has been used to allow the calculation of the axial strains, as well as to provide a measurement of the bending moment around the major XX axis. However, any bending around the minor YY axis will affect the reading to some extent. More importantly, there is the risk that one gauge can be affected by local bending without affecting the other gauge. **This configuration is not recommended**.

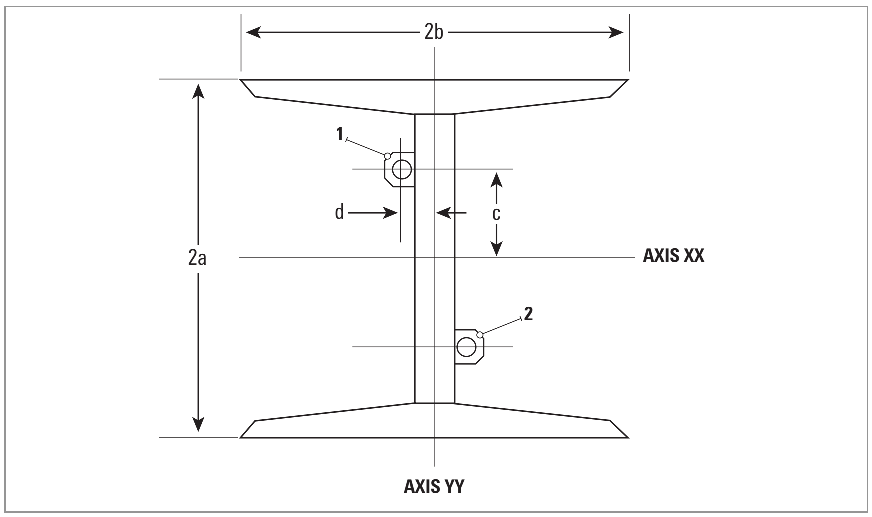


FIGURE 16: *Axial Strain and Bending Moment About Axis XX (NOT RECOMMENDED)*

6. TAKING READINGS

6.1 STRAIN GAUGE READOUT POSITIONS

Model	4000	4050
Readout Position	C	B
Display Units	microstrain (με)	digits ($f^2 x10^{-3}$)
Frequency Range	450-1250 Hz	1400-3200 Hz
Midrange Reading	2500 με	6000 digits
Minimum Reading	1000 με	2000 digits
Maximum Reading	4000 με	10000 digit

TABLE 1: *Strain Gauge 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 (με). 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

FIGURE 18: *Lemo Connector to 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.
- 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 (see Section 6.1).

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.

FIGURE 19: *GK-405 Readout*

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

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

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

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

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

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 (see Section 6.1).

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.

7. DATA REDUCTION

Readings in position C on GEOKON's readout boxes are displayed directly in microstrain based on the theoretical equation:

$$\mu\varepsilon_{\mathbf{theory}} = 4.062\ (f^2 \times 10^{-3})$$

EQUATION 5: *Theoretical Microstrain*

Where $\mu\varepsilon$ is the strain in the wire in microstrain and f is the resonant frequency of the vibrating wire.

7.1 CONVERSION OF THE READINGS TO STRAIN CHANGES

In practice, the method of wire clamping effectively shortens the vibrating wire slightly, causing it to over-register the strain. This effect is removed by applying the batch gauge factor (B) from the calibration report supplied with the gauges.

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

EQUATION 6: *Strain Calculation*

Where R_0 is the initial reading on position C and R_1 is a subsequent reading.

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

The value obtained from the above equation is required for computing stresses in equations steps two through four in Appendix B. The stresses thus computed are the total of those caused by both construction activity and by any temperature change that may have occurred.

7.2 CONVERTING STRAINS TO STRESSES

Strain gauges measure strain or deformation of the structure, however, the designer is usually more interested in the structural loads or stresses. This requires a conversion from the measured strains to computed stresses.

Strain changes are computed from strain gauge readings taken at various times, and by comparison with some initial readings taken at time zero. This initial reading is best taken when the structural member is under no load, i.e., the gauges should be mounted while the member is still in the steel yard or warehouse.

This is not always possible and often strain gauges are installed on members that are under some existing load so that subsequent strain changes will always begin from some unknown datum. However, a technique exists, namely the "Blind Hole Drilling Method" (Photolastic 1977), whereby residual or existing stresses can be measured. The procedure is to cement a strain gauge rosette to the surface and then analyze the strains caused by drilling a short blind hole in the center of the rosette. However, it is a well-known fact that strains can be locked into the steel during its manufacture. (Often, the skin of a rolled steel structural member is under tension relative to the underlying steel.)

Sometimes it is possible, especially where temporary supports are being monitored, to measure the strain in the structural member after the structure has been dismantled. This "no load" reading should agree with the initial "no load" reading. Any lack of agreement would be an indication of gauge zero drift, although the possibility of some permanent plastic deformation of the member should not be overlooked, particularly where measured strains were high enough to approach the yield point.

8. TROUBLESHOOTING

Maintenance and troubleshooting of Model 4000 Vibrating Wire Strain Gauges is confined to periodic checks of cable connections and maintenance of terminals. Once installed, the gauges are usually inaccessible and remedial action is limited. Should difficulties arise, consult the following list of problems and possible solutions. Return any faulty gauges to the factory. **Gauges should not be opened in the field.** For additional troubleshooting and support, contact GEOKON.

SYMPTOM: THERMISTOR RESISTANCE IS TOO HIGH

- ☐ It is likely that there is an open circuit. Check all connections, terminals, and plugs. If a cut is located in the cable, splice according to instructions in Section 4.4.

SYMPTOM: THERMISTOR RESISTANCE IS TOO LOW

- ☐ Check all connections, terminals, and plugs for a short-circuit. If a short is located in the cable, splice according to instructions in Section 4.4.
- ☐ Water may have penetrated the interior of the strain gauge. 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. Loosen the two oval point setscrews in one of the mounting blocks. This will permit the internal spring to re-tension the gauge and the gauge will read again. Set the gauge to some new datum and re-tighten the setscrews. If the gauge does not respond to resetting, and if the old plucking coil will pluck a new gauge, replace the gauge.
- ☐ 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

- ☐ Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.
- ☐ Is the cable cut or crushed? Check the resistance of the cable by connecting an ohmmeter to the sensor leads. Table 2 on the next page shows the expected resistance for the various wire combinations; you can use Table 3 on the next page to fill in the actual resistance found. 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. If the resistance is very low, the gauge conductors may be shorted. If a break or a short is present, splice according to the instructions in Section 4.4.

Vibrating Wire Sensor Lead Grid - SAMPLE VALUES					
	Red	**Black**	**White**	**Green**	**Shield**
Red	N/A	≅**180Ω (**≅**50**Ω for model 4050**)**	infinite	infinite	infinite
Black	≅**180**Ω (≅**50**Ω for model 4050)	N/A	infinite	infinite	infinite
White	infinite	infinite	N/A	**3000Ω at 25°C**	infinite
Green	infinite	infinite	**3000Ω at 25°C**	N/A	infinite
Shield	infinite	infinite	infinite	infinite	N/A

TABLE 2: *Sample Resistance*

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

TABLE 3: *Resistance Work Sheet*

APPENDIX A. SPECIFICATIONS

A.1 VIBRATING WIRE STRAIN GAUGE

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

	Model 4000	Model 4050
Range (FS), (nominal)[1]	3000$\mu\varepsilon$	3000$\mu\varepsilon$
Resolution	1.0$\mu\varepsilon$	1.0$\mu\varepsilon$
Batch Accuracy[2]	Calibration: ±0.5% FS	Calibration: ±0.5% FS
Individual Accuracy[2]	Calibration: ±0.1% FS	Calibration: ±0.1% FS
Zero Stability	0.02% FS/yr	0.02% FS/yr
Linearity	±0.5% FS	±0.5% FS
Thermal Coefficient	12.2$\mu\varepsilon$ / °C	12.2$\mu\varepsilon$ / °C
Dimensions (gauge) (L x D)	165 x 12.5 mm (6.5 x 0.50")	321 x 12.5 mm (12.625 x 0.50")
Active Gauge Length[3]	150 mm (5.875")	300 mm (12")
Dimensions (end blocks) (W x H)	25 x 22 mm (1 x 7/8")	25 x 22 mm (1 x 7/8")
Dimensions (coil)	22 x 22 mm (0.875 x 0.875")	Internal
Frequency Range	450 – 1250 Hz	1400 – 3200 Hz
Coil Resistance	180Ω	50Ω
Temperature Range[4]	-20 to +80 °C	-20 to +80 °C

TABLE 4: *Specifications*

Notes:

[1] Also available with 5,000 or 10,000 $\mu\varepsilon$ range

[2] Using curve fitting techniques, (second order polynomial)

[3] Other lengths available on request

[4] Other ranges available on request

A.2 THERMISTOR

See Appendix C for more information.

Range: -80 to +150 °C

Accuracy: ±0.5 °C

A.3 4000-4 MOUNTING BLOCKS

Material: Carbon Steel

Plating: Bright Zinc with Clear Chromate

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 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:

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

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 the previous step 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:
Ɛ is the strain in the body.
Lg 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 the 4000 strain gauge)
Lw is 6.25 inches
Lg is 5.875 inches

12. Therefore:

$$\varepsilon = 4.062 \text{ x } 10^3 \left[\frac{1}{T^2}\right] \quad \varepsilon = 0.391 \text{ x } 10^3 \left[\frac{1}{T^2}\right]$$

13. The display on position "C" of the readout is based on the equation:

$$\varepsilon = 0.391 \text{ x } 10^9 \left[\frac{1}{T^2}\right] \quad \varepsilon = 4.062 \text{ x } 10^9 \left[\frac{1}{T^2}\right]$$

The squaring, inverting, and multiplication by the factor 4.062 x 10^9 is all done internally by the microprocessor of the readout, so that the displayed reading in position C is given in microinches per inch (Ɛ).

Note: In the previous two steps, T is in seconds x 10^6 and Ɛ is in microinches per inch.

Alternatively:

Ɛ = 4.062 x 10^{-3} f^2 micro strain, where f is the frequency in Hz.

APPENDIX C. THERMISTOR TEMPERATURE DERIVATION

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 7: *3kΩ Thermistor Resistance*

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

A = 1.4051×10^{-3}

B = 2.369×10^{-4}

C = 1.019×10^{-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 5: *3KΩ Thermistor Resistance*

APPENDIX D. MODEL 4050 SPECIAL INSTRUCTIONS

The Model 4050 Vibrating Wire Strain Gauge is a modified version of the Model 4000 Strain Gauge designed for measuring strains over a longer base. The following instructions are for the standard gauge length of 305 mm (12").

FIGURE 20: *Model 4050 Vibrating Wire Strain Gauge*

THESE INSTRUCTIONS ARE APPLICABLE TO THE 4050; HOWEVER, PLEASE BE SURE TO NOTE THE FOLLOWING EXCEPTIONS:

- This model requires spacer bar model 4050-8, which is 12 ⅝ inches long.
- Before installing the gauge, remove the black protective washer located between the tube and the end block with the 'V' groove.
- Model 4050 is read on position B of GEOKON's readouts. To set the gauge for all tension levels, the reading should be approximately 2000; for all compression levels, 10000; for midrange set to 6000.

  Note: Select the 1400 – 3500 Hz excitation range when using a CR10.
- To set the gauge, pull or push on the end of the gauge tube where the cable exits. **(Do not pull on the cable!)**
- Convert the position B reading to microstrain using the following equation along with the individual calibration factor (expressed in terms of microstrain/digit) supplied with the instrument.

$$\text{Microstrain } (\mu\varepsilon) = (R_1 - R_0)GF$$

EQUATION 8: *Reading to Microstrain*

- To correct for temperature effects, **for the gauge only**, use this equation:

$$\text{Microstrain } (\mu\varepsilon) = (R_1 - R_0)GF + (T_1\text{-}T_0)K$$

EQUATION 9: *Gauge-Only Temperature Effects*

Where:
R_1 = current reading (position B)
R_0 = initial reading (position B)
T_1 = current temperature (°C)
T_0 = initial temperature (°C)
K= 12.0 microstrain / °C

Note: If the gauge is attached to steel, the net thermal effect is practically zero. If mounted on concrete, use a K factor of 2 microstrain / °C

- Contact GEOKON for information on other Model 4050 gauge lengths.

APPENDIX E. TEMPERATURE EFFECTS

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

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

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

EQUATION 10: *Temperature-Induced Stress*

Subtract this from the observed apparent stress change using this equation:

$$\sigma_{apparent} = (R_1 - R_0)BE$$

EQUATION 11: *Apparent Stress*

Where:
B is the batch gauge factor.
E is Young's modulus.

Use the following equation to determine the part of the stress change that is due to construction activity loads only:

$$\sigma_{load} = [(R_1 - R_0)B - K_t(T_1 - T_0)]E$$

EQUATION 12: *Load-Related Stress*

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

If, for whatever reason, the **actual** strain of the steel member is required, (i.e., the change of unit length that would be measured by a dial gauge attached to the surface) you can arrive at this using this equation:

$$\mu\varepsilon_{actual} = (R_1 - R_0) \text{ x } B + (T_1 - T_0) \text{ x } CF_1$$

EQUATION 13: *Actual Strain*

CF_1 is the coefficient of expansion of steel = 12.2 microstrains / °C. When the ends of the structural member are perfectly restrained then $(R_1 - R_0)B$ the compressive strain induced by temperature change alone would be exactly canceled by $(T_1 - T_0) \times CF_1$, the expansive strain and $\mu\varepsilon_{actual}$ would be zero.

APPENDIX F. TEMPERATURE CORRECTION WHEN USED ON CONCRETE

In a free field, where no loads are acting, the thermal concrete strains are given by the following equation:

$$\mu\varepsilon_{thermal} = (T_1 - T_0) \text{ x } CF_2$$

***EQUATION 14:** Thermal Concrete Strains*

CF_2 represents the coefficient of expansion of concrete. Unless this figure is known, assume a nominal value of 10.4 microstrains/°C.

If the actual strain of the concrete member is required, (i.e., the change of unit length that would be measured by a dial gauge attached to the surface,) you can arrive at this using this equation:

$$\mu\varepsilon_{actual} = (R_1 - R_0)B + (T_1 - T_0) \text{ x } CF_1$$

***EQUATION 15:** Actual Strain*

Where CF_1 represents the coefficient of expansion of steel = 12.2 microstrains/°C, and $(R_1 - R_0)B$ is the apparent strain recorded by the readout box.

To calculate the strain in the concrete due to load changes only:

$$\mu\varepsilon_{load} = \mu\varepsilon_{actual} - \mu\varepsilon_{thermal} = (R_1 - R_0)B + (T_1 - T_0) \text{ x } (CF_1 - CF_2)$$

***EQUATION 16:** Strain Due to Load Changes Only*

Note the following example, where B = 0.91
R_0 = 3000 microstrain, T_0 = 20 °C
R_1 = 2900 microstrain, T_1 = 30 °C

$$\mu\varepsilon_{apparent} = (2900 - 3000) \text{ x } 0.91 = -91_{(compressive)}$$

$$\mu\varepsilon_{actual} = (2900 - 3000) \text{ x } 0.91 = +(30 - 20) \text{ x } 12.2 = 31_{(tensile)}$$

$$\mu\varepsilon_{thermal} = (30 - 20) \text{ x } 10.4 = 104_{(tensile)}$$

$$\mu\varepsilon_{load} = (2900 - 3000) \text{ x } 0.91 + (30 - 20) \text{ x } (12.2 - 10.4) = -73_{(compressive)}$$

Note: Because assumptions have been made regarding the thermal coefficients for the concrete, these equations should only be used as a general guide.

Explanation: The apparent compressive strain, indicated by the readout box after application of the batch factor, B, is $(R_1 - R_0) \text{ x } B = -91$ microstrain. If the strain in the concrete had not changed, the steel vibrating wire would have expanded and gone slack by the equivalent of $(30 - 20) \text{ x } 12.2 = -12.2$ microstrain, therefore the concrete must have actually expanded by $+31$ microstrain to account for the observed apparent strain. The concrete should have expanded by $(30 - 20) \text{ x } 10.4 = +104$ microstrain on account of the temperature increase, the fact that it didn't reach this value must mean that there has been a superimposed buildup of compressive strain equal to $104 - 31 = -73$ microstrains. This, multiplied by Young's Modulus, will give the actual stress in the concrete caused by the imposed load change.

APPENDIX G. CALCULATIONS FROM THREE STRAIN GAUGES, AT 60 DEGREES, ON A CIRCULAR PIPE

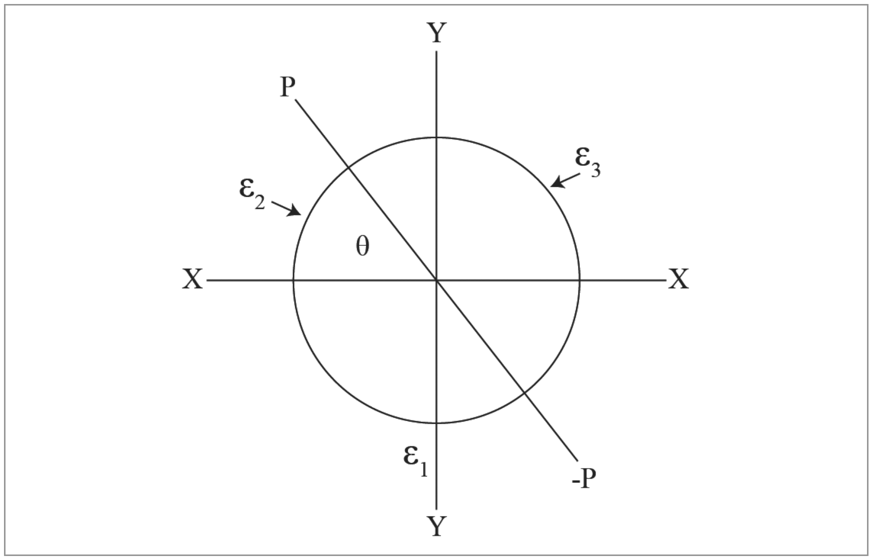


FIGURE 21: *Three Strain Gauges Mounted on a Circular Pipe Diagram*

$A = (\varepsilon_1 + \varepsilon_2 + \varepsilon_3) / 3$

EQUATION 17: *Average Axial Strain*

$(Y) = \pm[((\varepsilon_1 + \varepsilon_2 + \varepsilon_3) / 3) - \varepsilon_1]$

EQUATION 18: *Maximum Bending Strain Around the YY Axis*

$(X) = \pm[(\varepsilon_2 - \varepsilon_3) / 1.732]$

EQUATION 19: *Maximum Bending Strain Around the XX Axis*

$P = \pm[X\cos\theta + Y\sin\theta] + A$ and $\tan\theta = Y/X$

EQUATION 20: *Maximum Strain*

Example:
Let $\varepsilon_1 = 20$, $\varepsilon_2 = 192$ and $\varepsilon_3 = 88$ (all tensile strains)
Average Axial Strain, $A = (20 + 192 + 88) / 3 = 100$ microstrains, tension
$X = \pm(104 / 1.732) = \pm60$
$Y = \pm(300 / 3 - 20) = \pm80$
$\tan\theta = 80 / 60 = 1.333$ and $\theta = 53$ degrees from the X axis
$P = \pm[60 \times 0.6 + 80 \times 0.8] + 100 = 200$ microstrains, tensile, 0 microstrain minimum

APPENDIX H. TWO STRAIN GAUGES MOUNTED ONE ABOVE THE OTHER

Where only one surface of the straining member is accessible, you can use two strain gauges, one weld-mounted above the other, to separate axial strains from strains due to bending.

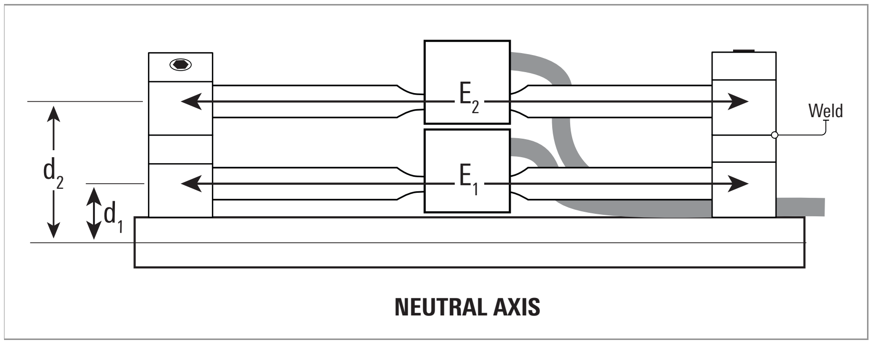


FIGURE 22: *Two Strain Gauges Mounted One Above the Other*

$\mathbf{E_1}$ and $\mathbf{E_2}$ are two measured strains at distances $\mathbf{d_1}$ and $\mathbf{d_2}$ from the neutral axis of a steel member (e.g., a sheet pile).

Note: $\mathbf{E_2}$ must be welded onto $\mathbf{E_1}$

If $\mathbf{R} = \mathbf{d_2} / \mathbf{d_1}$ then:

The Axial Strain along the neutral axis = $(\mathbf{RE_1} - \mathbf{E_2}) / (\mathbf{R-1})$

The Bending Strain at a distance $\mathbf{d_1}$ from the neutral axis = $(\mathbf{E_2} - \mathbf{E_1}) / (\mathbf{R-1})$

GEOKON
48 Spencer Street
Lebanon, New Hampshire
03766, USA

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