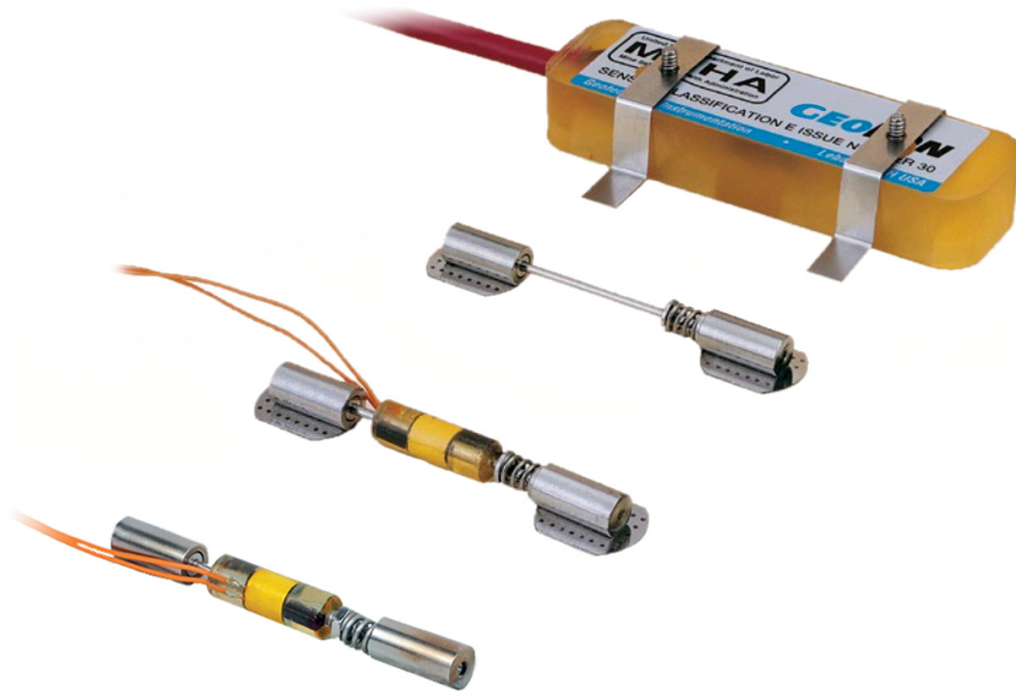

Model 4100/4150 Series Vibrating Wire Strain Gauges

Instruction Manual



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.

No part of this instruction manual may be reproduced, by any means, without the written consent of GEOKON. The information contained herein is believed to be accurate and reliable. However, GEOKON assumes no responsibility for errors, omissions or misinterpretation. The information herein is subject to change without notification.

The GEOKON® wordmark and logo are registered trademarks with the United States Patent and Trademark Office.

TABLE OF CONTENTS

| | |
|--|----|
| 1. INTRODUCTION | 1 |
| 2. PRELIMINARY CHECKS | 3 |
| 2.1 USING A READOUT | 3 |
| 2.2 USING AN OHMMETER | 3 |
| 3. INSTRUMENT PROTECTION | 4 |
| 3.1 CABLE SPLICING AND TERMINATION | 4 |
| 3.2 PROTECTION FROM MECHANICAL DAMAGE | 4 |
| 3.2.1 SECURING CABLES | 4 |
| 3.2.2 COVER PLATES | 4 |
| 3.3 CABLE AND CONNECTOR PROTECTION | 6 |
| 3.4 PROTECTION FROM CORROSION | 6 |
| 3.5 PROTECTION FROM ELECTRICAL NOISE | 7 |
| 3.6 PROTECTION FROM SUNLIGHT AND TEMPERATURE CHANGES | 7 |
| 3.7 LIGHTNING PROTECTION | 7 |
| 4. GAUGE INSTALLATION | 9 |
| 4.1 ADJUSTING THE GAUGE WIRE TENSION | 9 |
| 4.2 INSTALLING THE 4100/4150 VIA SPOT WELDING | 9 |
| 4.2.1 PREPARE THE SURFACE | 9 |
| 4.2.2 SPOT WELD TEST STRIPS | 9 |
| 4.2.3 SPOT WELDING THE 4100 GAUGE | 10 |
| 4.2.4 SPOT WELDING THE 4150 GAUGE | 10 |
| 4.2.5 WELDING THE SECOND END PIECE | 11 |
| 4.2.6 INSTALLING COLLAR SHIMS | 11 |
| 4.2.7 INSTALLING THE PLUCKING COIL HOUSING (MODEL 4100 ONLY) | 13 |
| 4.2.8 INSTALLING THE GAUGE COVER (MODEL 4150 ONLY) | 13 |
| 4.2.9 SECURING THE 4150 GAUGE CABLE | 13 |
| 4.3 INSTALLING THE 4100/4150 VIA EPOXY BONDING | 13 |
| 4.4 INSTALLING THE 4151 STRAIN GAUGE | 15 |
| 5. GAUGE LOCATION | 16 |
| 5.1 END EFFECTS | 16 |
| 5.2 WELDING EFFECTS | 16 |
| 5.3 BENDING MOMENTS | 16 |
| 6. TAKING READINGS | 20 |
| 6.1 STRAIN GAUGE READOUT POSITIONS | 20 |

| | |
|---|----|
| 6.2 GK-404 VIBRATING WIRE READOUT | 20 |
| 6.2.1 OPERATING THE GK-404 | 20 |
| 6.3 GK-405 VIBRATING WIRE READOUT | 21 |
| 6.3.1 CONNECTING SENSORS WITH 10-PIN BULKHEAD CONNECTORS ATTACHED | 21 |
| 6.3.2 CONNECTING SENSORS WITH BARE LEADS | 21 |
| 6.3.3 OPERATING THE GK-405 | 21 |
| 6.4 MEASURING TEMPERATURES | 22 |
| 7. DATA REDUCTION | 23 |
| 7.1 CONVERSION OF THE READINGS TO STRAIN CHANGES | 23 |
| 7.2 CONVERTING STRAINS TO STRESSES | 23 |
| 8. TROUBLESHOOTING | 24 |
| APPENDIX A. SPECIFICATIONS | 25 |
| A.1 VIBRATING WIRE STRAIN GAUGE | 25 |
| A.2 THERMISTOR | 25 |
| APPENDIX B. THEORY OF OPERATION | 26 |
| APPENDIX C. THERMISTOR TEMPERATURE DERIVATION | 28 |
| C.1 3KΩ THERMISTOR RESISTANCE | 28 |
| C.2 10KΩ THERMISTOR RESISTANCE | 29 |
| APPENDIX D. TEMPERATURE CORRECTION WHEN USED ON CONCRETE | 30 |
| APPENDIX E. TEMPERATURE EFFECTS | 31 |
| APPENDIX F. CALCULATIONS FROM THREE STRAIN GAUGES, AT 60 DEGREES, ON A CIRCULAR PIPE | 32 |
| APPENDIX G. MODEL 4150-5 EXTENDED RANGE STRAIN GAUGE | 33 |
| APPENDIX H. PARTS LIST | 34 |

FIGURES

| | |
|---|----|
| FIGURE 1: MODEL 4100 VIBRATING WIRE STRAIN GAUGE | 1 |
| FIGURE 2: MODEL 4150 VIBRATING WIRE STRAIN GAUGE | 2 |
| FIGURE 3: MODEL 4151 VIBRATING WIRE STRAIN GAUGE | 2 |
| FIGURE 4: MODEL 4100 COVER PLATE - TOP VIEW | 5 |
| FIGURE 5: MODEL 4150 COVER PLATE - TOP VIEW | 5 |
| FIGURE 6: COVER PLATE - END VIEW | 5 |
| FIGURE 7: COVER PLATE INSTALLATION, TOP VIEW | 6 |
| FIGURE 8: COVER PLATE INSTALLATION, SIDE VIEW | 6 |
| FIGURE 9: LIGHTNING PROTECTION SCHEME | 8 |
| FIGURE 10: PEEL TEST | 10 |
| FIGURE 11: SPOT-WELDING SEQUENCE, OUTER ROWS (4100) | 10 |
| FIGURE 12: SPOT WELDING SEQUENCE, OUTER ROWS (4150) | 10 |
| FIGURE 13: SPOT WELDING SEQUENCE, INNER ROWS | 11 |
| FIGURE 14: USING THE ALIGNMENT TOOL | 11 |
| FIGURE 15: COLLAR SHIM | 12 |
| FIGURE 16: WELDING THE COLLAR SHIM IN PLACE | 12 |
| FIGURE 17: COMPLETED COLLAR SHIM | 12 |
| FIGURE 18: SPOT WELDED COVER PLATE | 13 |
| FIGURE 19: MODEL 4151 STRAIN GAUGE INSTALLATION | 15 |
| FIGURE 20: STRAIN GAUGES MOUNTED ON CENTRAL WEB | 16 |
| FIGURE 21: STRAIN GAUGES MOUNTED ON FLANGES | 18 |
| FIGURE 22: AXIAL STRAIN MEASUREMENT/BENDING MOMENT ABOUT YY AXIS .. | 18 |
| FIGURE 23: AXIAL STRAIN AND BENDING MOMENT ABOUT XX AXIS | 19 |
| FIGURE 24: AXIAL STRAIN AND BENDING MOMENT ABOUT AXIS XX (NOT RECOMMENDED) | 19 |
| FIGURE 25: GK-404 READOUT | 20 |
| FIGURE 26: LEMO CONNECTOR TO GK-404 | 20 |
| FIGURE 27: GK-405 READOUT | 21 |
| FIGURE 28: GAUGE ASSEMBLY DIMENSIONS | 25 |
| FIGURE 29: COVER ASSEMBLY DIMENSIONS | 25 |
| FIGURE 30: THREE STRAIN GAUGES MOUNTED ON A CIRCULAR PIPE | 32 |

TABLES

| | |
|--|----|
| TABLE 1: GUIDE TO INITIAL TENSION SETTINGS | 9 |
| TABLE 2: STRAIN GAUGE READOUT POSITIONS | 20 |
| TABLE 3: SPECIFICATIONS | 25 |
| TABLE 4: 3KΩ THERMISTOR RESISTANCE | 28 |
| TABLE 5: 10KΩ THERMISTOR RESISTANCE | 29 |
| TABLE 6: MODEL 4100/4150 SERIES MODEL AND PARTS LIST | 34 |

EQUATIONS

| | |
|---|----|
| EQUATION 1: AXIAL STRESS CALCULATION | 17 |
| EQUATION 2: STRESS DUE TO BENDING ON AXIS YY | 17 |
| EQUATION 3: STRESS DUE TO BENDING ON AXIS XX | 17 |
| EQUATION 4: MAXIMUM STRESS | 17 |
| EQUATION 5: THEORETICAL MICROSTRAIN | 23 |
| EQUATION 6: STRAIN CALCULATION | 23 |
| EQUATION 7: 3KΩ THERMISTOR RESISTANCE | 28 |
| EQUATION 8: 10KΩ THERMISTOR RESISTANCE | 29 |
| EQUATION 9: THERMAL CONCRETE STRAINS | 30 |
| EQUATION 10: ACTUAL STRAIN | 30 |
| EQUATION 11: STRAIN DUE TO LOAD CHANGES ONLY | 30 |
| EQUATION 12: EXTERNAL LOAD STRESS ONLY | 31 |
| EQUATION 13: FREE FIELD THERMAL STRAINS | 31 |
| EQUATION 14: ACTUAL STRAIN | 31 |
| EQUATION 15: AVERAGE AXIAL STRAIN | 32 |
| EQUATION 16: MAXIMUM BENDING STRAIN AROUND THE YY AXIS | 32 |
| EQUATION 17: MAXIMUM BENDING STRAIN AROUND THE XX AXIS | 32 |
| EQUATION 18: MAXIMUM STRAIN | 32 |
| EQUATION 19: MODEL 4150-5 TEMPERATURE EFFECTS | 33 |

1. INTRODUCTION

GEOKON's 4100/4150 Series Vibrating Wire Strain Gauges are intended primarily for measuring strain on structural steel members, such as tunnel linings, arches, struts, piles, sheet piling, etc.

- Model 4100 consists of a vibrating wire gage element and removable coil assembly.
- Model 4150 consists of a vibrating wire gage element and integral coil assembly. (Also available is Model 4150-5, which has a range of 10,000 microstrains. See Appendix G for more information.)
- Model 4151 is a modification of the 4150 strain gauge, in which the spot-weldable tabs have been replaced by pins welded to the end blocks. These are designed to be grouted into holes drilled into the material under test.

Versions of Model 4151 are available with extended ranges. These gauges are useful for measurements in high strain regimes such as on plastic pipes or piles and on fiberglass structural members and rebars. Their small size makes them particularly suitable where space and or access is limited.

The primary means of attaching the Model 4100/4150 strain gauges to steel members is spot-welding, but they may also be epoxy bonded to the surface (see Section 4.3).

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

Two coils, one with a magnet insert and the other with a pole piece insert, are located close to the vibrating wire. Applying a pulse of varying frequency (swept frequency) to the coils causes the wire to vibrate primarily at its resonant frequency.

Portable readouts and dataloggers are available from GEOKON. These devices, when used with vibrating wire strain gauges, 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 provided, along with some suggestions for data interpretation.

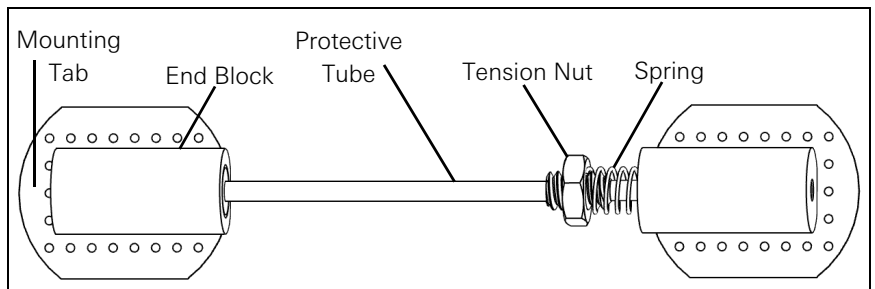


FIGURE 1: Model 4100 Vibrating Wire Strain Gauge

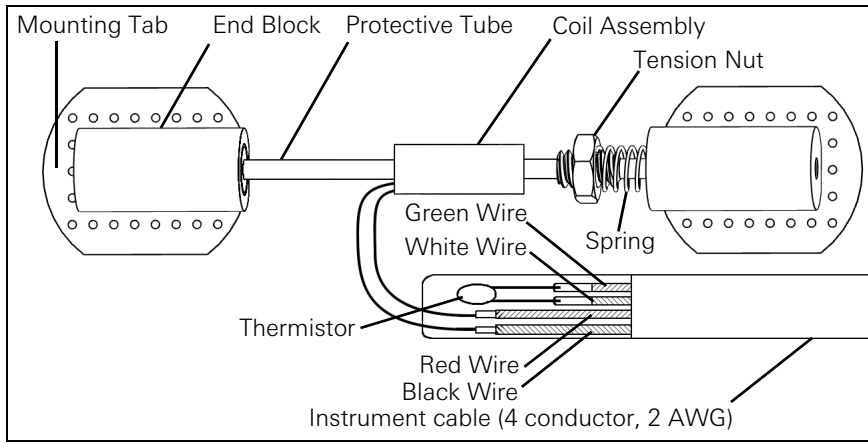


FIGURE 2: Model 4150 Vibrating Wire Strain Gauge

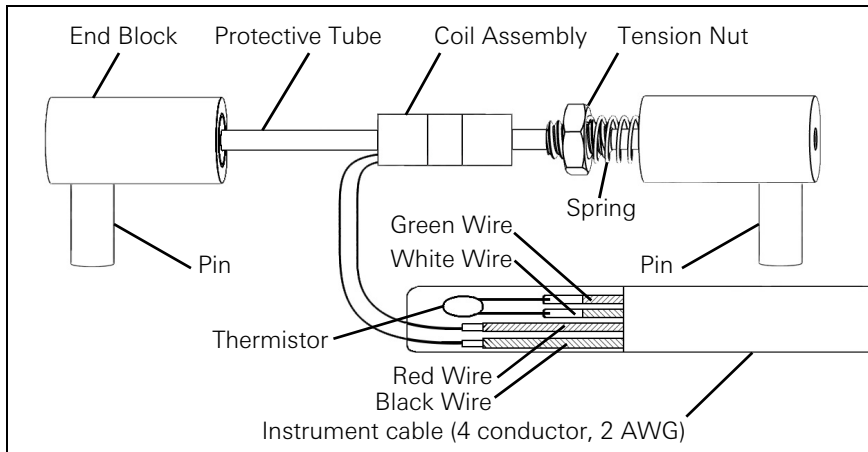


FIGURE 3: Model 4151 Vibrating Wire Strain Gauge

2. PRELIMINARY CHECKS

2.1 USING A READOUT

Perform a preliminary check before installing the gauge in the field. To perform the preliminary check, complete the following steps:

1. Insert the gauge into the underside of the coil assembly (4100 only).
2. Connect the gauge leads to a readout box. See Section 6 in necessary.
3. Observe the displayed readout. The reading should be around the midrange position as defined in Section 6. The temperature reading should match the ambient temperature.

Note: Strain gauges are supplied with the wire tension set near midrange; this gives enough range in both tension and compression to be suitable for most applications. If adjustment to the strain range is necessary, see Section 4.1. **Under no circumstances should the procedures described in Section 4.1 be used after the gauge has been welded down.**

4. Gently pull on the gauge end points; confirm that numbers on the readout rise as the tension increases. **Do not apply excessive tension (greater than 10 Kgm / 20 lb.), as this may break the vibrating wire!**

2.2 USING AN OHMMETER

If a readout is not available, the preliminary checks can be done using an ohmmeter, as follows:

1. Check electrical continuity using the ohmmeter. Resistance between the gauge leads (usually red and black) should be approximately 180 ohms (50 ohms for model 4150 series gauges.)

Note: Be sure 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.

2. Resistance between thermistor leads (usually green and white) will vary based on temperature; refer to Appendix C. 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. INSTRUMENT PROTECTION

3.1 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.

3.2 PROTECTION FROM MECHANICAL DAMAGE

The cover of the 4100 coil housing provides a measure of protection for the strain gauge, which is adequate in most cases. In extreme environments and/or where long term performance is required, gauge and lead wires may require additional protection from corrosion and mechanical damage.

3.2.1 SECURING CABLES

Cables should be adequately restrained so that there is no danger of the coil housing being damaged (Model 4100) or the lead wires torn out (Model 4150) by tugging on the cable. Cables may be secured using pieces of stainless steel shim strips (supplied), spot welded in place over the top of the cable. Tie wraps, tape, or wire ties may also be used to secure the gauge cables.

3.2.2 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.

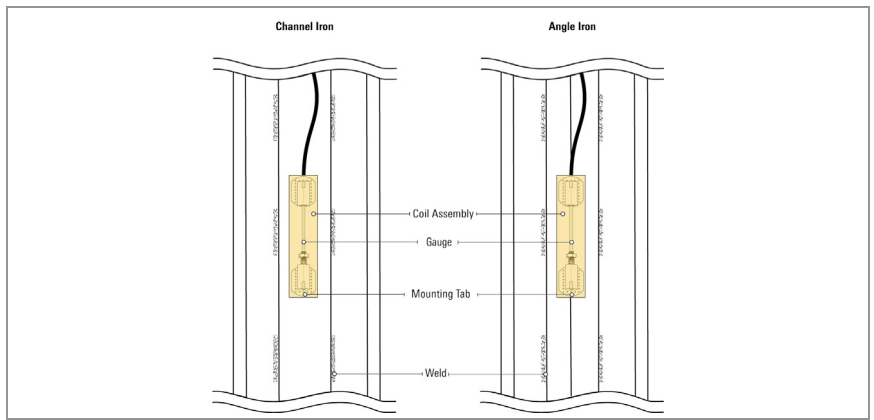


FIGURE 4: Model 4100 Cover Plate - Top View

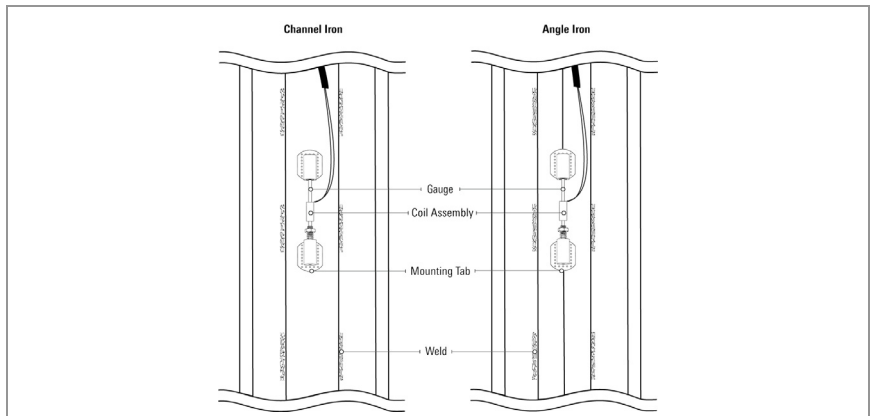


FIGURE 5: Model 4150 Cover Plate - Top View

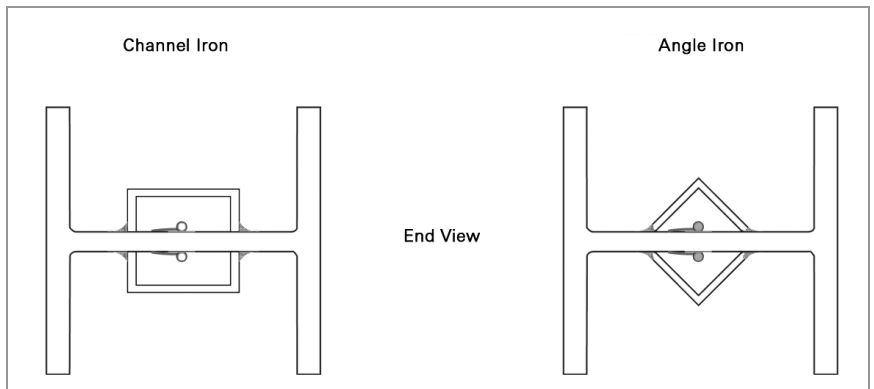


FIGURE 6: Cover Plate - End View

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.

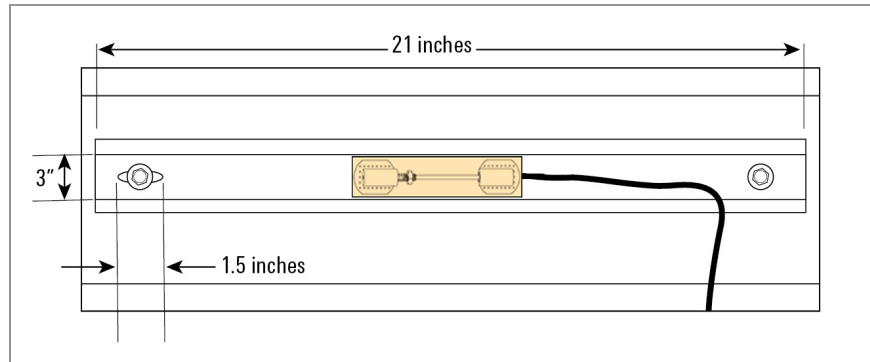


FIGURE 7: Cover Plate Installation, Top View

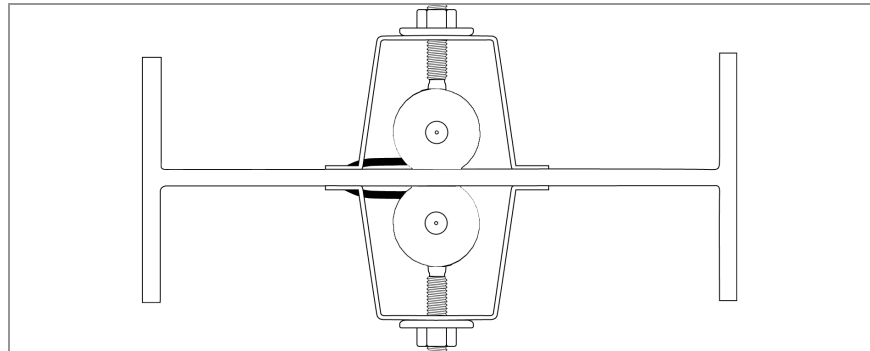


FIGURE 8: Cover Plate Installation, Side View

3.3 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.)

3.4 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.

In severe environments and for long term protection, the space between the coil housing and the Model 4100 gauge, and the space between the cover plate and the Model 4150 gauge, can be filled with a stiff grease (e.g., axle grease). For further protection, the entire assembly can be covered by a layer of insulating mastic (e.g. Plymouth 10 Plyseal), which is available from GEOKON.

3.5 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.

3.6 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.

3.7 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:

- Lightning 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.

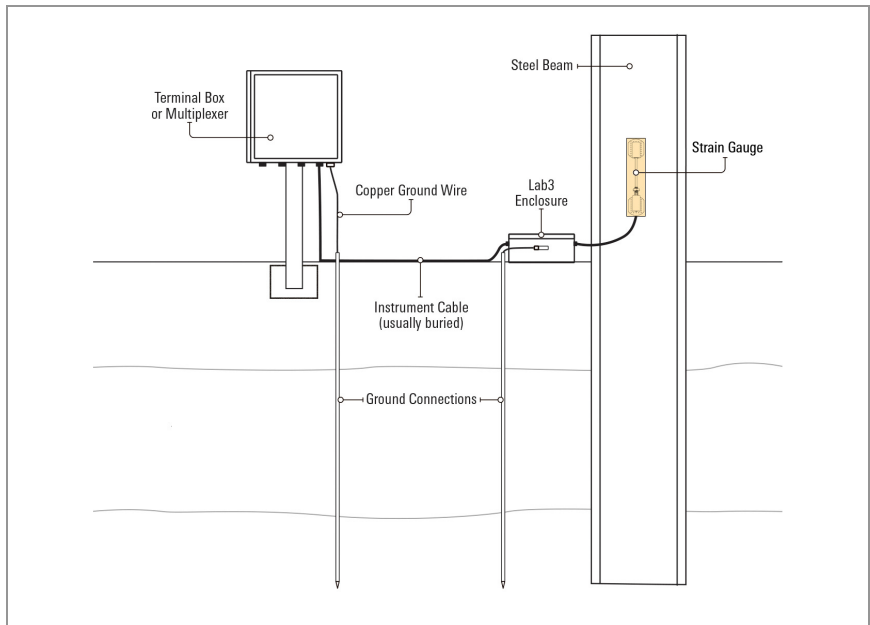


FIGURE 9: *Lightning Protection Scheme*

4. GAUGE INSTALLATION

4.1 ADJUSTING THE GAUGE WIRE TENSION

WARNING! Under no circumstances should the gauge tension be adjusted after the gauge has been welded down.

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

If the strain directions are known, the wire tension can be adjusted for greater range in either compression or tension by completing the following:

1. Attach the red and black leads to a readout box which has been set to position E.
2. Keep the gauge still by grasping the 4100 gauge by the tube, or the 4150 series gauges by the coil assembly.
3. Using a mini wrench, rotate the tensioning nut. The position of the nut controls the spring tension. To increase the range of measurement to accommodate more compressive strain, turn the nut in a clockwise direction and set the initial reading to between 2500 and 3000 microstrains. To increase the range of measurement for tensile strains rotate the nut in a counterclockwise direction, setting the initial reading to between 1500 and 2000. A rotation of 1/2 turn will give a change of about 600 microstrains. Table 1 details various tension settings.

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

TABLE 1: Guide to Initial Tension Settings

4. The gauge end piece will often turn with the tensioning nut. After the adjustment is made the end piece should be rotated back to its original position so that the flats of the two end pieces are aligned. Again, hold the tube/coil assembly while doing this.
5. Check the reading. If okay, apply a drop of thread locking cement to preserve the nut position and the tension.

4.2 INSTALLING THE 4100/4150 VIA SPOT WELDING

CAUTION! Wear safety glasses while performing the following tasks.

4.2.1 PREPARE THE SURFACE

The surface of the steel member should be flat, clean, and free from rust, grease, and pitting. Degrease the surface using an appropriate cleaning agent, then use a power grinder or sander, file, wire brush or sandpaper, to achieve a flat, smooth surface.

4.2.2 SPOT WELD TEST STRIPS

Before welding, it is necessary to test the spot welder to make sure that the correct weld energy is being used. Weld energy, and to a certain extent, contact pressure, determines the quality of the weld. Approximately 20 to 40 watt-seconds of weld energy is required to properly weld 4100 or 4150 strain gauges to structural steel.

Using the test material provided with the gauges, run a series of tests to determine the correct weld energy. When the correct weld energy is used, the test strip will show a series of holes where the welded strip has been left behind on the substrate when peeled back from the steel surface with pliers, as shown below.

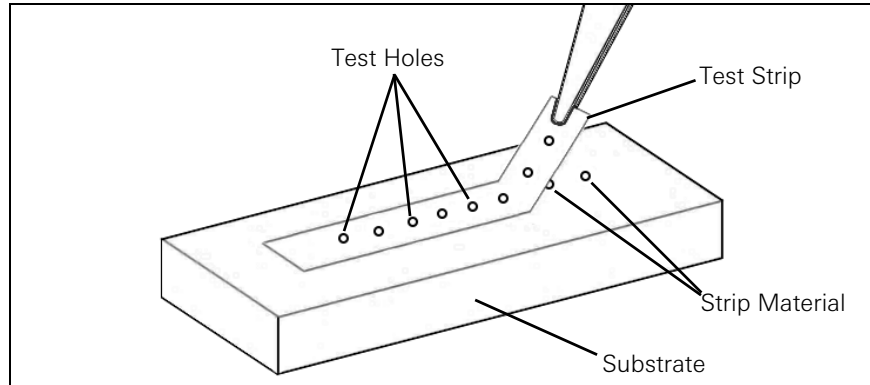


FIGURE 10: Peel Test

If insufficient weld energy is used, the test strip will pull loose without holes being torn in it. If excessive weld energy is used, the test strip will discolor, melt, and be ejected away from the spot. Sparking is usually an indication of dirt between the test strip and the substrate. It may also be an indication of insufficient force, in which case the force setting of the hand probe should be adjusted. Excessive deformation of the weld area calls for either a decrease of the force applied by the hand probe and/or a decrease of weld energy.

4.2.3 SPOT WELDING THE 4100 GAUGE

Spot weld one end of the gauge by placing a weld point at each of the marked dots on the mounting tab, in the sequence shown below. Once that is complete, weld the second mounting tab using instructions in Section 4.2.5.

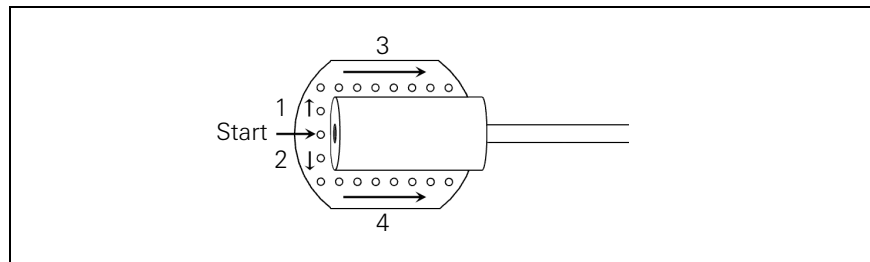


FIGURE 11: Spot Welding Sequence, Outer Rows

4.2.4 SPOT WELDING THE 4150 GAUGE

Spot weld the end of the gauge where the cable comes out by placing a weld point at each of the marked dots on the mounting tab in the sequence shown below. Carefully move the lead wires out of the way before beginning.

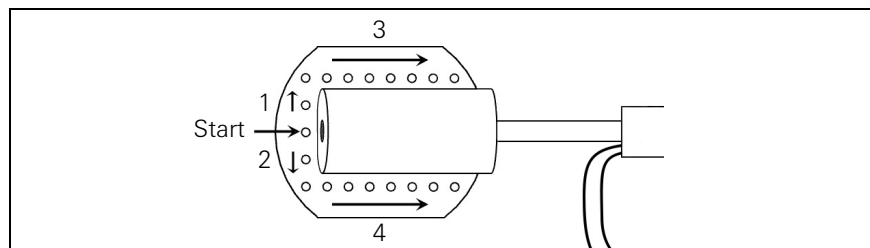


FIGURE 12: Spot welding Sequence, Outer Rows

Next, add another row of welds as close to gauge ends as possible, between the welds of the previous row, as shown in below. Once that is complete weld the second mounting tab per the instructions in Section 4.2.5.

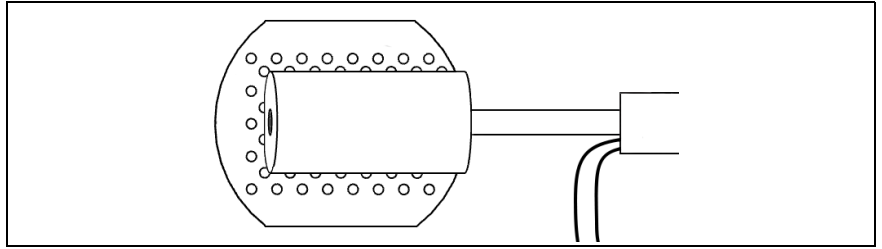


FIGURE 13: Spot Welding Sequence, Inner Rows

4.2.5 WELDING THE SECOND END PIECE

When all the weld dots on one mounting flange have been welded, proceed to weld the other end as follows:

Place the alignment tool over the two ends of the gauge as shown below. This will ensure that the two ends of the gauge are welded in a straight line.

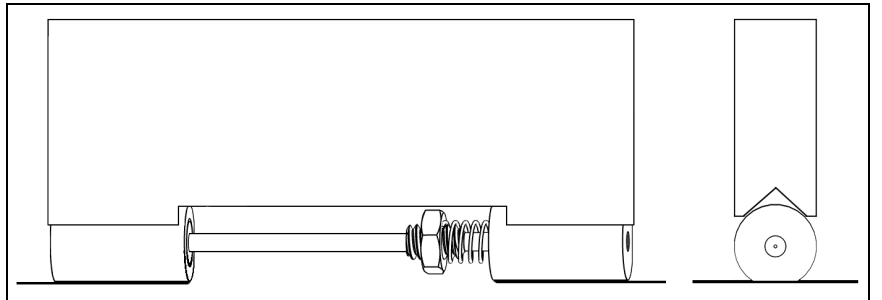


FIGURE 14: Using the Alignment Tool

With the alignment tool held in place, make a preliminary weld in the center of the second tab, outside of the back row, and close to the outer edge. When this spot has been welded, connect the gauge to the readout box and check the reading.

- If the reading is within the acceptable range, proceed to spot weld two more welds along the back line. Remove the alignment tool and weld the rest of the tab following the same pattern and sequence used for the first tab.
- If the reading is not acceptable, the preliminary weld can be undone by using a sharp razor blade to pry under the tab at a point close to the weld.

Welds should have a slight depression and be uniform in appearance. Keep the hand probe weld-tip clean and free of burrs. Periodically sand it gently with 400-grit sandpaper. Take care to keep the weld-tip a well-rounded point. Proper dressing will keep the tip from sticking to the mounting tab during welding.

Note: When the gauge is used on curved surfaces, make a third row of welds on the periphery of the mounting tab (between the stenciled row and the outside edge).

4.2.6 INSTALLING COLLAR SHIMS

Strain gauge performance is enhanced by the addition of the supplied collar shims. These shims are preformed in the shape of an L, and are welded over the top of the gauge ends as follows:

1. Take the shim and position it over the gauge end so that the edge of the 6 mm (.25") wide shim is flush with the back edge of the end.
2. Use the tip of the welder to press the angle in the collar shim tightly into the corner between the gauge end and the mounting tab as shown below.

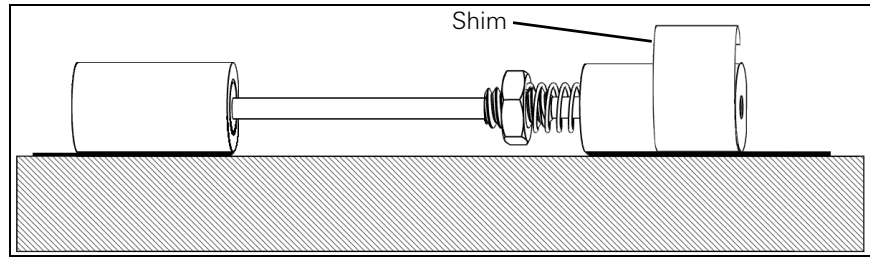


FIGURE 15: Collar Shim

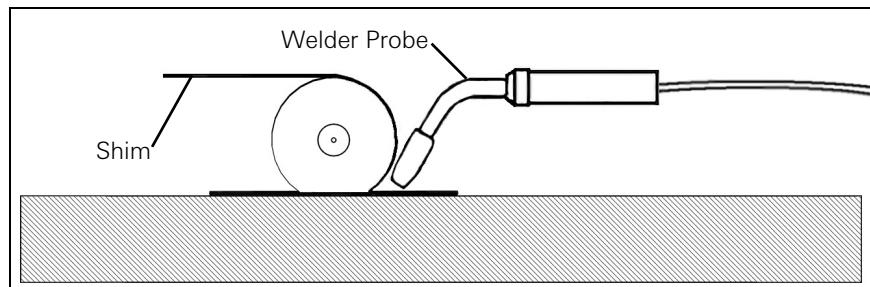


FIGURE 16: Welding the Collar Shim in Place

3. Weld the bottom end of the collar shim L onto the mounting tab using three welds positioned as close to the corner as possible, and three welds at the outer edge of the collar shim.
4. Bend the collar shim over the gauge end and force it into the corner on the other side of the gauge end using the weld probe as before.
5. Weld it into the corner as before, using a total of six welds.
6. Weld the collar shim to the end block using three welds along the highest point of the gauge end, as shown below.

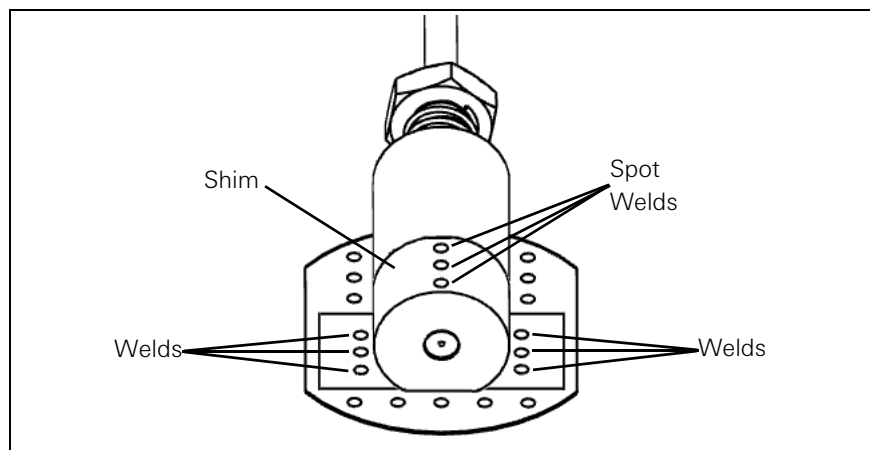


FIGURE 17: Completed Collar Shim

7. Repeat the process on the other gauge end.
8. When both ends of the gauge have been spot welded, take the handle of a small screwdriver and lightly tap both end blocks at points over the flanges

only. The purpose of the tapping is to relieve any local stresses induced by the welding procedure.

9. After tapping four or five times on each gauge end, read the gauge. Continue the tapping procedure until the readings have settled down and are not changing more than a few digits.

All readings are referred to an initial reading; therefore, it is important that this initial reading be taken carefully. It is preferable to install gauges on steel members that are still in an unloaded condition, i.e., prior to their assembly into the structure. In this way, the initial readings correspond to zero load. Otherwise, the initial readings will correspond to some unknown load level.

Record the ambient temperature at the time of each reading, along with notes concerning the construction activity that is taking place. This data might supply logical reasons for observed changes in the readings. For temperature correction factors when used on concrete, see Appendix D.

4.2.7 INSTALLING THE PLUCKING COIL HOUSING (MODEL 4100 ONLY)

Remove any masking and place the plucking coil housing over the gauge. Connect the gauge to the readout box and adjust the housing until a steady reading is obtained. In this position, use the spot welder to weld the tabs holding the coiled housing to the substrate.

Next, protect the tabs and surrounding bare metal from corrosion as described in Section 3.4.

4.2.8 INSTALLING THE GAUGE COVER (MODEL 4150 ONLY)

GEOKON provides the 4150 with a semicylindrical metal cover. Spot weld the cover in place over the gauge as shown in the figure below.

Next, waterproof the spot-welding tabs as described in Section 3.4.



FIGURE 18: Spot welded Cover Plate

4.2.9 SECURING THE 4150 GAUGE CABLE

Using the shim stock provided, spot weld the cable to lead wire junction firmly to the steel substrate. Be sure to leave some slack in the lead wires. Using another piece of shim stock, spot weld the cable to the steel substrate, approximately 25 mm (1") behind the lead wire junction.

4.3 INSTALLING THE 4100/4150 VIA EPOXY BONDING

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

Use the following tools and accessories to install the 4100 or 4150 onto steel by epoxy bonding:

- Power grinder or sander, files, wire brush, sandpaper
- Quick-setting two-part adhesive, such as Loctite 410 with accelerator

- Strain gauge setting jig
- Waterproofing compound such as Dow Corning RTV-3145
- Cable ties and/or duct tape (as required)

Do the following to install the gauge:

1. **Prepare the surface:** Follow the instructions outlined in the spot welding section.
2. **Fasten the gauge:** Position the gauge in the slot of the setting jig. Apply Loctite 410 to the mounting tabs of the strain gauge. Apply activator to the steel at the approximate locations for the mounting tabs. Press the gauge firmly against the beam and hold for at least 30 seconds, until the Loctite has set.
3. **Gauge protection:** Apply a layer of waterproofing compound over the mounting tab area.
4. **Install the plucking coil housing (for the 4100):** Before the waterproofing layer has hardened, install the plucking coil housing over the strain gauge. Don't use an excessive amount of waterproofing compound. Keep the waterproofing compound away from the gauge tube so that it does not impede the gauge tube's freedom to move relative to the gauge end.

If the plucking coil housing is to be kept portable, squeeze excess waterproofing compound out of the way so that when it sets up it will not prevent the proper seating of the plucking coil housing.

If the plucking coil housing is to be fixed in place permanently, position it over the gauge and look through the transparent housing, moving it until it is clear of the gauge. In this position, fasten it in place using the shim stock provided and procedure described in step 2 above. The area of the substrate to which the tabs are welded will require surface preparation as described in Section 4.2.1. The tabs should be protected from corrosion as described in Section 3.4.

5. **Secure the gauge cable:** For the 4150, using the shim stock provided, fasten the cable to lead wire junction firmly to the steel. Be sure to leave some slack in the lead wires. Using the second shim stock, fasten the cable to the steel, approximately 25 mm (1") behind the lead wire junction. For the 4100 or 4150, use cable ties or duct tape to secure the gauge cable to the steel member.
6. **Fasten the 4150 cover plate:** Fill the cover with the waterproofing compound and place it over the gauge. Using the special shim stock strips provided, fasten the strips first to the split tube, and then to the steel member.

All readings are referred to an initial reading; therefore, it is important that these initial readings be taken carefully. Install gauges on steel members that are still in an unloaded condition, i.e., prior to their assembly into the structure. This will ensure that the initial readings correspond to zero load. Otherwise, the initial readings will correspond to some unknown load level.

Record the ambient temperature at the time of each reading, along with notes concerning the construction activity that is taking place. This data might supply logical reasons for observed changes in the readings. For temperature correction factors when used on concrete, see Appendix D.

4.4 INSTALLING THE 4151 STRAIN GAUGE

Drill two 5 mm (3/16") diameter holes 13 mm (1/2") deep, at a spacing of 51 mm (2"). GEOKON provides a drill hole spacer bar to make this easier. After drilling the first hole, secure the spacer bar to the hole then use the spacer bar to locate the second hole.

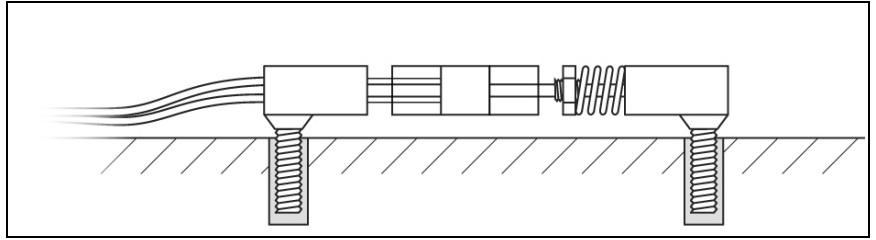


FIGURE 19: Model 4151 Strain Gauge Installation

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 F). On an H pile or I-beam, at least four strain gauges would be required. On sheet piling, two gauges 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.

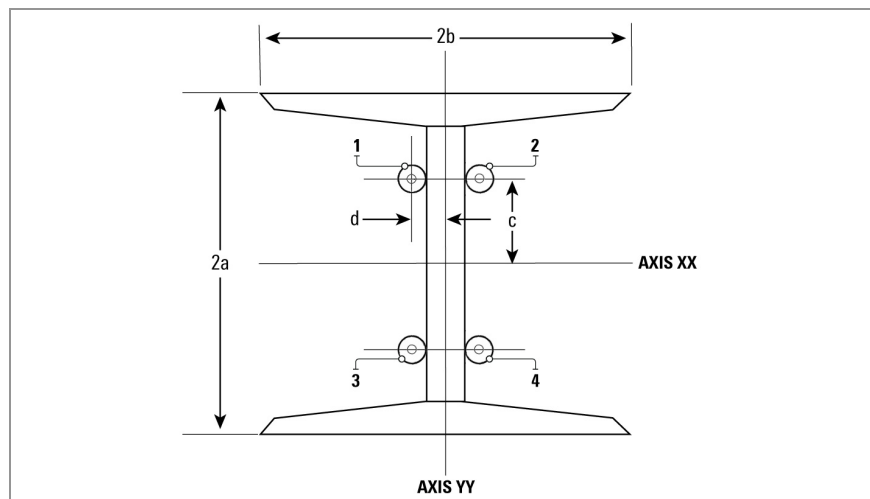


FIGURE 20: Strain Gauges Mounted on Central Web

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.

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

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 around Axis YY is given by:

$$\sigma_{\text{yy}} = \frac{(\varepsilon_1 + \varepsilon_3) - (\varepsilon_2 + \varepsilon_4)}{2} \times \frac{b}{d} \times E$$

EQUATION 2: Stress Due to Bending on Axis YY

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

$$\sigma_{\text{xx}} = \frac{(\varepsilon_1 + \varepsilon_2) - (\varepsilon_3 + \varepsilon_4)}{2} \times \frac{a}{c} \times E$$

EQUATION 3: Stress Due to Bending on Axis XX

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

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.

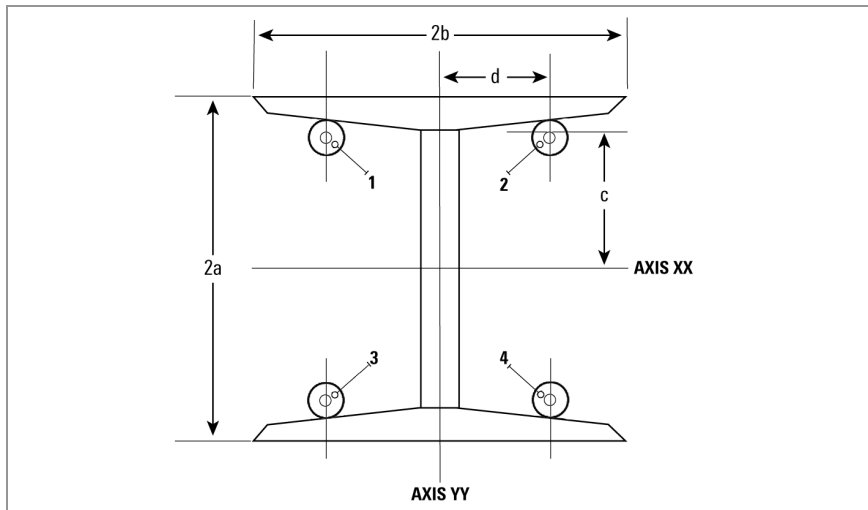


FIGURE 21: Strain Gauges Mounted on Flanges

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**.

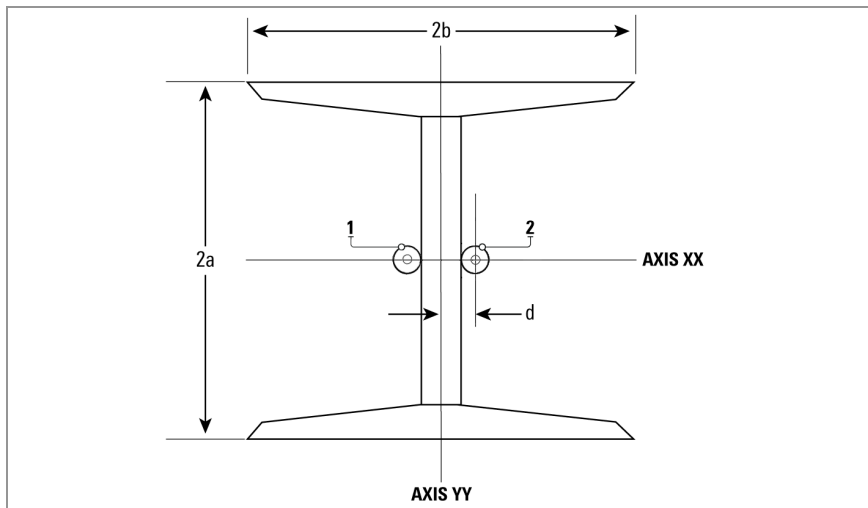


FIGURE 22: Axial Strain Measurement/Bending Moment About YY Axis

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 23.

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.

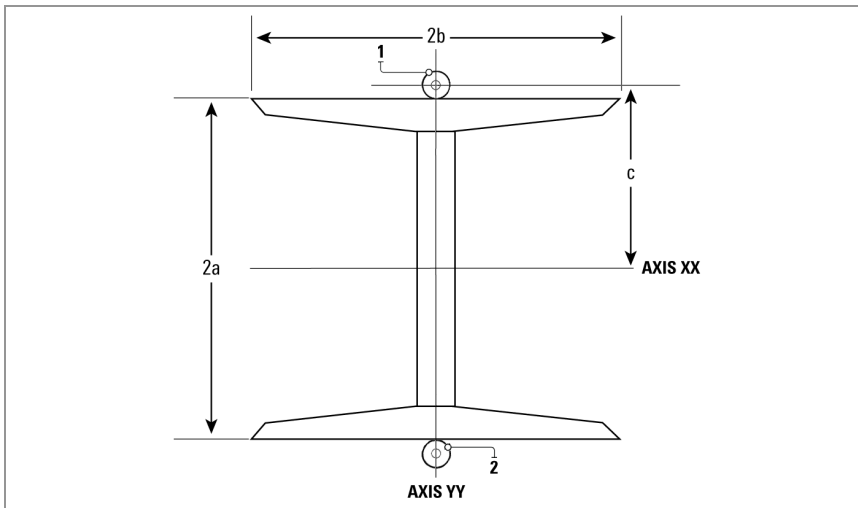


FIGURE 23: Axial Strain and Bending Moment About XX Axis

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.**

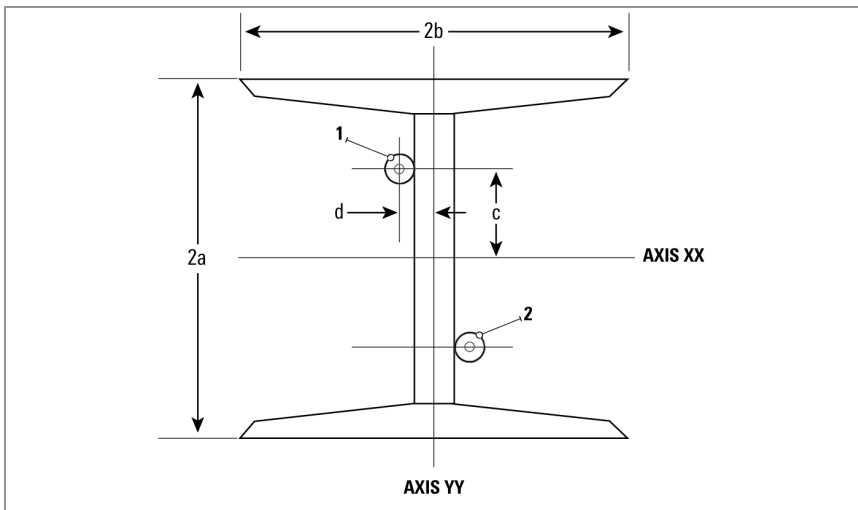


FIGURE 24: Axial Strain and Bending Moment About Axis XX (NOT RECOMMENDED)

6. TAKING READINGS

6.1 STRAIN GAUGE READOUT POSITIONS

| Model | 4100 / 4150 (Standard Range) | 4100-8 / 4150-4 (5,000 Microstrain) | 4100-9 / 4150-5 (10,000 Microstrain) |
|-------------------|---------------------------------|--|---|
| Readout Position | E | B | B |
| Display Units | microstrain ($\mu\epsilon$) | digits | digits |
| Frequency Range | 1400-3500 Hz | 1400-3500 Hz | 1400-3500 Hz |
| Mid-Range Reading | 2500 $\mu\epsilon$ | 6500 | 6000 |
| Minimum Reading | 1000 $\mu\epsilon$ | 3500 | 2500 |
| Maximum Reading | 4000 $\mu\epsilon$ | 9500 | 10,000 |

TABLE 2: Strain Gauge Readout Positions

Note: When reading the 4150, the reading may continue to change slightly due to a coil heating effect. Record the reading within the first few seconds of exciting the gauge.

6.2 GK-404 VIBRATING WIRE READOUT

The Model GK-404 VW Readout is a portable, low-power, hand-held unit that is capable of running for more than 20 hours continuously on two AA batteries. It is designed for the readout of all GEOKON vibrating wire instruments, and is capable of displaying the reading in digits, frequency (Hz), period (μs), or microstrain ($\mu\epsilon$). The GK-404 also displays the temperature of the transducer (embedded thermistor) with a resolution of 0.1 °C.



FIGURE 25: GK-404 Readout



FIGURE 26: Lemo Connector to GK-404

6.2.1 OPERATING THE GK-404

1. Attach the flying leads by aligning the red circle on the silver Lemo connector with the red line on the top of the GK-404 (see Figure 26). Insert the Lemo connector into the GK-404 until it locks into place.
2. Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).
3. To turn on the GK-404, press the **On/Off** button on the front panel of the unit. The initial startup screen will display.
4. After a delay, the GK-404 will start taking readings and display them based on the settings of the **Pos** and **Mode** buttons.

The unit display (from left to right) is as follows:

- The current position: set by the **Pos** button, displayed as A through F.

- The current reading: set by the **Mode** button, displayed as a numeric value followed by the unit of measure.
- Temperature reading of the attached instrument in degrees Celsius.

Use the **Pos** and **Mode** buttons to select the correct position and display units for the model of equipment purchased.

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

For more information, consult the GK-404 manual.

6.3 GK-405 VIBRATING WIRE READOUT

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

- The Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout application.
- The GK-405 Remote Module, which is housed in a weather-proof enclosure.

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

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

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.



FIGURE 27: GK-405 Readout

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

6.3.2 CONNECTING SENSORS WITH BARE LEADS

Attach the flying leads to the bare leads of a GEOKON vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

6.3.3 OPERATING THE GK-405

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

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

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

Set the Display mode to the correct letter required by your equipment.

For more information, consult the GK-405 Instruction Manual.

6.4 MEASURING TEMPERATURES

All GEOKON vibrating wire instruments are equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. The white and green leads of the instrument cable are normally connected to the internal thermistor.

The GK-404 and GK-405 readouts will read the thermistor and display the temperature in degrees Celsius.

TO READ TEMPERATURES USING AN OHMMETER:

1. Connect an ohmmeter to the green and white thermistor leads coming from the instrument. Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant. For long cables a correction can be applied equal to approximately 48.5Ω per km (14.7Ω per 1000') at 20 °C. Multiply these factors by two to account for both directions.
2. Look up the temperature for the measured resistance in Appendix C.

7. DATA REDUCTION

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

$$\mu\epsilon_{\text{theory}} = 0.391 (f^2 \times 10^{-3})$$

EQUATION 5: Theoretical Microstrain

Where $\mu\epsilon$ 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.

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

EQUATION 6: Strain Calculation

Where R_0 is the initial reading on position E 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.

Stresses are computed by multiplying the measured strain by the Young's modulus for steel, which varies between 190 to 206 Gpa, (28 to 30 x 106 psi). Loads are computed by multiplying the stress by the cross-sectional area of the steel member.

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.

8. TROUBLESHOOTING

Maintenance and troubleshooting is confined to periodic checks of cable connections and maintenance of terminals. Once installed, these instruments 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. **Instruments should not be opened in the field.** For additional troubleshooting and support, contact GEOKON.

SYMPTOM: THERMISTOR RESISTANCE IS TOO HIGH

- Check for an open circuit. Check all connections, terminals, and plugs. If a cut is located in the cable, splice according to instructions in Section 3.1.

SYMPTOM: THERMISTOR RESISTANCE IS TOO LOW

- Check for a short circuit. Check all connections, terminals, and plugs. If a short is located in the cable, splice according to instructions in Section 3.1.
- Water may have penetrated the interior of the instrument. There is no remedial action.

SYMPTOM: INSTRUMENT 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 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. Connect the shield drain wire to the readout using the blue clip.
- Does the readout or datalogger work with another instrument? If not, it may have a low battery or possibly be malfunctioning.

SYMPTOM: INSTRUMENT FAILS TO READ

- Does the readout or datalogger work with another instrument? 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; resistance is approximately 48.5Ω per km (14.7Ω per 1000') of 22 AWG wire.

If the resistance is very high or infinite, the cable is probably broken. If the resistance is very low, the conductors may be shorted. If a break or a short is present, splice according to the instructions in Section 3.1.

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

Vibrating Wire Sensor Lead Resistance Levels

Red/Black $\cong 180\Omega$ ($\cong 50\Omega$ for Model 4150)

Green/White 3000Ω at 25 °C

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

APPENDIX A. SPECIFICATIONS

A.1 VIBRATING WIRE STRAIN GAUGE

| Model | Model 4100 | Model 4150/4151 | Model 4150-5 |
|-------------------------------|-------------------------------------|-----------------|----------------------|
| Range (nominal) | 3000 $\mu\epsilon$ | | 10,000 $\mu\epsilon$ |
| Resolution ¹ | 0.4 $\mu\epsilon$ | | 1.3 $\mu\epsilon$ |
| Accuracy ² | 0.5% FS | | 0.5% FS |
| Stability | 0.1% FS / yr | | 0.1% FS/yr |
| Linearity | $\pm 2.0\%$ FSR | | $\pm 7.5\%$ FSR |
| Thermal Coefficient | 12.2 $\mu\epsilon / ^\circ\text{C}$ | | See Appendix G |
| Freq. Range | 1400 – 3500 Hz | | |
| Dimensions (gauge) (L x D) | 57.2 x 6.4 mm (2.25 x 0.25") | | |
| Dimensions (coil) (L x W x H) | 76.2 x 22.2 x 12.7 mm | 19.1 x 6.4 mm | 19.1 x 6.4 mm |
| | 3.000 x 0.875 x 0.500" | 0.750 x 0.250" | 0.750 x 0.250" |
| Coil Resistance | 180 Ω | 50 Ω | 50 Ω |
| Temp. Range | -20 to +80 $^\circ\text{C}$ | | |

| Model | Model 4100-8 | Model 4150-4 | Model 4100-9 |
|-------------------------------|------------------------------|----------------|------------------------|
| Range (nominal) | 5000 $\mu\epsilon$ | | 10,000 $\mu\epsilon$ |
| Freq. Range | 1400 – 3500 Hz | | |
| Dimensions (gauge) (L x D) | 57.2 x 6.4 mm (2.25 x 0.25") | | |
| Dimensions (coil) (L x W x H) | 76.2 x 22.2 x 12.7 mm | 19.1 x 6.4 mm | 76.2 x 22.2 x 12.7 mm |
| | 3.000 x 0.875 x 0.500" | 0.750 x 0.250" | 3.000 x 0.875 x 0.500" |
| Coil Resistance | 180 Ω | 50 Ω | 180 Ω |
| Temp. Range | -20 to +80 $^\circ\text{C}$ | | |

TABLE 3: Specifications

Notes:

¹ Resolution depends on the readout; figures shown here pertain to the GK-404.

² 0.1% FS with individual calibration

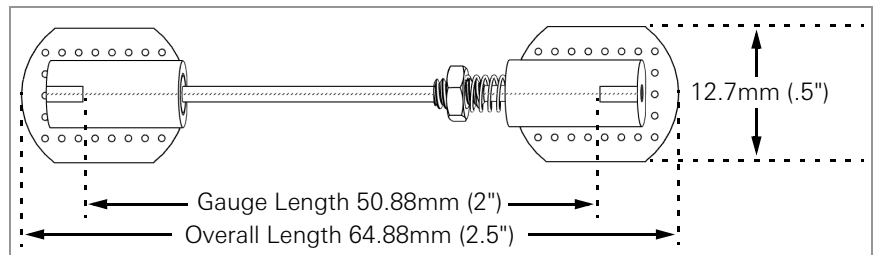


FIGURE 28: Gauge Assembly Dimensions

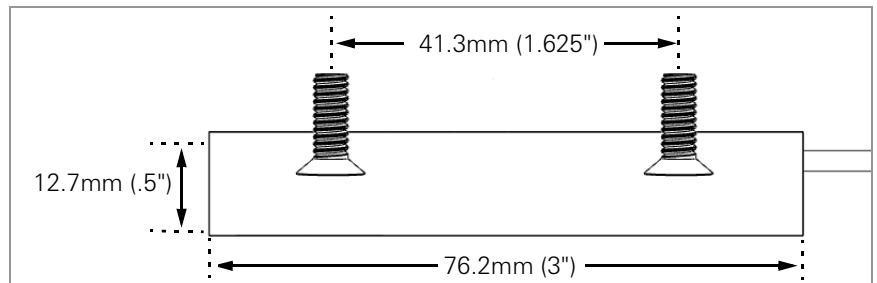


FIGURE 29: Cover Assembly Dimensions

A.2 THERMISTOR

See Appendix C for more information.

Range: -80 to +150 $^\circ\text{C}$

Accuracy: ± 0.5 $^\circ\text{C}$

APPENDIX B. THEORY OF OPERATION

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

THE 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, seconds²/inches²).

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/seconds²).

3. And:

$$W = \rho a L_w$$

Where:

ρ is the wire material density (0.283 pounds/inches³).

a is the cross-sectional area of the wire in inches².

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.,

$$F = \epsilon_w E a$$

Where:

ϵ_w is the wire strain (inches/inches).

E is the Young's modulus of the wire (30×10^6 Psi).

6. Combining the equations from steps four and five gives:

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

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

$$f = \frac{101142}{L_W} \sqrt{\epsilon_W}$$

8. In position A, (which displays the period of vibration, T) multiplied by a factor of 10⁶:

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

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

$$\epsilon_W = \frac{97.75 L_W^2}{T^2}$$

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:

$$\epsilon_W L_W = \epsilon L_g$$

Where:

ε is the strain in the body.

L_g is the gauge length in inches.

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

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

Where: (for the 4100/4150 strain gauge)

L_w is 2.000 inches

L_g is 2.000 inches

12. Therefore:

$$\epsilon = 0.391 \times 10^3 \left[\frac{1}{T^2} \right]$$

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

$$\epsilon = 4.062 \times 10^9 \left[\frac{1}{T^2} \right]$$

The squaring, inverting, and multiplication by the factor 0.391 × 10⁹ is all done internally by the microprocessor of the readout, so that the displayed reading in position C is given in microinches per inch (ε).

Note: In the previous two steps, T is in seconds × 10⁶ and ε is in microinches per inch.

Alternatively:

ε = 0.391 × 10⁻³ f² micro strain, where f is the frequency in Hz.

APPENDIX C. THERMISTOR TEMPERATURE DERIVATION

C.1 3KΩ THERMISTOR RESISTANCE

Thermistor Types:

- YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3
- Honeywell 192-302LET-A01

Resistance to Temperature Equation:

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

EQUATION 7: 3kΩ Thermistor Resistance

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

A = 1.4051 x 10⁻³

B = 2.369 x 10⁻⁴

C = 1.019 x 10⁻⁷

Note: Coefficients calculated over the -50 to +150 °C span.

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

TABLE 4: 3KΩ Thermistor Resistance

C.2 10KΩ THERMISTOR RESISTANCE

Thermistor Type: US Sensor 103JL1A

Resistance to Temperature Equation:

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

EQUATION 8: 10KΩ Thermistor Resistance

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

A = 1.127670 × 10⁻³

B = 2.344442 × 10⁻⁴

C = 8.476921 × 10⁻⁸

D = 1.175122 × 10⁻¹¹

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

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

TABLE 5: 10KΩ Thermistor Resistance

APPENDIX D. 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:

$$\mu\epsilon_{\text{thermal}} = (T_1 - T_0) \times CF_2$$

EQUATION 9: 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:

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

EQUATION 10: 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:

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

EQUATION 11: 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

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

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

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

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

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 $(R_1 - R_0) \times B = -91$ microstrain. If the strain in the concrete had not changed, the steel vibrating wire would have expanded and gone slack by the equivalent of $(30 - 20) \times 12.2 = -12.2$ microstrain, therefore the concrete must have actually expanded by +31 microstrain to account for the observed apparent strain. The concrete should have expanded by $(30 - 20) \times 10.4 = +104$ 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 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 yields an empirical correction factor, CF_{emp} microstrain/degree. This empirical correction factor can be applied to the total strain and temperature data to remove the temperature-induced stresses leaving only those stresses produced by changing external loads, i.e.

$$\text{External Load Stress} = [(R_1 - R_0)B + (T_1 - T_0)CF_{emp}] \times E$$

EQUATION 12: *External Load Stress Only*

Note that the correction factor, CF_{emp} 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 in order to calculate a new temperature correction factor.

In a free field, where no loads are acting and the steel is free to expand or contract without restraint, then R_1 would equal R_0 and the thermal strains in the steel are given by the following equation:

$$\mu\epsilon_{thermal} = (T_1 - T_0) \times CF_1$$

EQUATION 13: *Free Field Thermal Strains*

Where CF_1 is the coefficient of expansion of steel = +12.2 microstrains/ C.

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:

$$\mu\epsilon_{actual} = (R_1 - R_0) \times B + (T_1 - T_0) \times CF_1$$

EQUATION 14: *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 $\mu\epsilon_{actual}$ would be zero.

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

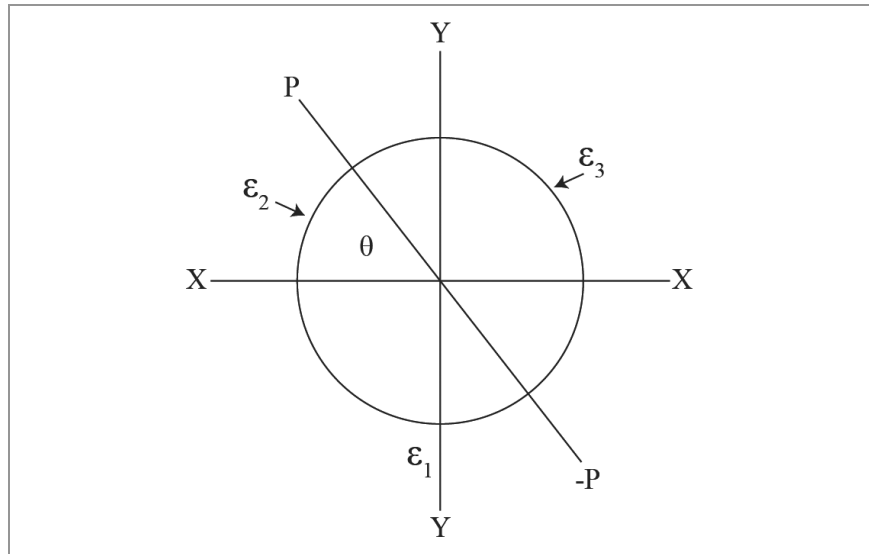


FIGURE 30: Three Strain Gauges Mounted on a Circular Pipe Diagram

$$A = (\epsilon_1 + \epsilon_2 + \epsilon_3) / 3$$

EQUATION 15: Average Axial Strain

$$(Y) = \pm [((\epsilon_1 + \epsilon_2 + \epsilon_3) / 3) - \epsilon_1]$$

EQUATION 16: Maximum Bending Strain Around the YY Axis

$$(X) = \pm [(\epsilon_2 - \epsilon_3) / 1.732]$$

EQUATION 17: Maximum Bending Strain Around the XX Axis

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

EQUATION 18: Maximum Strain

Example:

Let $\epsilon_1 = 20$, $\epsilon_2 = 192$ and $\epsilon_3 = 88$ (all tensile strains)

Average Axial Strain, $A = (20 + 192 + 88) / 3 = 100$ microstrains, tension

$X = \pm (104 / 1.732) = \pm 60$

$Y = \pm (300 / 3 - 20) = \pm 80$

$\tan \theta = 80 / 60 = 1.333$ 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 G. MODEL 4150-5 EXTENDED RANGE STRAIN GAUGE

The Model 4150-5 strain gauge, a modified version of the 4150 gauge, features a range of 10,000 microstrains. Note the following when using the 4150-5:

- The gauge is installed in the same manner as the standard 4150 gauge; however, the position within the range should be set by the user, using the calibration report for each gauge as a guide.
- Push or pull gently on the gauge before spot welding the second tab.
- For maximum accuracy, use polynomial data reduction equations.
- 4150-5 gauges are individually calibrated due to the technique used to obtain the required range.
- The thermal coefficient of the gauge is also different from the standard gauge, in that it varies throughout the range of readings. Use the instructions below to make corrections for temperature effects:

WHEN USING THE LINEAR EQUATION:

$$\text{Strain} = G[R_1 - R_0] - K_t(T_1 - T_0)$$

EQUATION 19: Model 4150-5 Temperature Effects

Where:

$$K = (M \cdot R_1 + B)$$

M is 0.0002205

$$B = -0.03886$$

G is the linear gauge factor = 1.0296 microstrain/digit (position B)

R₁ is the current reading

R₀ is the initial reading

T₁ is the temperature of R₁

T₀ is the temperature of R₀

For example:

If:

$$R_1 = 6682$$

$$R_0 = 6596$$

$$T_1 = 30.13\text{C}$$

$$T_0 = 20.09\text{C}$$

$$K = [(0.0002205 \cdot 6682) - 0.03886] = 1.4345$$

Then, after temperature correction;

$$\text{Strain} = 1.0296[(6682 - 6596) + 1.4345(30.13 - 20.09)] = +103 \text{ microstrains.}$$

WHEN USING THE POLYNOMIAL EQUATION:

The value of R₁ for temperature must be corrected before using the polynomial equation.

$$\text{Using the same example as above, the correction to } R_1 \text{ is } K(T_1 - T_0) = 1.4345(10.04) = +14.4.$$

Therefore, if the current value of R₁ is 6682, the value (corrected for temperature) which must be entered into the polynomial equation is 6682 + 14.4 = 6696.4.

APPENDIX H. PARTS LIST

The following table lists components of the Model 4100/4150 series of strain gauges.

| 4100 Part Numbers | Description |
|-------------------|---|
| 4100 | Strain gauge only |
| 4100A-1 | Vibrating Wire Strain gauge, spot weldable type, 2" gauge length, spot weldable shims. Complete with 10'/3 m cable and thermistor. |
| 4100A-2 | Vibrating Wire Strain gauge, spot weldable type, 2" gauge length, spot weldable shims. Cable sold as separate line item. |
| 4100-1 | Plucking coil, with thermistor and mounting straps, varied cable. Cable sold as separate line item. |
| 4100-2 | Plucking coil, with thermistor and mounting straps, 10' cable length |
| 02-187V3-E | Red PVC Cable, 0.187" Ø, 2 twisted pairs, for the above |
| 02-187V3-M | Red PVC Cable, 0.187" Ø, 2 twisted pairs, for the above |
| 4150-3 | Positioning tool |
| 4100-4 | Tension wrenches |
| 4100-5 | Weldable cover plate, 2" channel × 12" long, with mounting bolts |
| 4100-6 | Micro-Measurements Model 700 spot welder for 4100/4150 spot weldable shims. Includes one angled and one straight tip. |
| 4100-7-A | Micro-Measurements Model 700 spot welder electrodes (angled) |
| 4100-7-S | Micro-Measurements Model 700 spot welder electrodes (straight) |
| 4100-8 | VW Strain Gauge, 5,000 microstrain, calibrated, spot weldable type |
| 4100-9 | VW Strain Gauge, 10,000 microstrain, calibrated, spot weldable type |
| 4100-10 | Gauge Protection Kit, comprising of 128 RTV (ADH-124B), Permabond 910 SuperGlue (ADH-104) and Mastic Tape (enough for approximately 25 gauges). MSDS sheets required for all shipments. |
| 4100-10A | Gauge Protection Kit, comprising of 128 RTV (ADH-124B) and Permabond 910 SuperGlue (ADH-104) (enough for approximately 25 gauges). MSDS sheets required for all shipments. |
| 4100-15 | Adhesive Kit. Loctite 410 adhesive (0.70 oz.) and Loctite 712 accelerator (0.70 oz.), sufficient for up to 50 gauges. MSDS Sheet Required. |

| 4150 Part Numbers | Description |
|-------------------|--|
| 4150 | Vibrating Wire Strain gauge, 3,000 microstrain range, with spot weldable shims, integral plucking coil, cover plate and thermistor. Cable sold as separate line item. |
| 4150-4 | Vibrating Wire Strain gauge, 5,000 microstrain range, with spot weldable shims, integral plucking coil and cover plate. Includes thermistor and individual calibration. Cable sold as separate line item. |
| 4150-5 | Vibrating Wire Strain gauge, 10,000 microstrain range, with spot weldable shims, integral plucking coil and cover plate. Includes thermistor and individual calibration. Cable sold as separate line item. |
| 4150-1 | Extra cover plate with welding straps |
| 02-187V3-E | Red PVC Cable, 0.187" Ø, 2 twisted pairs, for the above |
| 02-187V3-M | Red PVC Cable, 0.187" Ø, 2 twisted pairs, for the above |
| 4150-3 | Positioning tool |
| 4150A | Vibrating Wire Strain gauge, 3,000 microstrain range without spot weldable shims, with integral plucking coil, and thermistor. Cable sold as separate line item. |
| 4150A-4 | Vibrating Wire Strain gauge, 5,000 microstrain range, without spot weldable shims, with integral plucking coil. Includes thermistor and individual calibration. Cable sold as separate line item. |
| 4150A-5 | Vibrating Wire Strain gauge, 10,000 microstrain range, without spot weldable shims, with integral plucking coil. Includes thermistor and individual calibration. Cable sold as separate line item. |
| 4150A-1 | End blocks for 4150A series gauges. (add 4150A-2 Cover Plate and 4150A-3 Spacer Bar if required). |
| 4150A-2 | Protective Cover Plate with welding straps, for use over 4150A-1 End Blocks |
| 4150A-3 | Spacer Bar, for use with 4150A-1 End Blocks |

| 4151 Part Numbers | Description |
|-------------------|---|
| 4151 | Vibrating Wire Surface Mount Strain gauge, 3,000 microstrain range, with integral plucking coil, end blocks with pins for grouting, cover plate and thermistor. Cable sold as separate line item. |
| 4151-1 | As above, but with 5,000 microstrain range. Includes individual calibration. |
| 4151-2 | As above, but with 10,000 microstrain range. Includes individual calibration. |
| 02-187V3-E | Red PVC Cable, 0.187" Ø, 2 twisted pairs, for the above |
| 02-187V3-M | Red PVC Cable, 0.187" Ø, 2 twisted pairs, for the above |
| 4151-3 | Drilling Template for 4151 |

TABLE 6: Model 4100/4150 Series Model and Parts List

GEOKON®

GEOKON
48 Spencer Street
Lebanon, New Hampshire
03766, USA

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

GEOKON
is an **ISO 9001:2015**
registered company