48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603·448·1562
Fax: 603·448·3216
Email: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Model 1250

A-5 Borehole Extensometer

(Rev. H 06/19/19)

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TABLE of CONTENTS

FIGURES

TABLES

EQUATIONS

1. INTRODUCTION

Borehole extensometers, as the name implies, are used primarily for measuring extensions associated with rock failures brought about by strata separations, joint openings, shearing, and cracking. A series of borehole anchors (eight maximum), installed at different depths, each with a measurement rod attached leading to the surface, enables the amount of movement in each inter-anchor zone to be measured.

The Model A-5 Multiple Position Borehole Extensometer, (MPBX), is made up of three to four basic components:

1) Hydraulic Borehole Anchors:

There are two types of Hydraulic Borehole Anchors: The Bladder type, designed for all kinds of rock materials, and the Borros type, which is used in soft ground only. The Bladder type anchor can be used in all kinds of harder rock material, whereas, the Borros type anchor is for soft ground only. Bladder type hydraulic anchors are particularly suited for use in upward directed boreholes. Usually the number of anchors lies between one and six.

2) Connecting rods and tubing:

The standard connecting rod is made from 1/4-inch stainless steel encased in rigid, 1/4 inch schedule 40, PVC pipe. The sections of stainless steel rod are flush coupled to form a continuous string. Fiberglass rods may also be used, but their lower modulus may lead to lower precision in applications where high resolution, (< 0.1 mm), is required. Graphite rods, which have a very low thermal coefficient, are available for high temperature applications and for applications where thermal effects on the rods must be minimized. Tell-tales, or rods extending below the bottom anchor are sometimes used in tunnel applications. When installed ahead of the tunnel face, the tell-tale is designed to be exposed during the tunneling operation so that the position of the bottom anchor relative to the roof of the tunnel can be accurately determined.

3) Extensometer head assembly:

Various styles of head assemblies are available. The head usually has its own hydraulic anchor, which may be designed for recessing into an enlarged section of the borehole or it may have a flange for mounting to a standpipe grouted into the mouth of the borehole. Provision may be made for manual or electronic readout or for both. Manual readout is by a 50 mm, or two-inch, range dial indicator.

Electronic displacement transducers (optional):

The standard transducer is the model 4450 vibrating wire displacement transducer with ranges of 25, 50, or 100 mm. Linear potentiometers are also available.

2. PRELIMINARY REQUIREMENTS

2.1 Borehole Requirements

The Model A-5 is designed to fit 75 mm (3 inch) or larger diameter boreholes. The mouth of the borehole may be cased with a two-and-a-half-inch standpipe or enlarged to take a three or three-and-a-half-inch standpipe, or it may be left free. Boreholes should be free of debris and drilled slightly longer (60 cm /2 ft.) than the deepest anchor.

2.2 Anchor Spacing

Anchor spacing is sometimes dictated by geologic features and by the size and geometry of the rock mass being monitored. Drill cores can be inspected to reveal zones and planes of weakness, which would suggest appropriate anchor locations. At least one anchor, usually the deepest anchor, should be installed in stable ground so that it can serve as a nonmoving point of reference for the rest of the anchors. For extensometers installed in tunnels the deepest anchor should be located at least one tunnel diameter, and preferably nearer two tunnel diameters, away from the tunnel opening.

2.3 Instrument Head Protection

The instrument head should be protected from damage. This may require recessing the instrument head inside the borehole to avoid blasting damage or, in exposed locations, the construction of a protective enclosure to ward against falling objects, moving equipment and vandalism.

MPBX heads installed downwards from street level are best contained within manholes with access covers. The manhole should be large enough to accommodate the instrument head and any datalogger that may be in use. The minimum size of manhole is 300 mm (12 inch). A better size is 550 mm (22 inch) diameter. Covers may be equipped with a locking device. The manhole should be provided with a drain so that it cannot become filled with rainwater.

Heads may be equipped with a flange to engage the flange on top of any standpipe grouted into the mouth of the borehole. This arrangement works well with Borros type hydraulic anchors. Where Bladder type hydraulic anchors are in use, the instrument head comes equipped with its own hydraulic anchor, so standpipes and flanges are not always required.

2.4 Swagelok Tube Fitting Instructions

These instructions apply to one inch (25 mm) and smaller fittings.

2.4.1 Installation

1) Fully insert the tube into the fitting until it bumps against the shoulder.

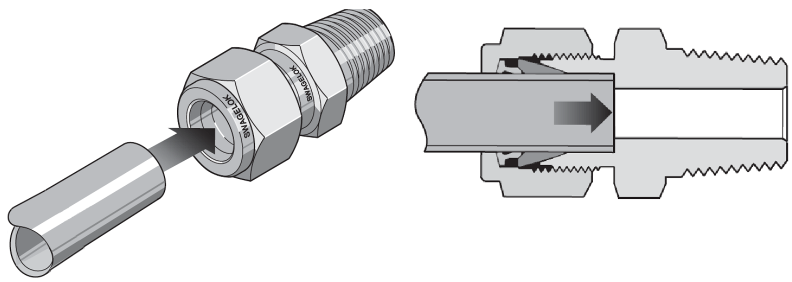

Figure 1 - Tube Insertion

2) Rotate the nut until it is finger-tight. (For high-pressure applications as well as high-safety-factor systems, further tighten the nut until the tube will not turn by hand or move axially in the fitting.)

3) Mark the nut at the six o'clock position.

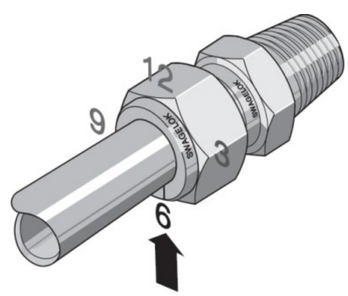

Figure 2 - Make a Mark at Six O'clock

4) While holding the fitting body steady, tighten the nut one and one-quarter turns until the mark is at the nine o'clock position. (Note: For 1/16", 1/8", 3/16", and 2, 3, and 4 mm fittings, tighten the nut three-quarters of a turn until the mark is at the three o'clock position.)

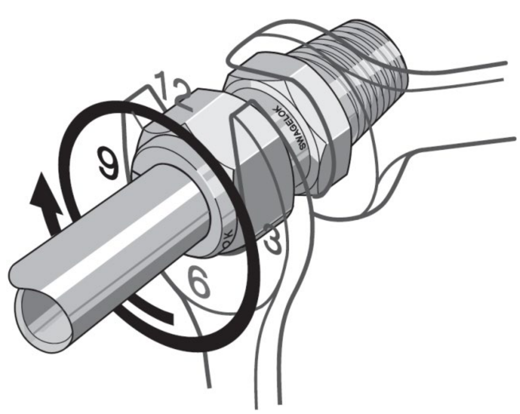

Figure 3 - Tighten One and One-Quarter Turns

2.4.2 Reassembly Instructions

Swagelok tube fittings may be disassembled and reassembled many times.
Warning: Always depressurize the system before disassembling a Swagelok tube fitting.

1) Prior to disassembly, mark the tube at the back of the nut, then make a line along the nut and fitting body flats. *These marks will be used during reassembly to ensure the nut is returned to its current position.*

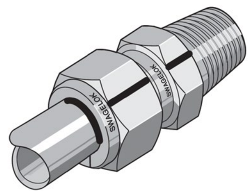

Figure 4 - Marks for Reassembly

2) Disassemble the fitting.

3) Inspect the ferrules for damage and replace if necessary. **If the ferrules are replaced the connector should be treated as a new assembly. Refer to the section above for installation instructions.**

4) Reassemble the fitting by inserting the tube with preswaged ferrules into the fitting until the front ferrule seats against the fitting body.

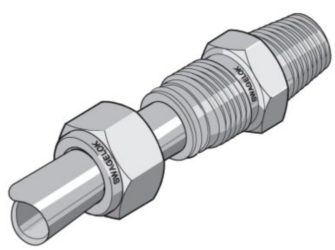

Figure 5 - Ferrules Seated Against Fitting Body

5) While holding the fitting body steady, rotate the nut with a wrench to the previous position as indicated by the marks on the tube and the connector. At this point, there will be a significant increase in resistance.

6) Tighten the nut slightly.

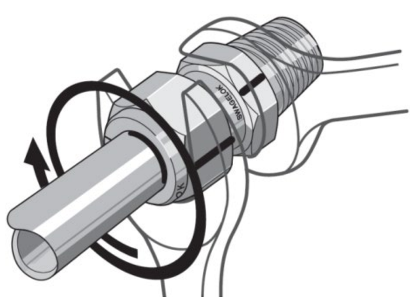

Figure 6 - Tighten Nut Slightly

2.5 List of Installation Tools Required

Note: Installation Tool kits may be purchased as an accessory. They may include the following:

1. Two pair of Vise Grips
2. Adjustable wrenches
3. Screw Drivers
4. Allen Wrenches
5. Hacksaw
6. Files
7. Tape measure
8. Marking Pens
9. Loctite adhesive
10. PVC Cement
11. PVC Primer
12. Hydraulic hand pump with pressure gauge and fittings
13. Sharp Knife
14. Tape (Filament)
15. Tape (Duct)
16. Spare parts –Swagelok Connectors and spare ferrules, O-rings, setscrews, bolts, screws, etc. (Normally shipped with the extensometer parts.)

3. MANUAL READ OUT INSTALLATION

3.1 Bladder Type Anchors in Open Boreholes

A typical system is shown in Figure 7.

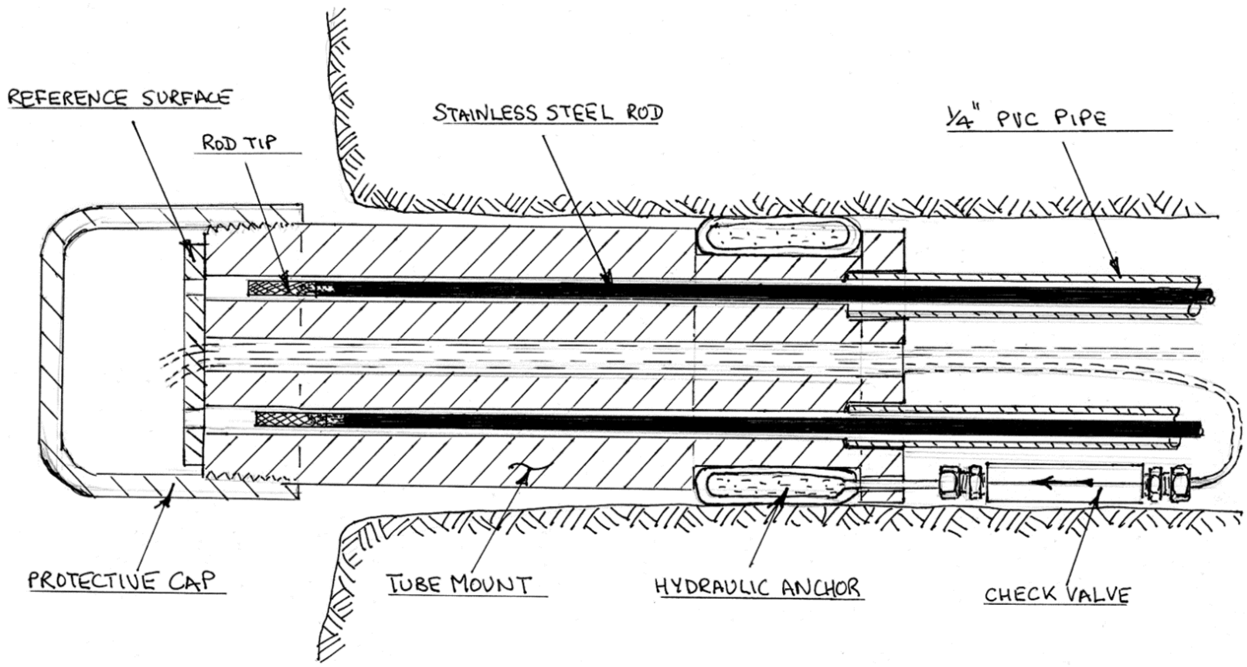

Figure 7 - Typical A-5 Extensometer

1) A standpipe, made from steel or PVC pipe, is not usually required except where the mouth of the borehole is fractured, oversize, or irregular. If a standpipe is needed to stabilize the borehole collar, then the mouth of the borehole may have to be enlarged so that standpipe used can have at least the same I.D. as the rest of the borehole. Apply quick-setting cement on the outside of the standpipe and insert into the borehole to the desired depth. Hold in place until the cement hardens, using wooden wedges or sackcloth soaked in quick-setting cement, as required.

2) When the various anchor depths have been determined, the assembly of the rod/tube strings is performed on an unobstructed surface. Join the correct lengths of measurement rod using a pair of vise-grips and Loctite on all the threads. Thread the end with the female connector into the anchor and the rod tip onto the other end.

3) Slide the 1/4-inch PVC pipe over the rods and couple them together using the PVC Pipe Couplers provided. When doing this be careful not to put too much PVC cement inside the coupler – the best technique is to put very little glue inside the coupler and plenty on the outside of the pipe. In this way, there is no danger of pushing cement into the inside of the pipe where it can set up and grip the rods. Allow enough time for the cement to harden. In cold weather, it may be advisable to warm the connector with a propane torch.

4) The final section of PVC is to be cemented in the appropriate hole in the Tube Mount. Note that the Tube Mount is numbered, the shallowest anchor is Anchor #1, and the anchor with the highest number will be deepest in the hole. Before the final section of PVC pipe is connected, it must be trimmed to its correct length using a hacksaw. The correct length is that which places the rod tip in the correct position relative to the Reference Surface. For anticipated extensions of the borehole, the rod tip should be positioned 10 mm (1/2 inch) below the reference surface. (Note: If the borehole is in unstable ground, and is cased, then the casing must be pulled while the anchor strings are inside the borehole. If this is the case, then the Tube Mount must be installed only after the casing has been pulled.)

5) When all the rod/pipe assemblies have been glued to the Tube Mount, (and the Tube Mount Flange, if used, has been cemented to the Tube Mount), use nylon filament tape to bundle the various rod/pipe assemblies together. Start at the head and tape every two meters. Tape near but not directly on top of the anchors.

6) Push the MPBX into the borehole until the hydraulic anchor on the head assembly is well inside the borehole, (or inside the standpipe if one is used), be careful not to bend the MPBX in too tight a radius (not less than two meters).

7) The hydraulic bladder anchors are expanded beginning with the deepest anchor. If the end of the hydraulic tubing is plugged by a nail, cut off about 20 mm of the tubing and attach one of the 1/8-inch Swagelok tube fittings. Tighten the Swagelok fittings according to the instructions in Section 2.4. Do not overtighten the Swagelok as this may pinch the tube shut. If the end of the tube is already sealed by a Swagelok tube fitting, remove the cap. Connect the hydraulic line to the hand pump filled with hydraulic oil and inflate the cells. Watch the pressure gauge while pumping and be sure never to exceed a pressure of 17 MPa (2500 psi). More pressure than this can burst the tubing. Continue pumping until the anchor pressure holds steady at about 9 MPa (1300 psi). Disconnect the hydraulic pump – the check valve at the anchor will maintain the anchor pressure. (Note: tests have shown that the anchor will continue to hold even if the anchor pressure drops to zero).

8) Repeat this process for the rest of the anchors, in descending numerical order, and for the anchor on the MPBX Head.

9) Take initial readings with the dial indicator and record. Screw on the Protective Pipe Cap to protect the Reference Surface.

3.2 Bladder Type Anchors in Grouted Boreholes

Occasionally it may be necessary to seal the borehole with a Bentonite grout. These instructions cover this eventuality.

1) A standpipe, made from steel or PVC pipe, is not usually required except where the mouth of the borehole is fractured, oversize, or irregular. If a standpipe is needed to stabilize the borehole collar, then the mouth of the borehole may have to be enlarged so that standpipe used can have at least the same I.D. as the rest of the borehole. Apply quick-setting cement on the outside of the standpipe and insert into the borehole to the desired depth. Hold in place until the cement hardens, using wooden wedges or sackcloth soaked in quick-setting cement, as required.

2) When the various anchor depths have been determined, the assembly of the rod/tube strings is performed on an unobstructed surface. Join the correct lengths of measurement rod using a pair of vise-grips and Loctite on all the threads. Thread the end with the female connector into the anchor and the rod tip onto the other end.

3) Slide the 1/4-inch PVC pipe over the rods and couple them together using the PVC Pipe Couplers provided. When doing this be careful not to put too much PVC cement inside the coupler – the best technique is to put very little glue inside the coupler and plenty on the outside of the pipe. In this way, there is no danger of pushing cement into the inside of the pipe where it can set up and grip the rods. Allow enough time for the cement to harden. In cold weather, it may be advisable to warm the connector with a propane torch.

4) The final section of PVC is to be cemented in the appropriate hole in the Tube Mount. Note that the Tube Mount is numbered, the shallowest anchor is Anchor #1, and the anchor with the highest number will be deepest in the hole. Before the final section of PVC pipe is connected, it must be trimmed to its correct length using a hacksaw. The correct length is that which places the rod tip in the correct position relative to the Reference Surface. For anticipated extensions of the borehole, the rod tip should be positioned 10 mm (1/2 inch) below the reference surface. (Note: If the borehole is in unstable ground, and is cased, then the casing must be pulled while the anchor strings are inside the borehole. If this is the case, then the Tube Mount must be installed only after the casing has been pulled.

5) When all the rod/pipe assemblies have been glued to the Tube Mount, (and the Tube Mount Flange, if used, has been cemented to the Tube Mount), use nylon filament tape to bundle the various rod/pipe assemblies together. Start at the head and tape every two meters. Tape near but not directly on top of the anchors.

6) Thread the grout tube through the hole in the Tube Mount and through the hole in each of the bladder anchors. Cut two or three notches in the side of the grout tube near its bottom end then attach the end of the grout tube to the deepest anchor only, using masking tape, so that the end of the grout tube protrudes a short distance (about 30 cm) beyond the anchor. Do not tape the grout tube to the rest of the bundle.

7) Push the MPBX into the borehole until the hydraulic anchor on the head assembly is well inside the borehole, (or inside the standpipe if one is used), be careful not to bend the MPBX in too tight a radius (not less than two meters).

8) The hydraulic bladder anchors are expanded beginning with the deepest anchor. If the end of the hydraulic tubing is plugged by a nail, cut off about 20 mm of the tubing and attach one of the 1/8-inch Swagelok tube fittings. Tighten the Swagelok fittings according to the instructions in Section 2.4. Do not overtighten the Swagelok as this may pinch the tube shut. If the end of the tube is already sealed by a Swagelok tube fitting, remove the cap. Connect the hydraulic line to the hand pump filled with hydraulic oil and inflate the cells. Watch the pressure gauge while pumping and be sure never to exceed a pressure of 17 MPa (2500 psi). More pressure than this can burst the tubing. Continue pumping until the anchor pressure holds steady at about 9 MPa (1300 psi). Disconnect the hydraulic pump – the check valve at the anchor will maintain the anchor pressure. (Note: tests have shown that the anchor will continue to hold even if the anchor pressure drops to zero).

9) Repeat this process for the rest of the anchors, in descending numerical order, and for the anchor on the MPBX Head.

10) When all the hydraulic anchors have been set, and with the Grout Plate in place on the Tube Mount, connect the 1/2-inch polyethylene grout pipe to a grout pump and pump a little water through the grout line to lubricate it. Mix up a batch of neat cement grout with the consistency of pancake batter. Use Portland Type II cement, with 5 to 10% of Bentonite powder added, mixed with water in approximately one to one mixture. Pump the grout into the borehole while slowly pulling the grout tube from the borehole. If the grout tube is to be used again, flush it now with water.

11) Take initial readings with the dial indicator and record. Screw on the Protective Pipe Cap to protect the Reference Surface.

3.3 Borros Type Anchors

Borros Anchors are reserved for applications in soft ground. Where large compressions or tensions are anticipated it will be necessary to introduce telescoping joints into the PVC Pipe string. (Alternatively, more compressible nylon tubing may be used, in conjunction with fiberglass rods. For installations of this type, consult the Installation Manual for the Model 1280 (A-6) MPBX).

Often the ground is too weak for a borehole to remain open without being cased. Where the hole will stay open, the installation can proceed as described in Section 3.

The following procedure is for cased boreholes. Here it is necessary to install the rod/tube/anchor assemblies before pulling the casing. They can then be attached to the Tube Mount after the casing has been pulled.

1) When the various anchor depths have been determined, the assembly of the rod/tube strings is performed on an unobstructed surface. Join the correct lengths of measurement rod using a pair of vise-grips and Loctite on all the threads. Thread the end with the female connector into the anchor.

2) Slide the 1/4-inch PVC pipe and telescoping sections over the rods and couple them together using the PVC Pipe Couplers provided. When doing this be careful not to put too much PVC cement inside the coupler – the best technique is to put very little glue inside the coupler and plenty on the outside of the pipe. In this way, there is no danger of pushing cement into the inside of the pipe where it can set up and grip the rods. Allow sufficient time for the cement to harden. In cold weather, it may be advisable to warm the connector with a propane torch. Use masking tape to tape the telescoping sections in their correct positions – closed for anticipated extensions or open for anticipated compressions.

3) Before the final section of PVC pipe is connected, it must be trimmed to its correct length using a hacksaw. The correct length is that which places the rod tip in the correct position relative to the Reference Surface. For anticipated extensions, the rod tip should be positioned 10 mm (1/2 inch) below the reference surface.

4) Use nylon filament tape to bundle the various rod/pipe assemblies together. Start at the head end and tape every two meters. Tape the rod/tubes to the Borros anchors in such a way that they do not lie directly over the ports from which the prongs will emerge. If the hole is to be grouted using a Bentonite grout, then the grout tube should be taped to the bottom anchor using masking tape so that it can be broken free at the commencement of grouting.

5) Tie a nylon cord to the rod/tube bundle and use it lower the bundled rod/tubes into the cased borehole. If stainless steel rods are in use be careful not to bend the MPBX in too tight a radius (>2 meters) or the stainless steel rods could be permanently bent. Use as many people as required to support the rod/pipe string along its length. Suspend the bundle rod/tubes in their final position by tying the nylon cord to the top of the drill tower.

6) As the first section of casing is pulled, it is recommended that the deep anchor be actuated. This is done by connecting the hydraulic line to the hydraulic pump and at first SLOWLY applying a pressure of no greater than 17 MPa (2500 psi) to the Borros anchor. Pressures greater than 17 MPa, (2500 psi), can burst the hydraulic tubing. The prongs on the Borros anchor will begin to expand at a pressure of around 5 MPa (700 psi) and will continue to arc out into the soft ground as the pressure is increased. For maximum anchor engagement, the pumping pressure can now be increased until the tubing bursts.

7) As each section of casing is pulled, the nylon cord is untied from the drill mast and the casing section is then threaded over it. The nylon cord is retied back to the mast and casing is pulled until the next anchor position is cleared. This anchor is actuated and then the procedure is repeated for all the other anchors.

8) When the casing has been completely removed from the borehole then the Standpipe, with its flange or coupling attached to the top, can be lowered into the top of the borehole and temporarily wedged in place at a position lower than its final position. The borehole can now be grouted if necessary.

9) Screw the rod tips onto the ends of the measurement rods, if they are not already in place.

10) The ends of the PVC tubes can now be cemented in the appropriate hole in the Tube Mount. Note that the Tube Mount is numbered, the shallowest anchor is Anchor #1, and the anchor with the highest number will be deepest in the hole. (If a flange is being used, then it is important to place it over the rod/tube bundle before the PVC tubes are cemented to the Tube Mount. When all the PVC tubes have been cemented, this flange can be attached to the Tube Mount).

11) When the PVC cement has hardened, the Standpipe is loosened and raised until either the two flanges can be bolted together, or, the Tube Mount can be cemented inside the coupling. The standpipe is now wedged in its final position and quick-setting cement used to cement it into the borehole.

12) Initial readings can now be taken, and the Protective Cap threaded onto the Tube Mount.

4. ELECTRONIC READOUT INSTALLATION

Electronic readout is usually accomplished by means of transducers and a transducer housing that are assembled and bolted to the MPBX head after the initial installation of the anchors and head has been performed. There are many variations and specific and detailed instructions are supplied with each extensometer. The following instructions apply, in a general way only, to the two main standard designs: one that permits electronic readout only and one that permits both electronic and manual readout. These general instructions will serve as an explanation for the more detailed instruction and why they are necessary.

4.1 Electronic Readout Only

A typical MPBX head assembly, designed to accept vibrating wire displacement transducers is shown in Figure 8. This design uses a flanged Standpipe to grip the MPBX Head rather than a hydraulic anchor.

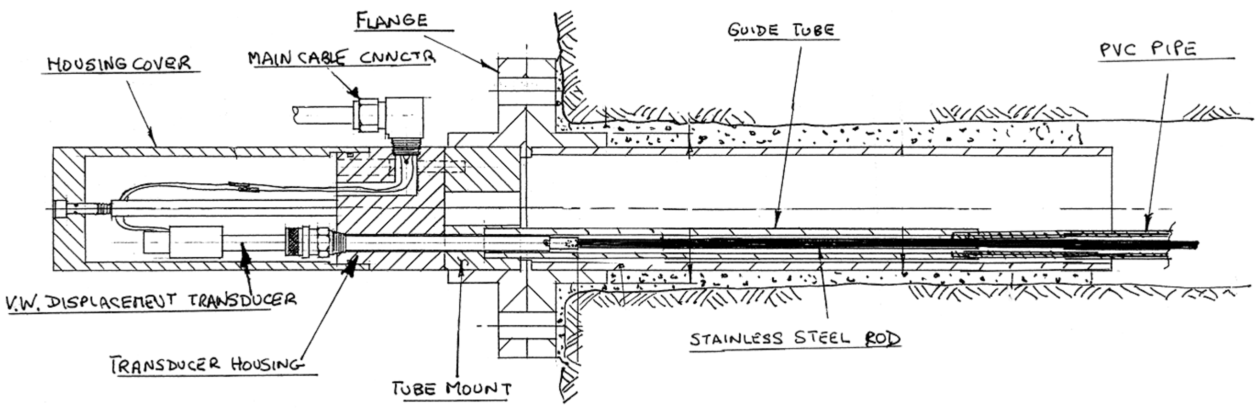

Figure 8 - MPBX with Electronic Readout Only

1) The Guide Tubes provide a space in which the transducers are located. They may be shipped separately. If shipped separately then they must be attached, to the Tube Mount by threading and/or gluing, and then, by gluing, to the PVC pipe, after a specified amount of the PVC pipe has been removed. The amount to be removed is such that when the stainless steel rod is connected to the transducer the transducer will be correctly positioned within the Guide Tube. Numbers stamped on the Tube Mount ensure that the correct anchor is connected to the corresponding Guide Tube and transducer.

2) If a Standpipe is in use, the rods and anchors are pushed into the borehole and the Tube Mount, with its Guide Tubes, is now glued, or bolted, to the standpipe. Extension Rods are screwed onto the end of the stainless steel rods and are then clamped to the Tube Mount by Temporary Swagelok Connectors. (See Section 2.4 for Swagelok instructions.) The extension rods are designed to hold the ends of the stainless steel rods in their correct positions relative to the head of the MPBX while the anchors and rods are being installed inside the borehole. Without them the friction and pull of the anchors, and changes of temperature, during installation could move the rod tips by an unacceptable amount.

3) After the installations have been made, as per the instructions of Section 3, the extension rods and Temporary Swagelok Connectors are removed.

4) The Transducer Housing can now be bolted to the Tube Mount using the numbers stamped on the tube mount to ensure correct orientation.

5) Vibrating Wire Displacement Transducers are now threaded onto the end of the stainless steel rod tips. **Be sure the pin in the Transducer shaft is in the notch on the transducer when the Transducer is screwed onto the rod tip. If the pin is not in the notch when the Transducer is twisted, then serious damage can result.** Once connected, they can then be extended to the correct part of their range before being gripped by the Swagelok fittings in the Transducer Housing. Note: If difficulty is experienced connecting the transducer t the rod tips, completely remove the Swagelok fitting from the head, this will permit the connection to be made.

6) The installation is completed, by connecting the individual transducer leads to the main cable connector inside the MPBX Head and bolting the Housing Cover to the Transducer Housing using the long Standoff Bolts provided. Wiring Charts are given in Appendix A.

7) Initial Readings can now be taken.

4.2 Electronic Readout with Manual Readout Capability

A typical MPBX head assembly, designed to accept vibrating wire displacement transducers and permit manual readout is shown in Figure 9. In this arrangement, the transducers are not directly in line with the stainless rods but, instead, are recessed in guide tubes alongside the rods, leaving the tip of the rods free to be sensed by a dial indicator. Because of this design, when a rod is pulled the shaft of the transducer will retract, causing a decrease in the vibrating wire reading.

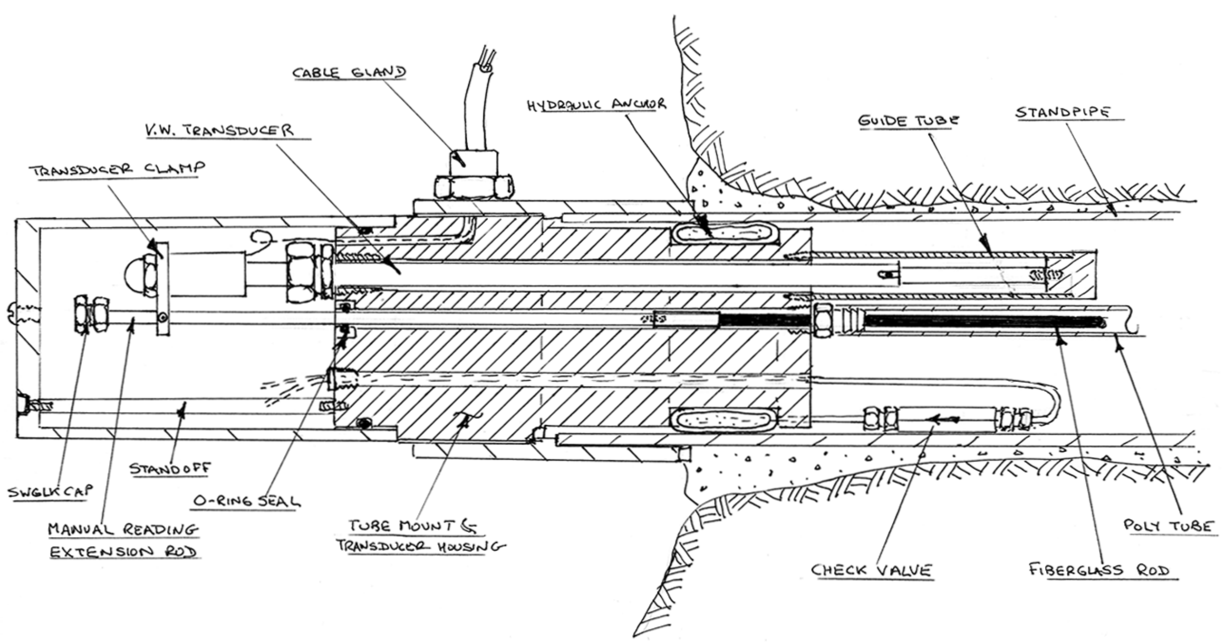

Figure 9 - MPBX with Manual and Electronic Readout Capability

1) The Tube Mount must first be separated from the MPBX Head Assembly by removing the cap and unbolting the Tube Mount from the Transducer Housing. The Guide Tubes provide a space in which the transducers are to be located; they are shipped already attached to the Tube Mount. These Guide Tubes need to be kept clean during any grouting operation. (They can be plugged with the O-ring plugs provided).

2) After the anchors and rod/pipe strings have been assembled they must now be cemented to the Tube Mount, but before this is done the last PVC pipe section must be trimmed to the correct length. The amount to be removed is such that when the installation is completed the tip of the stainless steel rod will be in the correct position relative to the Reference Surface. Numbers stamped on the Tube Mount ensure that the anchors are connected in the proper sequence.

3) If a Standpipe is in use it should be installed now, after which the installation may proceed in accordance with the instructions of Section 3.

4) After the installation of the rods, pipes, and anchors is completed, tapered Bullets are screwed onto the outer ends of the stainless steel rods so that the Transducer Housing can now be slid over these rods, without damaging the O-ring Seals in the Transducer Housing. The Transducer Housing can now be bolted to the Tube Mount.

5) The Vibrating Wire Transducers can now be installed inside the Guide Tubes after removing the O-ring Plugs by threading the Transducers onto the setscrew in the bottom of the Guide Tube. **Be sure the pin in the Transducer shaft is in the notch on the transducer when the Transducer is screwed onto the rod tip. If the pin is not in the notch when the Transducer is twisted, then serious damage can result.** The Transducer Clamps are slid over the stainless steel rods and secured to the backs of their corresponding Transducers. Each Transducer is connected in turn to a Readout Box and the Transducer is set in the desired part of its range. In most instances, where the movements being monitored are extensions, this will mean that the Vibrating Wire Transducer will be almost fully extended. When the correct position is selected then the setscrew in the Transducer Clamp is tightened onto the Manual Readout Rod.

6) The bullets are removed from the end of the stainless steel rods and replaced by Swagelok Caps, which will provide a large flat surface for the dial indicator tip to find. (The rods may be trimmed to their correct length, if necessary, by means of a hacksaw).

7) The individual transducer leads are connected to the main cable connector and the Standoffs and Cap are replaced. Wiring Charts are given in Appendix A.

8) Initial readings can now be taken – both manual and electronic.

5. TAKING READINGS

An important note: For MPBX models designed for electronic readout only, when a rod is pulled the transducer shaft will extend, and the vibrating wire reading will increase. For MPBX models designed for electronic *and* manual readout, when a rod is pulled the transducer shaft will retract, and the vibrating wire reading will decrease.

The most important reading is the first reading; it is the base reading to which all subsequent readings will be compared. Verify that the readings are correct. If possible, install the MPBX well ahead of the time that movements are expected so that the MPBX has time to stabilize. (Most installations are subject to a "bedding-in" process during which slight movements can occur. These movements generally cease after two or three days). Often the best results can be obtained by using as the base line readings the readings taken on the third day. This, of course may not be possible if the ground is already moving.

5.1 Manual Readings

Manual readings are best taken using a dial indicator, although, depth micrometers have also been used. To take manual readings simply poke the stem of the indicator through the holes in the Cap on the MPBX Head assembly until the tip bears against the underlying Swagelok Cap. With the collar of the dial indicator held flush against the MPBX Cap or the Reference Surface take a reading on the indicator.

5.2 Electronic Readout

Readout frequency should be suitable to the purpose for which the readings are being made. All readings should be compared with previous readings as soon as they are taken. In this way, sudden changes of readings can be instantly checked to see if they are real or perhaps a reading error. If the changes are real, the observer is alerted to the possibility of serious ground movements, or to possible instrument damage, and can look for further evidence of either.

5.3 GK-404 Readout Box

The Model GK-404 Vibrating Wire Readout is a portable, low-power, handheld unit that can run continuously for more than 20 hours on two AA batteries. It is designed for the readout of all Geokon vibrating wire gauges and transducers; and is capable of displaying the reading in either 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.

5.3.1 Operating the GK-404

Before use, attach the flying leads to the GK-404 by aligning the red circle on the silver "Lemo" connector of the flying leads with the red line on the top of the GK-404, as shown in Figure 10 below. Insert the Lemo connector into the GK-404 until it locks into place.

Figure 10 - Lemo Connector to GK-404

Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

To turn the GK-404 on, press the "ON/OFF" button on the front panel of the unit. The initial startup screen will display:

Geokon Inc.
GK-404 verX.XX

After approximately one second, 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 letter 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 gauge in degrees Celsius.

Use the **POS** button to select position **B** and the **MODE** button to select **Dg** (digits). (Other functions can be selected as described in the GK-404 Manual.)

The GK-404 will continue to take measurements and display readings until the unit is turned off, either manually, or if enabled, by the Auto-Off timer. If no reading displays or the reading is unstable, consult Section 7 for troubleshooting suggestions.

For further information, please see the GK-404 manual.

5.4 GK-405 Readout Box

The GK-405 Vibrating Wire Readout is made up of two components: The Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout Application; and the GK-405 Remote Module, which is housed in a weatherproof enclosure and connects via a cable to the vibrating wire gauge to be measured. The two components communicate wirelessly. The Readout Unit can operate from the cradle of the Remote Module, or, if more convenient, can be removed and operated up to 20 meters from the Remote Module.

5.4.1 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.

5.4.2 Connecting Sensors with Bare Leads

Attach the GK-403-2 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).

5.4.3 Operating the GK-405

Press the button labeled “POWER ON”. A blue light will begin blinking, signifying that the Remote Module is waiting to connect to the handheld unit. Launch the GK-405 VWRA program by tapping on “Start” from the handheld PC’s main window, then “Programs” then the GK-405 VWRA icon. After a few seconds, the blue light on the Remote Module should stop flashing and remain lit. The Live Readings Window will be displayed on the handheld PC. Choose display mode “B”. Figure 11 shows a typical vibrating wire output in digits and thermistor output in degrees Celsius. If no reading displays or the reading is unstable, see Section 7 for troubleshooting suggestions. For further information, consult the GK-405 Instruction Manual.

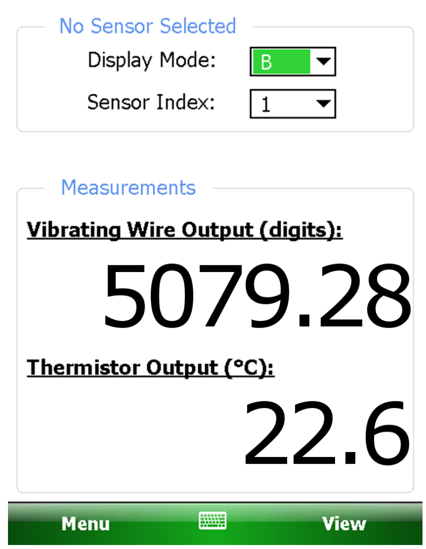

Figure 11 - Live Readings – Raw Readings

5.5 GK-403 Readout Box (Obsolete Model)

The GK-403 can store gauge readings and apply calibration factors to convert readings to engineering units. The following instructions explain taking gauge measurements using Mode "B". Consult the GK-403 Instruction Manual for additional information.

5.5.1 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.

5.5.2 Connecting Sensors with Bare Leads

Attach the GK-403-2 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).

5.5.3 Operating the GK-403

1) Turn the display selector to position "B".

2) Turn the unit on.

3) The readout will display the vibrating wire output in digits. The last digit may change one or two digits while reading.

4) The thermistor reading will be displayed above the gauge reading in degrees centigrade.

5) Press the "Store" button to record the value displayed.

If the no reading displays or the reading is unstable, see Section 7 for troubleshooting suggestions.

The unit will automatically turn off after approximately two minutes to conserve power.

6. DATA ANALYSIS

Raw data can be treated in several ways to reveal zones or planes of weakness in which movement is occurring. All raw data must be converted into time plots as soon as possible. Failure to plot the data in a timely manner can negate the purposes of the monitoring program. Inspection of the plots will show whether movements are steady, are accelerating, or have stopped. They may suggest the need for remedial measures and will be useful in monitoring their efficacy.

6.1 Example of MPBX Data Reduction Where the Deep Anchor is in Stable Ground

Table 1 shows a series of entries into a field book. In this example, Anchor 3 is installed in stable ground.

Date	Anchor 3 (Depth 20 m) millimeters	Anchor 2 (Depth 10 m) millimeters	Anchor 1 (Depth 3 m) millimeters	Remarks
12/01/00	38.10	25.19	34.75	Initial Reading (R_0)
12/02/00	38.91	26.01	35.51	
12/03/00	39.01	26.11	35.61	
12/05/00	39.12	26.16	35.61	
12/06/00	39.14	26.16	35.61	
12/08/00	40.18	27.13	36.58	Blasting in the Area
12/09/00	40.13	27.18	36.63	
12/10/00	40.26	27.31	36.65	
12/11/00	40.64	27.61	36.65	
12/15/00	43.82	28.58	36.83	Heavy Rain
12/16/00	43.87	28.58	36.83	
12/18/00	43.94	28.63	36.88	
12/20/00	43.99	28.65	36.88	

Table 1 - Raw Data

The first task is to calculate the measured displacements between the head and each anchor. This can easily be done for each anchor, by subtracting the initial reading, R_0 from each of the subsequent readings. This creates the table of figures shown in Table 2.

Date	Anchor 3 (Depth 20 m) millimeters	Anchor 2 (Depth 10 m) millimeters	Anchor 1 (Depth 3 m) millimeters	Remarks
12/01/00	0.00	0.00	0.00	Installed
12/02/00	0.81	0.82	0.76	
12/03/00	0.91	0.92	0.86	
12/05/00	1.02	0.97	0.86	
12/06/00	1.04	0.97	0.86	
12/08/00	2.08	1.94	1.83	Blasting in the Area
12/09/00	2.03	1.99	1.88	
12/10/00	2.16	2.12	1.90	
12/11/00	2.54	2.42	1.90	
12/15/00	5.72	3.39	2.08	Heavy Rain
12/16/00	5.75	3.39	2.08	
12/18/00	5.84	3.44	2.13	
12/20/00	5.89	3.46	2.13	

Table 2 - Relative Movement between the Instrument Head and Each Anchor

However, in the example chosen, it is the deepest anchor that is stable, not the Instrument Head, so that the movement of each of the anchors should be calculated relative to Anchor 3 and not to the head of the MPBX. Immediately it will be realized that the apparent movement of Anchor 3 is actually the absolute movement of the instrument head relative to stable ground.

When the Instrument head is in stable ground, such as would be the case for a MPBX head located at street level in a borehole drilled downwards to terminate slightly above a tunnel being excavated below, then the measured movements on each anchor are taken directly from the readings on each anchor. The analysis of the data would then proceed as before without the need for the steps described below.

Date	Anchor 2 (Depth 10 m) millimeters	Anchor 1 (Depth 3 m) millimeters	Instrument Head millimeters	Remarks
12/01/00	0.00	0.00	0.00	Installed
12/02/00	0.01	0.05	0.81	
12/03/00	0.01	0.05	0.91	
12/05/00	0.05	0.16	1.02	
12/06/00	0.07	0.18	1.04	
12/08/00	0.14	0.25	2.08	Blasting in the Area
12/09/00	0.04	0.15	2.03	
12/10/00	0.04	0.26	2.16	
12/11/00	0.12	0.64	2.54	
12/15/00	2.33	3.64	5.72	Heavy Rain
12/16/00	2.36	3.67	5.75	
12/18/00	2.40	3.71	5.84	
12/20/00	2.43	3.76	5.89	

Table 3 - Movement of the Instrument Head and Anchors Relative to Anchor 3 in Stable Ground

The data shown in Table 3 could be plotted and shown in a graph like the one shown in Figure 12.

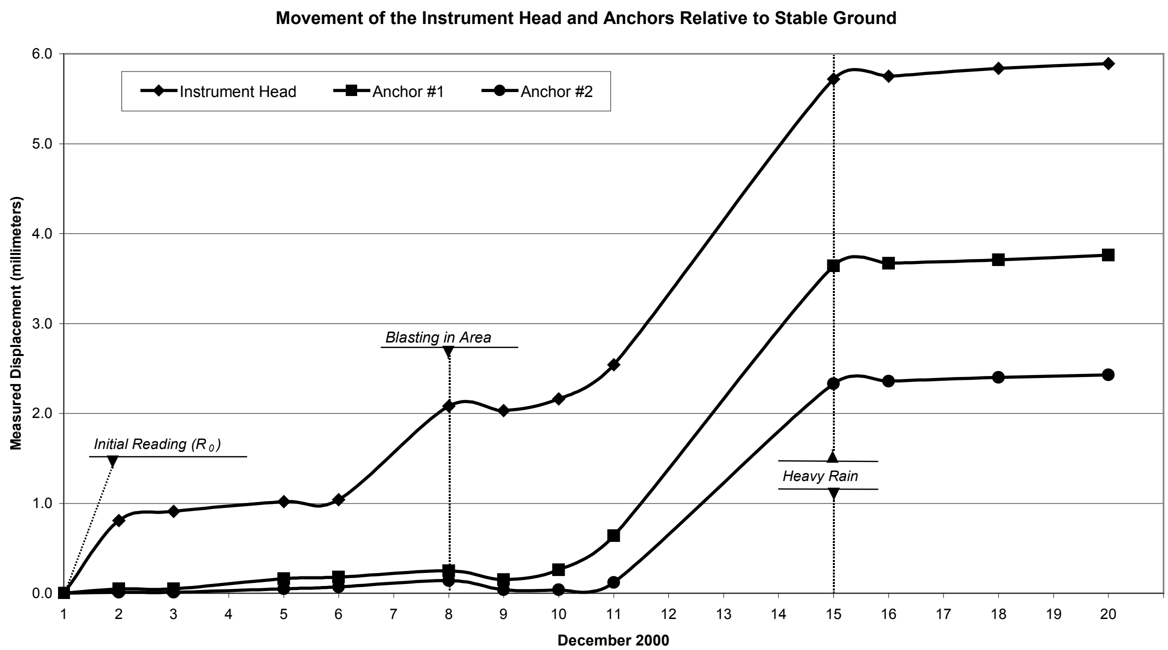

Figure 12 - Movement of the Head and Anchors Relative to Anchor 3 in Stable Ground

Inspection of the plot shows that initial movement occurred in the zone closest to the surface during the first three days and again on day eight following blasting in the area. On day 15, following a heavy rainfall, deep-seated movements occurred in the zone between Anchors 2 and 3 as well as in the shallower zones. Movements occurring in any inter-anchor zone can be inferred from the spacing between the individual plots of Figure 12, or they can be plotted separately as shown in Figure 13.

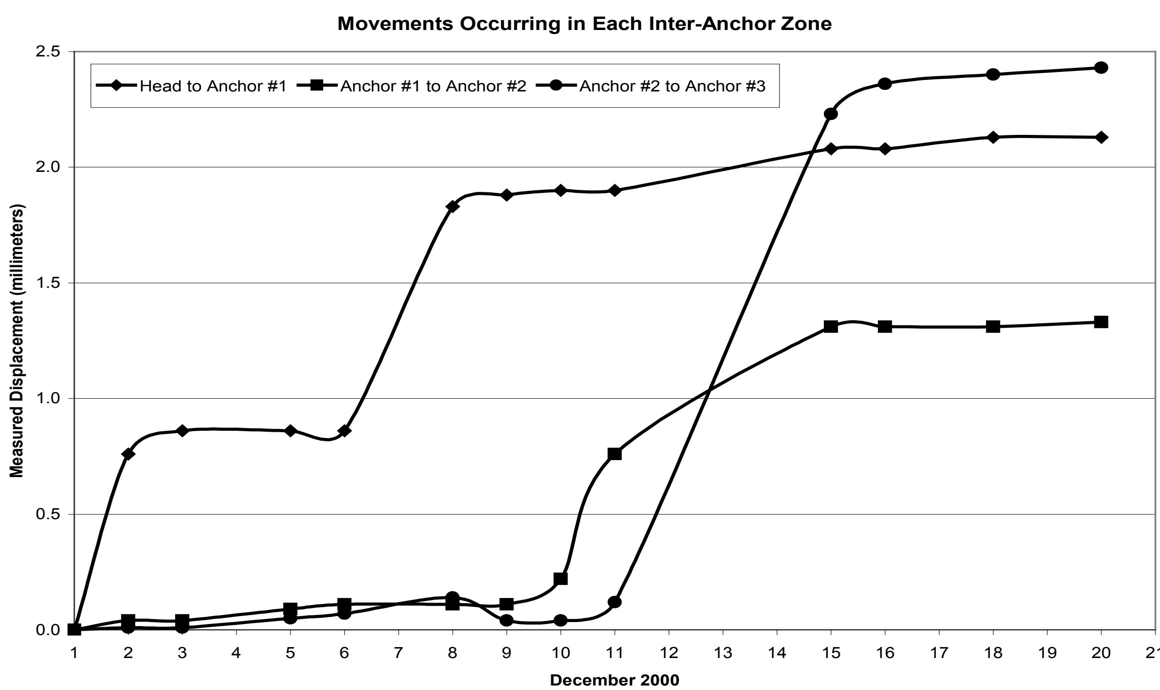

Figure 13 - Movements Occurring in Each Inter-Anchor Zone

7. TROUBLESHOOTING

The multiple anchor design tends to show confirming changes of readings on several rods from movements that affect more than one anchor. Bad readings on any intermediate anchor will tend to stand out as incompatible with the movements of the surrounding anchors. Nevertheless, it is possible that cracks in one zone might open while those in an adjacent zone might close.

7.1 Dial Indicators

Dial Indicators are delicate instruments and should always be kept clean and dry. It is advisable to have a Standard, which can be used to check that the dial gauge always gives the same reading when checked against this Standard. The Standard might be a block of steel in which a hole has been bored.

7.2 Vibrating Wire Transducers

Symptom: Displacement Transducer 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? Try reading the displacement transducer on a different readout position. For instance, channel A of the GK-404 and GK-405 might be able to read the transducer.

✓ Is there a source of electrical noise nearby? Probable sources of electrical noise include motors, generators, transformers, arc welders, and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger. If using the GK-403, GK-404, or GK-405, connect the clip with the blue boot to the shield drain wire. (Green for the GK-401.)

✓ Does the readout work with another displacement transducer? If not, the readout may have a low battery or be malfunctioning. Consult the appropriate readout manual for charging or troubleshooting directions.

✓ Has the transducer gone outside its range? If so, the transducer can be reset using the installation instructions in Section 4.

Symptom: Displacement Transducer Fails to Read

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

✓ Does the readout or datalogger work with another transducer? If not, the readout or datalogger may be malfunctioning. Consult the readout or datalogger manual for further direction.

Symptom: Displacement Transducer is hard to connect to the rod tip

✓ Completely remove the Swagelok fitting from the housing so that there is more freedom to make the connection.

APPENDIX A. WIRING CHARTS FOR VIBRATING WIRE TRANSDUCERS

A.1 Single Transducer Wiring Chart

Internal Wiring	Geokon Cable #02-205V6 (Blue)	Function / Description
Red	Red	Gauge 1+
Black	Black	Gauge 1-
Red	White	Thermistor
Black	Green	Thermistor
N/C	Shield (1)	N/A

Table 4 - Wiring for One Transducer

A.2 Two Transducer Wiring Chart

Internal Wiring	Geokon Cable #04-375V9	Function / Description
Red	Red	Gauge 1+
Black	Black of Red	Gauge 1-
Red	White	Gauge 2+
Black	Black of White	Gauge 2-
Blue	Blue	Thermistor
Black of Blue	Black of Blue	Thermistor
N/C	Shields (4)	Ground

Table 5 - Wiring for Two Transducers

A.3 Three Transducers Wiring Chart

Internal Wiring	Geokon Cable #04-375V9 (Violet)	Function / Description
Red	Red	Gauge 1+
Black	Black of Red	Gauge 1-
Red	White	Gauge 2+
Black	Black of White	Gauge 2-
Red	Green	Gauge 3+
Black	Black of Green	Gauge 3-
N/C	Blue	Thermistor
N/C	Black of Blue	Thermistor
N/C	Shields (5)	Ground

Table 6 - Wiring for Three Transducers

A.4 Four Transducers Wiring Chart

Internal Wiring	Geokon Cable #05-375V12 (Tan)	Function / Description
Red	Red	Gauge 1+
Black	Black of Red	Gauge 1-
Red	White	Gauge 2+
Black	Black of White	Gauge 2-
Red	Green	Gauge 3+
Black	Black of Green	Gauge 3-
Red	Blue	Gauge 4+
Black	Black of Blue	Gauge 4-
N/C	Yellow	Thermistor
N/C	Black of Yellow	Thermistor
N/C	Shields (6)	Ground

Table 7 - Wiring for Four Transducers

A.5 Five Transducers Wiring Chart

Internal Wiring	Geokon Cable #06-500V7 (Orange)	Function / Description
Red	Red	Gauge 1+
Black	Black of Red	Gauge 1-
Red	White	Gauge 2+
Black	Black of White	Gauge 2-
Red	Green	Gauge 3+
Black	Black of Green	Gauge 3-
Red	Blue	Gauge 4+
Black	Black of Blue	Gauge 4-
Red	Yellow	Gauge 5+
Black	Black of Yellow	Gauge 5-
Red	Brown	Thermistor
Black	Black of Brown	Thermistor
N/C	Shields (7)	Ground

Table 8 - Wiring for Five Transducers

A.6 Six Transducers Wiring Chart

Internal Wiring	Geokon Cable #012-625V5 (Brown CAB-507)		Function / Description
Red	Red		Gauge 1+
Black	Black of Red		Gauge 1-
Red	White		Gauge 2+
Black	Black of White		Gauge 2-
Red	Green		Gauge 3+
Black	Black of Green		Gauge 3-
Red	Blue		Gauge 4+
Black	Black of Blue		Gauge 4-
Red	Yellow		Gauge 5+
Black	Black of Yellow		Gauge 5-
Red	Brown		Gauge 6+
Black	Black of Brown		Gauge 6-
White	White		Thermistor
Red of White	Red of White		Thermistor
N/C	Shields (8)		Ground

Table 9 - Wiring for Six Transducers

A.7 Seven Transducers Wiring Chart

Internal Wiring	Geokon Cable #012-625V5 (Brown)	Function / Description
Red	Red	Gauge 1+
Black	Black of Red	Gauge 1-
Red	White	Gauge 2+
Black	Black of White	Gauge 2-
Red	Green	Gauge 3+
Black	Black of Green	Gauge 3-
Red	Blue	Gauge 4+
Black	Black of Blue	Gauge 4-
Red	Yellow	Gauge 5+
Black	Black of Yellow	Gauge 5-
Red	Brown	Gauge 6+
Black	Black of Brown	Gauge 6-
Red	Orange	Gauge 7+
Black	Black of Orange	Gauge 7-
N/C	White	Thermistor
N/C	Red of White	Thermistor
N/C	Shields (9)	Ground

Table 10 - Wiring for Seven Transducers

A.8 Eight Transducers Wiring Chart

Internal Wiring	Geokon Cable #012-625V5 (Brown)	Function / Description
Red	Red	Gauge 1+
Black	Black of Red	Gauge 1-
Red	White	Gauge 2+
Black	Black of White	Gauge 2-
Red	Green	Gauge 3+
Black	Black of Green	Gauge 3-
Red	Blue	Gauge 4+
Black	Black of Blue	Gauge 4-
Red	Yellow	Gauge 5+
Black	Black of Yellow	Gauge 5-
Red	Brown	Gauge 6+
Black	Black of Brown	Gauge 6-
Red	Orange	Gauge 7+
Black	Black of Orange	Gauge 7-
Red	Red	Gauge 8+
Black	Green of Red	Gauge 8-
N/C	White	Thermistor
N/C	Red of White	Thermistor
N/C	Shields (10)	Ground

Table 11 - Wiring for Eight Transducers

APPENDIX B. SPECIFICATIONS

B.1 Model 1250 Specifications

Standard Range	Up to 300 mm nominal
Least Reading	0.025 mm
Borehole Diameter[1]	38 mm to 102 mm
Maximum Length	100 m

Table 12 - A-5 Extensometer Specifications

Notes:
[1] Note that the size of the borehole required increases with the addition of more measuring points.

B.2 Rod Specifications

Material	Diameter	Weight per Meter	Young's Modulus	Temperature Coefficient
303 Stainless Steel	6 mm	0.25 Kg/m	200 GPa	17.5 ppm/°C
Fiberglass	6 mm	0.06 Kg/m	20 GPa	3.0 ppm/°C
Carbon Composite	6 mm	0.05 Kg/m	130 GPa	<1.0 ppm/°C

Table 13 - Rod Specifications

B.3 Model 4450 Vibrating Wire Transducer Specifications

Standard Ranges[1] **(mm)**	12.5, 25, 50, 100, 150, 200, 230, 300
Resolution[2]	0.025% FSR
Linearity	0.25% FSR
Thermal Zero Shift[3]	< 0.05% FSR/°C
Stability	< 0.2%/yr (under static conditions)
Accuracy[4]	
Overrange	115%
Temperature Range	-20 to +80 °C
Frequency Range	1200 - 2800 Hz
Coil Resistance	180 Ω, ±10 Ω
Cable Type[5]	Two twisted pair (four conductor) 22 AWG Foil shield, PVC jacket, nominal OD=6.3 mm (0.250")

Table 14 - Model 4450 Displacement Transducer Specifications

Notes:
[1] Other ranges available on request.
[2] Minimum; greater resolution possible depending on readout.
[3] Depends on application.
[4] Accuracy established under laboratory conditions.
[5] Polyurethane jacket cable available.

APPENDIX C. THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3
Resistance to Temperature Equation:

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

Equation 1 - Resistance to Temperature

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

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

Table 15 - Thermistor Resistance versus Temperature