Flexible Rod
Multi-Point Borehole Extensometer
Installation and User Manual

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TABLE OF CONTENTS

1 INTENDED AUDIENCE 4
2 SAFETY 4
3 ICONS AND CONVENTIONS USED IN THIS GUIDE 4
4 ABBREVIATIONS AND ACRONYMS 5
5 INTRODUCTION 6
5.1 Applications 9
5.2 Features 9
5.3 Installation in Downward Directed Boreholes 10
5.4 MPBX Head Installation Above Grade or Below Grade 11
5.4.1 Above Grade Head Installation 11
5.4.2 Below Grade Head Installation 11
5.5 Types of MPBX Anchors 12
5.5.1 Groutable Anchor 12
5.5.2 Groutable Anchor with Spring Legs 13
5.5.3 Hydraulic Borros Anchor 15
5.5.4 Bladder Type Hydraulic Anchor 17
6 INSTALLATION OF FLEXIBLE ROD MPBX 19
6.1 Required Tools and Components 19
6.2 Other Useful Tools/Spare Parts 19
6.3 Installation Guidelines 20
6.4 Sensor Function Test 20
6.5 Borehole Preparations 21
6.5.1 Grout Delivery Tube (Tremie Pipe) 22
6.6 Flexible Rod Installation Preparations 23
6.7 MPBX with Flexible Rod Installation 25
7 TAKING READINGS 29
7.1 Taking readings with VW2106 / DT Logger / FlexDAQ 29
7.2 Taking Readings with a Depth Micrometer 30
8 DATA REDUCTION 31
9 PRODUCT SPECIFICATIONS 32
10 SERVICE, REPAIR AND CONTACT INFORMATION 33

LIST OF FIGURES

Figure 1: Flexible Fiberglass Rods Coil Connected to a Combination Head 7
Figure 2: MPBX Head and Collar Diagrammatic Overview 8
Figure 3: Groutable Anchors 12
Figure 4: Spring-Type Groutable Anchor General Arrangement 13
Figure 5: Spring-Type Groutable Anchor with Legs Closed (Left) and Deployed (Right) 14
Figure 6: Borros Type Anchor General Arrangement 15
Figure 7: Borros Type Anchor Overview 16
Figure 8: Borros Type Anchor Elbow Fitting with Hydraulic Inflation Line Attached 17
Figure 9: Bladder-Type Hydraulic Anchor 18
Figure 10: Borehole is 1m deeper than the lowest anchor elevation 21
Figure 11: Hydraulic Inflation Line Taped Away from the Prongs 24
Figure 12: Grout Collar Installation 26
Figure 13: Components to Remove and Install Following Installation and Grouting 28
Figure 14: Manually Taking Readings with a Depth Micrometer 30

LIST OF TABLES

Table 1: Wiring Connection (Check Colour) 29
Table 2: Cement-Bentonite Grout Mix 34
Table 3: Thermistor Resistance (Ω) versus Temperature (°C) 36
Table 4: Temperature Correction Factor 37

LIST OF EQUATIONS

Equation 1: Thermistor Temperature Derivation 36
Equation 2: Linear Displacement Calculation 37
Equation 3: Temperature Correction Factor Calculation 37

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1 INTENDED AUDIENCE

This guide is for the personnel responsible for installing or using an RST Flexible Rod Multi-Point Borehole Extensometer (MPBX). This manual provides the installation steps for the different orientations and different type of anchors.

This manual also provides the instructions for taking and interpreting MPBX readings.

2 SAFETY

Normal safety precautions should be followed, and proper personal protective equipment (PPE) should be worn when working in the field, including safety glasses and nitrile gloves.

The installation of borros anchors requires the use of a hydraulic pump. Ensure the hydraulic pump is in working condition and all safety precautions are in place prior to using the tool.

3 ICONS AND CONVENTIONS USED IN THIS GUIDE

This guide uses the following icons to call attention to important information.

WARNING: This icon appears when an operating procedure or practice, if not correctly followed, could result in personal injury or loss of life.

CAUTION: This icon appears when an operating procedure or practice, if not strictly observed, could result in damage to or destruction of equipment.

NOTE: This icon appears to highlight specific non-safety related information.

4 ABBREVIATIONS AND ACRONYMS

This section lists abbreviations and acronyms used in the document.

Abbreviation or acronym	Definition
SS	Stainless Steel
PPE	Personal Protective Equipment
MPBX	Multi-Point Borehole Extensometer
ID	Inside Diameter
OD	Outside Diameter
HOSS	Heavy Over-hole Suspension System
PSI	Pound Per Square Inch
mPa	millipascal
PVC	Polyvinyl Chloride
ABS	Acrylonitrile Butadiene Styrene
HDPE	High Density Polyethylene
SPT	Standard Penetration Test

5 INTRODUCTION

RST's Multi-Point Borehole Extensometers (MPBX) are used to determine the stability and movement of soil, rock, and concrete structures. A Borehole Extensometer with multiple anchor points can be used to determine movements between set anchor points within a single borehole.

MPBX are usually installed within a borehole using a grout backfill which provides the bond connection between the Extensometer's anchor point ends and the borehole walls. Typical installations only have a single instrument cable exiting from the borehole collar, connected to a remote data logger or a readout unit.

A typical rod Extensometer consists of a reference head, usually installed at the collar of a borehole, and one or more in-hole anchors, each of which is fixed in place at a known depth in the borehole. As the soil or rock shifts, the spaces between nearby anchors inside the borehole change, as well as the spaces between each anchor and the reference head. This allows for an accurate determination of distribution, magnitude, rate, and acceleration of deformation in the rock or soil mass intersected by the borehole.

NOTE: The number of anchors and anchor depths should be selected based on site geology, area's structural geometry, and other location-specific details.

The use of two or more anchors at various depths allows the engineer to differentiate potentially dangerous deep-seated movements from more trivial surface spalling.

MPBX uses vibrating wire displacement transducers as measurement sensors for stable and accurate outputs which can be temperature corrected.
RST produces both Rigid Rod and Flexible Rod MPBX. The type of MPBX employed depends on the application and installation requirements.

The Flexible Rod Extensometers are particularly useful for applications where limited room is available, such as a small tunnel or cavern. They are a low-cost, convenient instrument for the monitoring of ground displacements and are designed to withstand severe field conditions and accommodate transverse shear. The compact design allows for installation in boreholes of minimum size; up to 6 rods may be accommodated in a 90 mm borehole.
The individually sheathed flexible fiberglass rods with a diameter of 3/16'', are lightweight (allowing easy transport and installation), non-corrosive (for longevity), and can be used with all anchor types.

RST's Flexible Rod MPBX are fully assembled and sealed at the facility prior to shipping (according to each customer's specifications), allowing for quick and easy installation at site.

NOTE: The Flexible Rod MPBX are typically used for extension measurements. If required, they can be used for compression measurements at a reduced initial precision.

Figure 1: Flexible Fiberglass Rods Coil Connected to a Combination Head

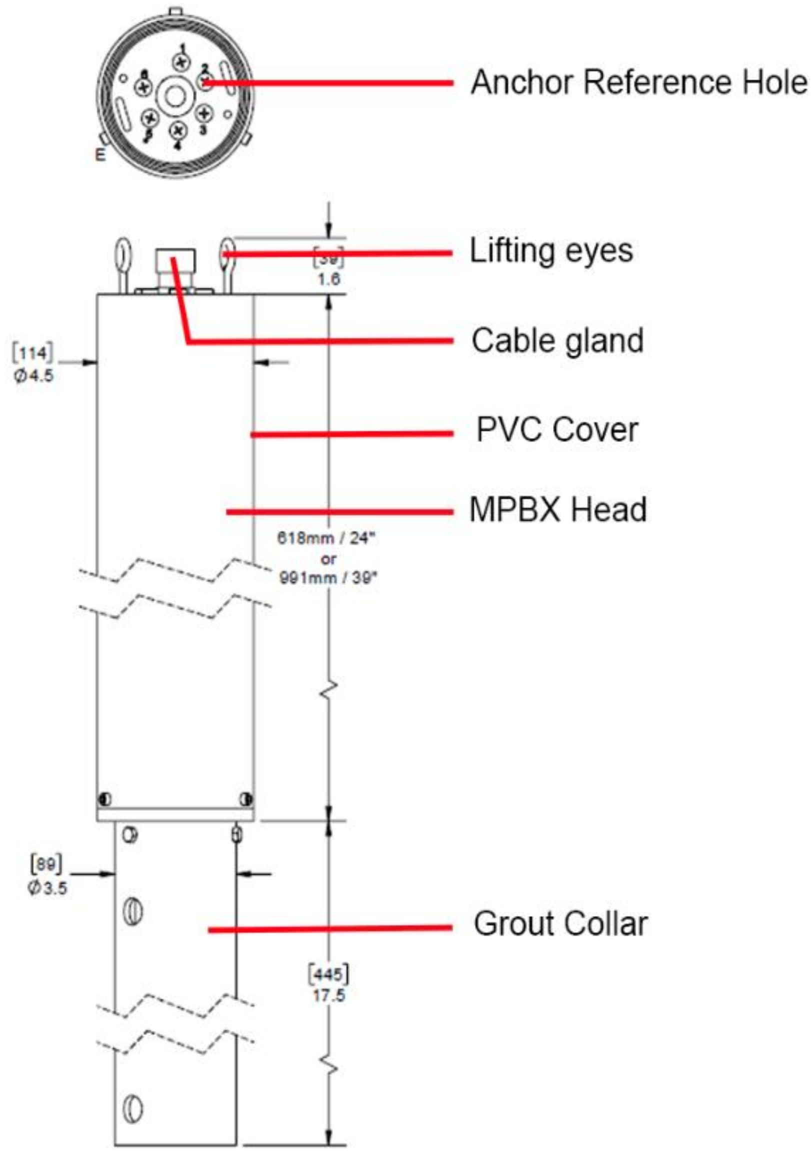

Figure 2: MPBX Head and Collar Diagrammatic Overview

5.1 APPLICATIONS

Typical applications of the MPBX include measurements of:

- Ground movements around tunnels
- Deformation of dam abutments and foundations
- Ground movement behind retaining walls, sheet piling, slurry walls, etc.
- Ground movements in the walls of open pit mines
- Deformation of concrete piles (tell-tales)
- Deformation in the walls and roofs of underground openings
- Subsidence above tunnels and mine openings
- Settlement and heave of foundations due to loading

5.2 FEATURES

- High accuracy and reliability
- Easily adaptable to remote readout unit
- Rugged construction for operation in challenging environments
- Simple installation and operation

5.3 INSTALLATION IN DOWNWARD DIRECTED BOREHOLES

NOTE: For upward, upward-inclined, or downward-inclined MPBX installations, Rigid Rod MPBX is recommended. Please refer to the RST Multi-Point Borehole Extensometer product page for a copy of the Rigid Rod MPBX installation manual for further directions.

NOTE: This is the most straightforward installation orientation as the Extensometer assembly rests on the borehole's invert level and can easily be lowered into the borehole.

CAUTION: Ensure that the system does not fall down the borehole.

Carefully unroll and lower the entire Extensometer assembly down into the borehole.
Use of safety cable and HOSS (Heavy Over-hole Suspension System) is recommended, especially for installation within deep boreholes as this reduces the exertion required to lower and lift instruments into boreholes.

5.4 MPBX Head Installation Above Grade or Below Grade

RST MPBX can be installed with the Extensometer head exposed above the borehole’s surface (above grade) or with the Extensometer head buried below the borehole’s surface (below grade).

5.4.1 Above Grade Head Installation

The MPBX is installed with the Extensometer head exposed above the borehole’s surface.

This is advantageous as the MPBX head is serviceable, and the installation is easier as the user is not required to work below the borehole surface or in a manhole with tight working space.

A disadvantage is that the exposed MPBX head may interfere with surface traffic, construction equipment, or the public. The exposed Extensometer head could also result in vandalism and/or damage due to debris from the surroundings or nearby construction.

5.4.2 Below Grade Head Installation

The MPBX is installed with the Extensometer head buried below the borehole’s surface or with only a small portion of the head sticking out of the borehole’s surface.

This is advantageous as the MPBX head will not obstruct surface traffic or construction equipment. It is also protected from possible vandalism or damage due to debris.

A disadvantage is that the MPBX head is not serviceable unless a manhole is constructed to house the Extensometer head. The user will have to work in an awkward position below the borehole surface and/or with a tight working space inside the manhole.

5.5 TYPES OF MPBX ANCHORS

3 common types of anchors for RST's MPBX system are:

5.5.1 Groutable Anchor

Groutable anchors are simple to install and the preferred anchor for downward directed holes.

Groutable anchors are unaffected by blasting activities.

NOTE: Groutable anchors are not suitable for use in soft ground or soil as the grout column may inhibit performance.

They can be used in upward directed boreholes with a special grouting technique. Contact RST Instruments for more information.

Figure 3: Groutable Anchors

5.5.2 Groutable Anchor with Spring Legs

Spring-type groutable anchors are recommended for use in boreholes in soft rock or consolidated soil where the standard groutable anchor may not be able to provide a secure attachment to the borehole wall.

The mechanically activated spring legs provide extra contact with the borehole wall to ensure that anchor slippage will not occur.

Figure 4 shows the configuration of the three-spring leg anchor arrangement, which when deployed (Figure 5), will attach to the borehole wall at six points.

NOTE: Backfill grouting must still be carried out when spring leg anchors are used. This ensures that the anchors are securely attached to the adjacent borehole walls. In addition, backfill grouting fixes the Extensometer sheaths and rods in the hole so that lateral movements, which result in reading inaccuracies, cannot occur. Backfill grouting also ensures that downhole caving or deterioration will not affect the Extensometer's long-term operation.

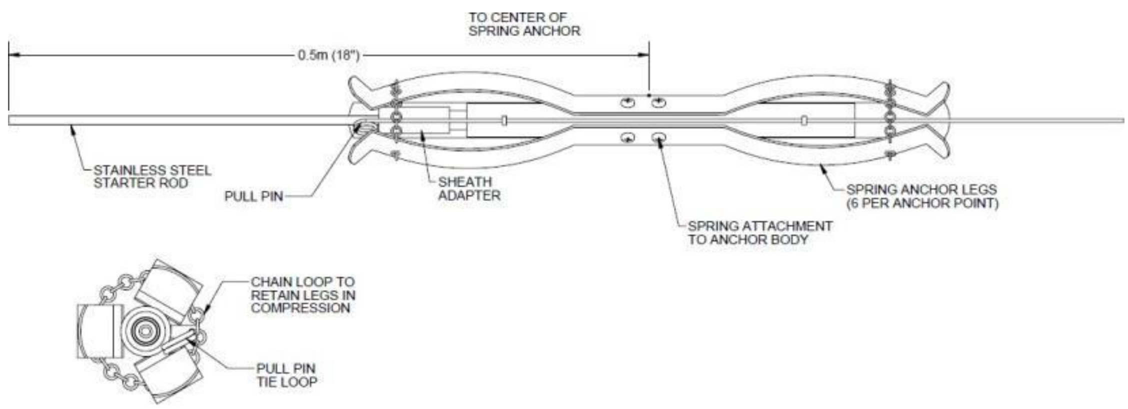

Figure 4: Spring-Type Groutable Anchor General Arrangement

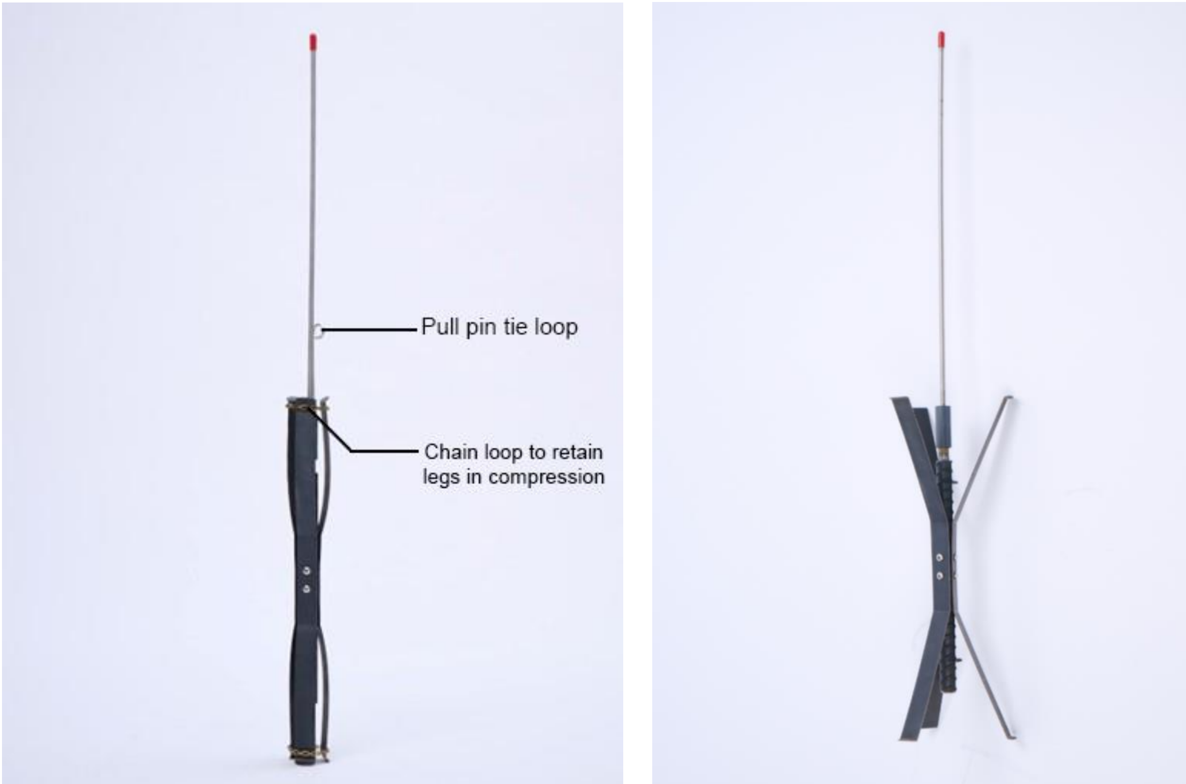

Figure 5: Spring-Type Groutable Anchor with Legs Closed (Left) and Deployed (Right)

5.5.3 Hydraulic Borros Anchor

Hydraulic borros anchors are recommended for use in soft ground and soil where deep penetration of the prongs is required for good anchorage, especially where hole squeezing is anticipated.

NOTE: Borehole squeezing occurs when the soil adjacent to the borehole moves inward, toward the hole, reducing the borehole diameter. Soft soil consisting of clay or silts (soil with SPT N-value less than 5) is especially prone to squeezing.

Standard Penetration Test (SPT) is a common in-situ test to determine the relative density of soils and the approximate shear strength parameters.

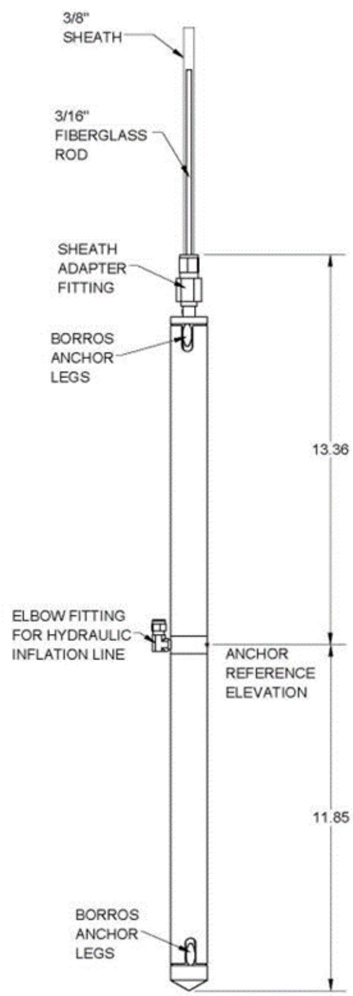

Figure 6: Borros Type Anchor General Arrangement

NOTE: A borehole that uses hydraulic borros anchors can also be grouted for additional bonding.

Figure 7: Borros Type Anchor Overview

Figure 8: Borros Type Anchor Elbow Fitting with Hydraulic Inflation Line Attached

5.5.4 Bladder Type Hydraulic Anchor

Bladder-type hydraulic anchors (see Figure 9) are generally used in boreholes with fractured rock or dense soil where grouting is difficult. These anchors use friction to attach to the borehole wall.

These anchors consist of a pressure-tight, copper tube wrapped around a reel of high tensile strength plastic. Attached to the copper bladder is a high-pressure nylon inflation line and check valve. The inflation of the anchors is done with a hydraulic pump which causes the copper bladder to expand and “unwind,” filling the space between the spool and the borehole wall. The copper permanently deforms so that the shape does not change, and the grip is not lost even if the check valve fails. The hydraulic bladder type anchors are designed for nominal borehole diameters but can accommodate up to 30 mm of oversize without loss of grip.

NOTE: Bladder type anchors are custom made with specific dimensions according to installation requirements and borehole considerations. Contact RST for more information.

Figure 9: Bladder-Type Hydraulic Anchor

6 INSTALLATION OF FLEXIBLE ROD MPBX

6.1 REQUIRED TOOLS AND COMPONENTS

The following tools and materials are recommended for the installation of the Extensometer system.

- Grout tube / tremie pipe
- Measuring tape
- Hex Allen Key set (Imperial)
- Wrench set (Imperial) – specifically, ½" and 9/16"
- Philips screwdriver (Phillips and Flathead)
- PVC electrical tape – ¾" rolls, multiple

6.2 OTHER USEFUL TOOLS/SPARE PARTS

The following tools and materials may be useful for the installation of the Extensometer system.

- Hydraulic pump (for hydraulic anchors)
- Tubing
- Tubing fittings
- Hydraulic Oil (for hydraulic anchors)
- Safety cable – RST recommends 3/32" 7x7 braided stainless steel for deep borehole systems
- RST's Heavy Over- hole Suspension System (HOSS) (recommended for deep borehole system)
- Vent tube (for upward installations)
- Grease for O-rings and moving parts
- Wire marker tape
- Marking pens
- Fast set cement (for upward directed boreholes)
- Spare parts (O-rings, set screws, bolts & screws)

6.3 Installation Guidelines

The Flexible Rod Extensometer is supplied fully assembled in a 1.2 m (4ft) diameter coil. At the installation site, the unit is uncoiled, fitted with suitable grout tube and air bleed tube, and installed into the borehole. After grout has been injected and initial set has been reached, the protective cap is removed, the temporary rod locks are released, and the initial displacement is recorded.

NOTE: These installation instructions are general and may require alteration to suit specific site conditions and the required configuration of the instrument.

Please consult and seek appropriate approval from site engineer / consultant for final installation procedures.

For additional installation support and troubleshooting help, please contact the support team at RST Instruments.

NOTE: For more information about the kind of oil to be used, please contact RST.

CAUTION: Care must be taken to protect the instrument cable from damage.

Normal safety precautions should be followed, and proper personal protective equipment (PPE) should be worn when working in the field with this equipment, including safety glasses and nitrile gloves.

The installation of borros anchors require of the use of a hydraulic pump. Ensure the hydraulic pump is in working condition and all safety precaution is in place prior to using the tool.

6.4 Sensor Function Test

CAUTION: Electrical sensors should be verified before installation to ensure they have not been damaged during shipment or handling on site.

1. Connect the MPBX cable to a readout according to the wiring chart in Table 1.
2. Confirm the reading matches the appropriate “B” value as per the calibration record as its current sensor stroke setup.

6.5 BOREHOLE PREPARATIONS

NOTE: Ensure that the borehole is drilled to the appropriate depth, so that the anchor and tremie pipe assembly rests on the bottom of the borehole and is not freely hanging.

It is recommended that the depth of the borehole is 1m deeper than the deepest anchor elevation (see Figure 10).

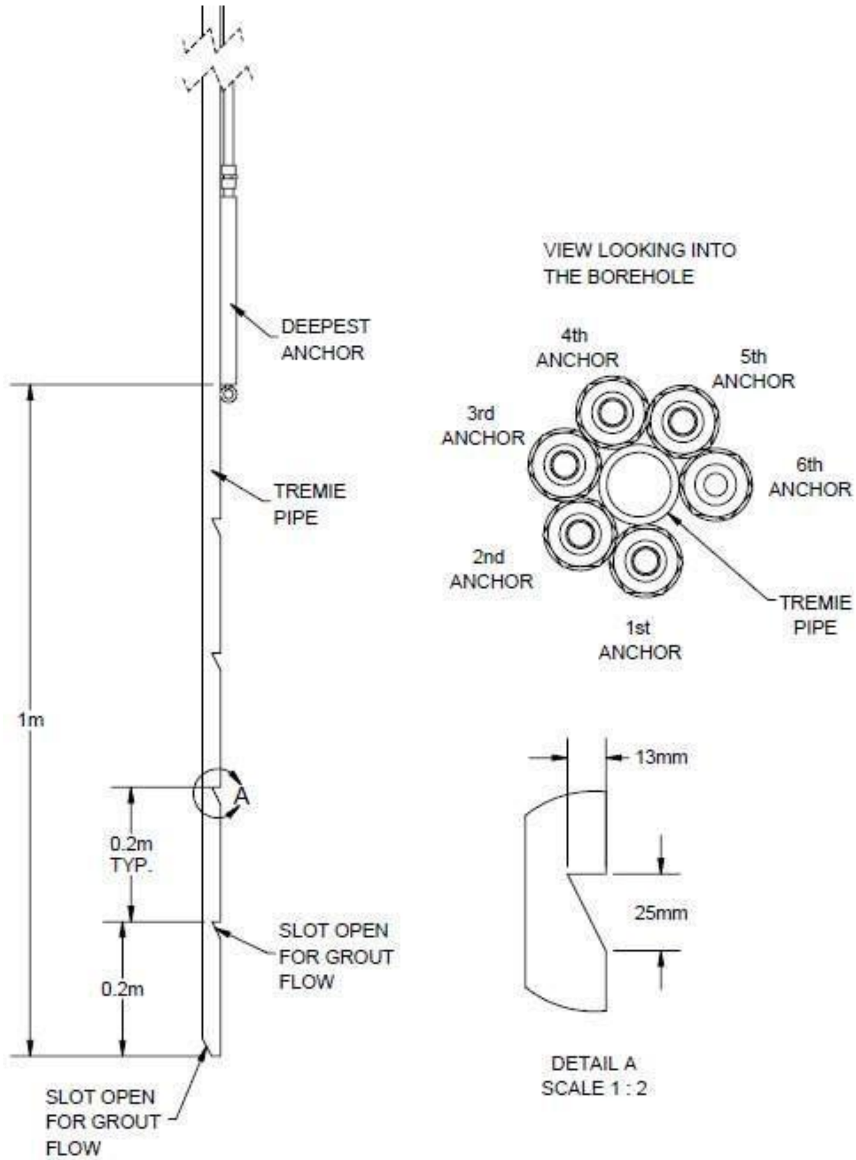

Figure 10: Borehole is 1m deeper than the lowest anchor elevation

6.5.1 Grout Delivery Tube (Tremie Pipe)

RST recommends using a semi-rigid delivery line to successfully navigate irregularities in the borehole wall. Note that ¾" Class 200 PVC plastic tremie pipe will work well, but other semi-rigid pipe/tube products made from ABS or Polyethylene plastics may also be acceptable with a slightly modified installation method.

The tubing ID should be between 12 and 25 mm to ensure low line friction and good grout delivery.

NOTE: For assistance with **downward directed borehole**, a weight can be attached to the bottom of the delivery grout tube.

For **upward directed borehole**, a more rigid grout delivery line is required.

CAUTION: Steel products should not be used for downhole grout delivery lines due to the tensile strength of the steel which could act as a reinforcement in the grout backfill and impact the function of the installed instrument anchors.

NOTE: Ensure that the required backfill grouting can be effectively carried out in the borehole.

It is recommended that downhole water pressure testing is performed prior to instrument installation.

If water loss problems are encountered during water testing, either:

- Pressure-grout the hole and re-drill to establish an acceptable lower permeability.

  OR

- Abandon the leaky hole in favor of a new hole without permeability issues.

CAUTION: It is necessary to resolve water-loss problems prior to the Extensometer installation.

6.6 FLEXIBLE ROD INSTALLATION PREPARATIONS

The Extensometer with groutable / spring / borros anchors is pre-assembled in the factory and only requires proper placement.

Remove any white tape to prepare the Extensometer for installation.

CAUTION: Ensure the sheathing is not ruptured during the deployment of the anchor prongs.

1. Compile a reference table containing the calculated lengths between each anchor, starting from:

   - The deepest anchor (for downward borehole), proceeding to the borehole collar

     OR

   - The uppermost anchor (for upward borehole), close to the borehole collar, all the way to the borehole collar

2. Unroll the assembly and check to ensure all the anchors are preassembled at the desired location.

If borros anchor is used:

1. Attach a 3/16" high pressure hydraulic inflation line to the elbow fitting on each borros anchor if the inflation line is not already attached. Ensure the inflation line is long enough to reach the pump (typically ground level + 3 m).

2. Tape the hydraulic inflation line along the anchor body. Ensure the line does not rest over the extrusion opening of the prongs.

CAUTION: Ensure that the hydraulic inflation line is taped in between the anchor prongs. Inflation lines not separated from prongs are at risk of being ruptured when the prongs get deployed.

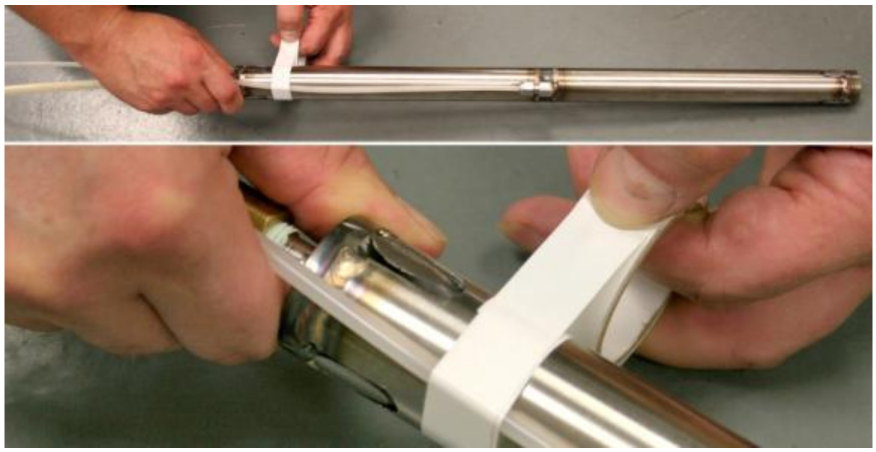

Figure 11: Hydraulic Inflation Line Taped Away from the Prongs

If spring anchor is used:

1. Attach a line or braided steel cable to the hook on the trigger pin for each spring anchors.

2. Leave a little slack in the pull lines near the trigger pins, and then tape the lines securely to the assembly to avoid an accidental activation. Ensure the line is long enough to reach the surface and each line is properly labelled to identify the anchor order from descending order down the borehole.

WARNING: Do NOT tape the trigger pin to the assembly as it could prevent the spring legs from activating.

Only tape the pull line to the assembly.

CAUTION: Ensure that the pull lines to the trigger pins (for the spring anchors) are not accidentally pulled and activated during the installation. This would disable the installation within the borehole, mid task, disabling movement in either direction. No troubleshooting action would be available without severely damaging the installation.

For this reason, groutable anchors with spring legs should only be used when there are no other options available.

Contact RST Instruments support team for further directions.

6.7 MPBX WITH FLEXIBLE ROD INSTALLATION

For the purposes of clarity, the instructions provided in this section are for downward oriented boreholes which will have a grout line (tremie pipe) installed at the bottom of the hole and a vent line or opening installed at the hole collar.

→| **NOTE**: **Upward directed boreholes** are the opposite; with grout delivery occurring at the hole collar and venting occurring by way of a vent line installed at the bottom of the borehole (at an elevation higher than the hole collar).

The following steps describe the procedure to install the Flexible Rod Multi-Point Borehole Extensometer:

1. Drill a borehole of minimum 4" in diameter and at least 1 m past the lowest anchor's elevation.

2. Unroll the Extensometer beside the borehole.

   Ensure that the anchor reference position is at the proper distance from the reference point of the Extensometer head.

3. Attach a grout tube alongside the MPBX assembly. Tape the bottom end of the grout line to the bottom anchor and tape the grout line along the MPBX assembly at every 3m.

4. Attach a safety line to the hook at the bottom of the anchor to prevent the Extensometer assembly from accidentally falling into the borehole while lowering into the borehole.

5. Lower the entire Extensometer assembly into the borehole until the anchors reach the desired elevation inside the borehole.

   a. For above grade installation: the entire Extensometer head should be above the ground surface with approximately 3" of grout collar sticking above the borehole's surface.

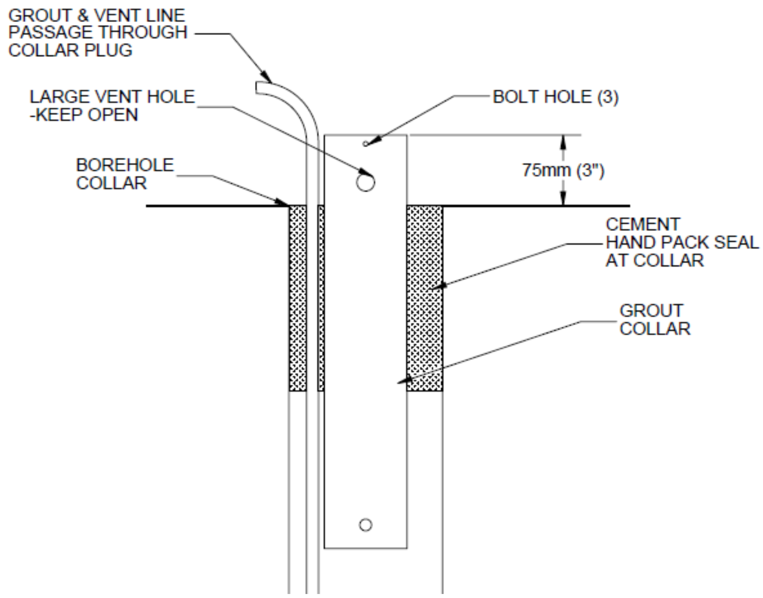

Figure 12: Grout Collar Installation

b. For below grade installation: most of the Extensometer head should be buried inside the borehole with only approximately 3" of the top of the head sticking above the borehole's surface.

→ **OPTIONAL:** Use two cross bars (not provided, order separately) or lifting line (not provided, order separately) and attach to the lifting eye on top of the MPBX if necessary to ensure that the Extensometer assembly can rest on top of the borehole before deploying the anchors.

If borros anchor is used:

- Connect a hydraulic pump to the high-pressure hydraulic inflation line for each anchor, starting from the lowest anchor going towards the top anchor.
- Slowly cycle the pump until the hydraulic borros anchor hydraulic line fails (at approx. 2500 psi).
- Repeat the last two steps until all hydraulic borros anchors have been deployed.

→ **NOTE**: The hydraulic pump is connected to a high-pressure hydraulic line, with a working pressure of 2500 psi (17.24MPa), which connects to the hydraulic borros anchors. The pressure will continue to build until the borros hydraulic line fails when the hydraulic borros anchors are deployed. Additional hydraulic oil will be needed for each anchor.

If spring anchor is used:

- Pull the line attached to the spring anchor's pull pin to activate the spring leg anchors, starting from the lowest anchor to the topmost anchor.
- Repeat the previous step until all spring anchors are activated.
- Once all the spring leg anchors are deployed, proceed to step 6 for grouting the borehole.

CAUTION: Keep a firm hold on the Extensometer during this process. Do not release the anchor and rod assembly, even when all the spider anchors have been deployed if the borehole is intended to be grouted

6. Connect the grout line to a pump to backfill the borehole with grout. (Refer to Appendix A for further details.)

7. Wait until the grout is set so that the anchors are fixed in place.

Referring to Figure 13, complete steps 8 – 10:

8. Unscrew all the threaded rods at the top of the Extensometer head to unlock the anchor rods to ensure they are free to move as the ground settles.

9. Install the provided brass reference bolts to the rod inside the head for the points that are active. The reference bolts will be used to provide a stable and flat surface for manual reading using a depth micrometer.

10. Install the provided sealing screws for all 6 holes at the top of the Extensometer head to prevent water from leaking into the instrument.

11. MPBX with flexible rods has now been installed and readings can be taken. See: Taking Readings.

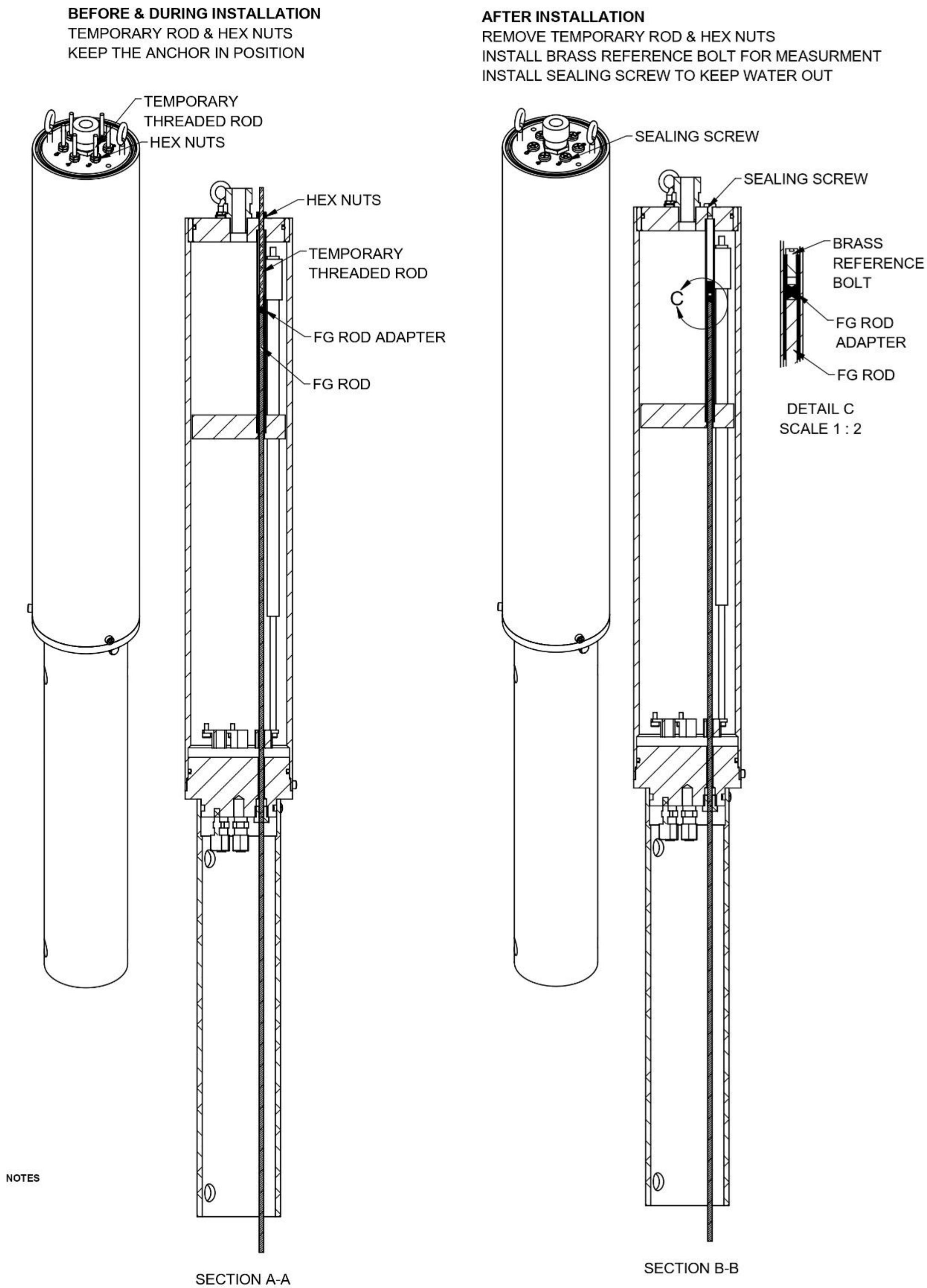

Figure 13: Components to Remove and Install Following Installation and Grouting

7 TAKING READINGS

7.1 TAKING READINGS WITH VW2106 / DT LOGGER / FLEXDAQ

1. Record the Serial Number of the MPBX marked on the top of the reference head. Serial numbers for individual sensors are provided with the calibration certificate and summary document upon delivery of the MPBX system.

2. Ensure the MPBX cable's wires are connected to a VW2106 Readout, RSTAR Affinity Logger, DT Logger, or FlexDAQ as per wiring Connection table below. B Sweep Setting: 1200-3550 Hz.

NOTE: If using any other third-party readout, please refer to the specific readout's instruction manual before operation.

3. Turn on the readout unit and the displacement will output data in digits called B units (Frequency Hz^2 / 1000).

4. Look up the Calibration Factor found on the calibration sheet for that sensor to convert the B unit readings to engineering units (i.e., mm).

5. The readout unit will also output temperature data in °C. If an Ohmmeter is used directly on the green and white wires, the equation and/or table in Appendix B can be used to calculate/derive the temperature in °C.

Table 1: Wiring Connection (Check Colour)

Cable Color Code							
Cable Type	**Sensor 1 Coil**	**Sensor 2 Coil**	**Sensor 3 Coil**	**Sensor 4 Coil**	**Sensor 5 Coil**	**Sensor 6 Coil**	**Thermistor**
EL360008 (For 1-3 Sensors)	Red & Black	Orange & Blue	Yellow & Brown	N/A	N/A	N/A	Green & White
EL380007P (For 4-6 Sensors)	Red & Black	Orange & Blue	Yellow & Brown	Grey & Violet	Tan & Pink	White & Black	Green & White

7.2 TAKING READINGS WITH A DEPTH MICROMETER

1. Record the Serial Number of the MPBX marked on the top of the reference head. Serial numbers for individual sensors are provided with the calibration certificate and summary document upon delivery of the MPBX system.

2. Insert the depth micrometer into hole/anchor #1 until its base sits flush on top of the reference head. The hole/anchor identifier number is stamped on the top of the reference head.

3. Turn the knob of the depth micrometer, lowering the feeler gauge into the hole until it clicks, indicating that it has reached the top of the rod.

4. Record the corresponding reading.

5. Repeat steps 2-4 for the remaining holes/anchors of the MPBX system.

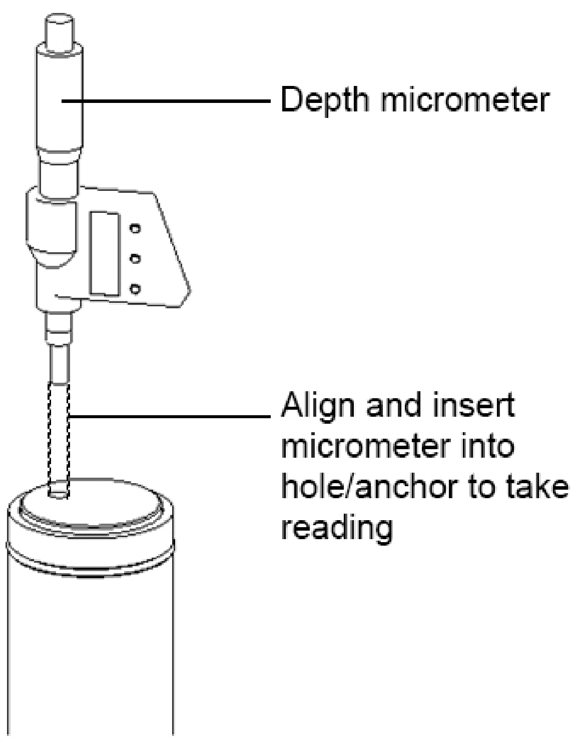

Figure 14: Manually Taking Readings with a Depth Micrometer

8 DATA REDUCTION

Linear Displacement Equation:

$$Displacement = CF(L - L_0)$$

Where:

CF	=	Calibration Factor (mm/B unit)
L	=	Current reading (B units)
L_0	=	Initial (at installation) reading (B units)

Polynomial Displacement Equation:

$$Displacement = A(L^2) + B(L) + C + K(T - T_0)$$

Where:

A	=	Polynomial Gauge Factor (in mm/(B unit)²)
B	=	Polynomial Gauge Factor (in mm/B unit)
C	=	Polynomial Gauge Factor (in mm)

NOTE: Polynomial Gauge Factor C is calculated using the following formula:
$C = -[A(L_0^2) + B(L_0)]$

L	=	Current reading (B units)
K	=	Temperature Correction Factor (mm/°C)

NOTE: See Equation 3 to calculate Temperature Correction Factor.
- displacement = compression
+ displacement = extension

Current anchor elevation = initial anchor elevation + displacement.

NOTE: Typically, this is done for each anchor after converting from B units to Engineering units.

9 Product Specifications

Item	Specification
Sensor	
Sensor Range	50, 100, 150, 200 mm
Accuracy	+/- 0.25 % FSR
Resolution	0.025% FSR
Linearity	0.50% FSR
Electrical	
Operating Temperature	-20°C to 80°C
Thermal Zero Shift	<0.05% FSR/°C
Mechanical	
Number of Anchors	1 to 6
Borehole Diameter	recommend minimum 4” (101 mm)

10 SERVICE, REPAIR AND CONTACT INFORMATION

Contact RST for product services or repairs.

- For sales information: sales@rstinstruments.com
- For technical support: support@rstinstruments.com
- Website: www.rstinstruments.com
- Toll free: 1-800-665-5599

RST Canada Office (Head Quarters)

Address: 11545 Kingston Street, Maple Ridge, BC, Canada V2X 0Z5

Telephone: 604-540-1100

Fax: 604-540-1005

Business hours: 7:30 a.m. to 5:00 p.m. (PST) Monday to Friday, except holidays

RST UK Office

Address: Unit 4 Charles Industrial Estate Stowupland Road, Stowmarket
Suffolk, UK, IP14 5AH

Telephone: +44 1449 706680

Business hours: 9:00 a.m. to 6:30 p.m. (GMT) Monday to Friday except holidays

APPENDIX A: GROUTING THE BOREHOLE

The grout to be injected is a homogenized mixture of cement and water made according to the usual grouting procedures. The cement/water ratio depends on stiffness of the surrounding ground. To ensure compliance of the grout with the surrounding ground, it is generally necessary to cast test specimens to confirm the grout stiffness and deformability. In case of highly fissured rock, it may be necessary to seal the fissures, to grout and drill the hole prior to the installation of the Extensometer or to use mechanical anchors. Once grouting is completed, make sure that grout tube that exceeds from the MPBX has been cut.

Making cement-bentonite grout in the field is a straightforward process. The most effective mixing is commonly done in a barrel or tub with the drill-rig pump, circulating the batch through the pump in 50-to-200-gallon quantities. The rig pump provides the kind of jet-mixing required to get the job done quickly. Any kind of bentonite powder used to make drilling mud combined with Type 1 or 2 Portland cement and water can be used, but the appropriate quantity of bentonite will vary somewhat depending on grade of bentonite, mixing sequence, mixing effort (agitation), water pH and temperature.

Grout mixes should be controlled by weight and proportioned to give the desired strength of the set grout. The conversion factors contained in Appendix H.10 in Dunnicliff (1988, 1993) are very helpful in mix design. Two mixes are given in Table 1 that varies in 28-day strength from 50 psi to 4 psi for water-cement ratios of 2.5 to 6.6 respectively.

Table 2: Cement-Bentonite Grout Mix

Application	**Grout for Medium to Hard Soils**		**Grout for Soft Soils**	
Materials	Weight	Ratio by Weight	Weight	Ratio by Weight
Water	30 gallons	2.5	75 gallons	6.6
Portland Cement	94 lbs. (1 sack)	1	94 lbs. (1 sack)	1
Bentonite	25 lbs. (as required)	0.3	39 lbs. (as required)	0.4
Notes	The 28-day compressive strength of this mix is about 50 psi, similar to very stiff to hard clay. The modulus is about 10,000 psi.		The 28-day strength of this mix is about 4 psi, similar to very soft clay.	

NOTE: Combine cement and water first, followed by bentonite. Adjust the amount of bentonite until the grout reaches the proper consistency.

If the grout is not thick enough, the solids and the water will separate, and there is risk of shrinkage.

If the grout is too thick, pumping will be difficult and there is risk of flash-set.

DOWNWARD DIRECTED BOREHOLES

Grouting is completed when the injected grout emerges from the borehole. After sufficient time has elapsed for curing of the grout, the Extensometer head is checked to ensure that it is adequately grouted in place. Additional mortar may be hand placed around the head if required.

UPWARD DIRECTED BOREHOLES

An installation into an upward directed borehole requires special means to support and apply the necessary lift force to position the Extensometer. Extra care should be taken to ensure that the full weight of the Extensometer assembly is supported prior to grouting operation. The easiest way is to secure the latter with wood wedges and to make a tight cap at the borehole collar level with oakum sealant and quick setting cement. The safest way to secure the Extensometer in place is with a wood support tightly anchored to the surface surrounding the borehole using tie bolts.

The grouting must be done only when the anchor head is solidly anchored to the head of the borehole. The shortest tube is used for injection; the longest is the vent tube. For long Extensometers, the cement plug may not be resistant enough to support the weight of the grout column applying on it. In that case, it may be necessary to inject in two stages. A second injection tube is necessary in that case. The first stage consists of pumping enough grout to reinforce the cement plug located at the Extensometer head. Once the grout has set, the rest of the borehole can be injected through the second tube. Grouting is completed when the material injected emerges from the vent tube. After sufficient time has elapsed for curing of the grout, the Extensometer head is checked to ensure that it is adequately grouted in place. Additional mortar may be hand placed around the head if required.

NOTE:

- The grout consistency will vary depending upon type of bentonite used, water content, pH level of water, temperature and mixing method. The amount of bentonite hence required to reach appropriate consistency will hence vary.
- A Marsh Funnel can be used to ensure proper grout consistency. Ideal time ~ 55 seconds.

Contact RST instruments for further details and support.

APPENDIX B: TEMPERATURE CONVERSION

The following equation may be used to convert the measured thermistor resistance R (Ω) into temperature T (°C).

$$T = \frac{1}{1.4051 * 10^{-3} + 2.369 * 10^{-4} * \ln(R) + 1.019 * 10^{-7} * (\ln(R))^3} - 273.2$$

Equation 1: Thermistor Temperature Derivation

Alternatively, the values may be looked up directly in the table below:

Table 3: Thermistor Resistance (Ω) versus Temperature (°C)

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	141.11	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
77.99K	-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	-35	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	282.4	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	56.92	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.	53	250.9	93	83.6	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

APPENDIX C: TEMPERATURE CORRECTION

Temperature correction may not be necessary in many cases as the Multi-Point Borehole Extensometer has a small coefficient of thermal expansion.

Temperature corrections may be applied for maximum accuracy or when temperature fluctuations are greater than 10°C.

$$Corrected\ Linear\ Displacement = CF(L_c - L_i) + K(T_c - T_i)$$

Equation 2: Linear Displacement Calculation

Enter the appropriate values into Equation 2 to calculate the displacement and convert the readings into linear units. All subsequent readings should be subtracted from the initial reading to calculate the distance the crack has opened, where:

L_C	Current reading	[B-unit]
L_i	Initial reading	[B-unit]
CF	Linear Calibration Factor (see calibration sheet)	[mm/B-unit]
T_C	Current temperature	[°C]
T_i	Initial temperature	[°C]
K	Temperature Factor (see Equation 3)	[mm/°C]

Use Equation 3 to calculate K, the temperature correction factor:

$$K = CF[(L_c * M) + B]$$

Equation 3: Temperature Correction Factor Calculation

L_C	Current reading	[B-unit]
M	Slope, see Table 3	[1/°C]
B	Constant, see Table 3	[B-unit/°C]
CF	Linear Calibration Factor, (see calibration sheet)	[mm/B-unit]

Stroke (mm)	50	100	150	200
Slope (M)	0.000311	0.000399	0.000359	0.000306
Constant (B)	-0.2758	-0.8128	-0.5579	-0.4498

Table 4: Temperature Correction Factor

Sample calculation:

Assuming the following measurements from a 150mm sensor:

L_C	3762	[B-unit]
L_i	4791	[B-unit]
CF	0.0291788	[mm/B-unit]
T_C	22.5	[°C]
T_i	13.3	[°C]
M	0.000359	[1/°C]
B	-0.5579	[B-unit/°C]

First, calculate the Temperature Correction Factor using Equation 3:

$$K = CF[(L_c * M) + B]$$

$$\mathrm{K} = (0.0291788) * [(3762 * 0.000359) + (-0.5579)]$$

$$\mathrm{K} = (0.0291788) * (0.792658)$$

$$\mathrm{K} = 0.023129$$

Next, apply K to Equation 2 to find the corrected Linear Displacement:

$$Corrected\ Linear\ Displacement = CF(L_c - L_i) + K(T_c - T_i)$$

$$= [(0.291788) * (3762 - \mathbf{4791})] + [(\mathbf{0.023129}) * (\mathbf{22.5 - 13.3})]$$

$$= (-\ \mathbf{1029} * \mathbf{0.291788}) + (\mathbf{0.023129} * \mathbf{9.2})$$

$$= -\ \mathbf{29.81\ mm}$$

APPENDIX D: SAMPLE CALIBRATION RECORD

Calibration Record

RST Instruments Ltd., 11545 Kingston Street, Maple Ridge, BC, Canada V2X 0Z5
Tel: 604-540-1100 • Fax: 604-540-1005 • Toll free: 1-800-665-5599 (North America only)
www.rstinstruments.com

Vibrating Wire Multi-Point Extensometer

Serial Number:	MB1049	
Calibration Date:	Sept. 12, 2023	
Sensor Number:	1	
Range:	200.0 mm	
Temperature:	23.0 °C	
Cable Length:	10 m	
Cable Markings:	n/a	
Cable Colour Code:	Red / Black (Coil)	Green / White (Thermistor)
Cable Type:	EL380007P	
Thermistor Type:	3 kOhms	

Applied Displacement (mm)	First Reading Up (B units)	Second Reading Up (B units)	Average Reading (B units)	Calculated Linear (mm)	Linear Error (% FS)	Calculated Polynomial (mm)	Polynomial Error (% FS)
0.00	2964	2964	2964	0.02	0.01	0.05	0.02
40.00	3879	3879	3879	39.96	-0.02	39.96	-0.02
80.00	4793	4793	4793	79.89	-0.05	79.87	-0.06
120.00	5714	5715	5715	120.17	0.08	120.15	0.07
160.00	6627	6627	6627	160.02	0.01	160.01	0.01
200.00	7542	7540	7541	199.94	-0.03	199.96	-0.02

Linear Calibration Factor (CF): **4.3681E-02 mm/B unit**

Polynomial Gauge Factors:

A: **8.7259E-09 mm/(B unit)^2** **B:** **4.3589E-02 mm/B unit** **C:** **_______________ mm**

Displacement is calculated using the following equations:

Linear: $D = CF(L - L_0)$

Polynomial: $D = D = A(L^2) + B(L) + C + K(T - T_0)$

NOTE: Users must establish site zero readings for calculation purposes.
Polynomial $C = -[A(L_0^2) + B(L_0)]$
See manual for K (Temperature Correction Factor, in mm/°C) value of sensor

L_0, L = initial (at installation) and current readings, in B units

T_0 ,T = initial (at installation) and current temperature, in °C

B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts

B units = Hz^2 / 1000 i.e. 1700 Hz = 2890 B units

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1