RST INSTRUMENTS LTD.

MEMS In-Place Inclinometer System
Instruction Manual

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MEMS In-Place Inclinometer System

Product: MEMS In-Place Inclinometer System
Installation Manual

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1 GENERAL DESCRIPTION

RST Micro-Electro-Mechanical Systems (MEMS) In-Place Inclinometer (IPI) Systems are designed to measure lateral movements of soil and rock or deflection of man made structures such as piles or retaining walls, especially when remote and continuous monitoring is required. MEMS in-place inclinometers are available with one or two MEMS sensors (i.e. uniaxial or biaxial). The integral signal conditioning electronics are housed in a watertight, stainless steel tube. Each sensor bay is separated from the next by stainless steel rods (or wire rope) and are connected with a flexible joint. Rod lengths can be varied to alter the gauge length of the system. By varying the gauge length, sensors can be concentrated in areas of expected movement. Wheel assemblies are sized to fit either 70mm (2.75") OD or 85mm (3.34") OD inclinometer casing. As movement occurs and the inclinometer casing deforms, each sensor can be automatically monitored and can be read at a remote readout location. If necessary, an alarm can be triggered when movement reaches a preset critical rate.

2 INSTALLATION

2.1 STANDARD IPI

Before beginning the installation, ensure that the following components and tools are present:

1. Correct number of IPI Bays (One Top Bay and Bottom Bay, and a residual number of Standard Bays to make up the total number of bays corresponding to their respective borehole).
2. Correct length of cable attached to IPI Instruments.
3. Set of Hex Head Wrenches in metric.
4. Tape for securing IPI cable and safety line.

The appropriate size inclinometer casing is first installed, aligned and grouted in-place. The In-Place Inclinometer bays are numbered from the bottom of the hole to the top.

1. Attach a safety line to the bottom wheel assembly (see Figure 2). For best control and safety on deep installations, this safety line should be secured to a winch. Contact RST for further details.
2. Install bay number one (with the **longest** cable) first.
3. Align the A-Axis wheels with the anticipated failure direction and insert the wheels in the inclinometer casing grooves. The A+ (sprung wheel) should be oriented towards the anticipated movement (see Figure 1).

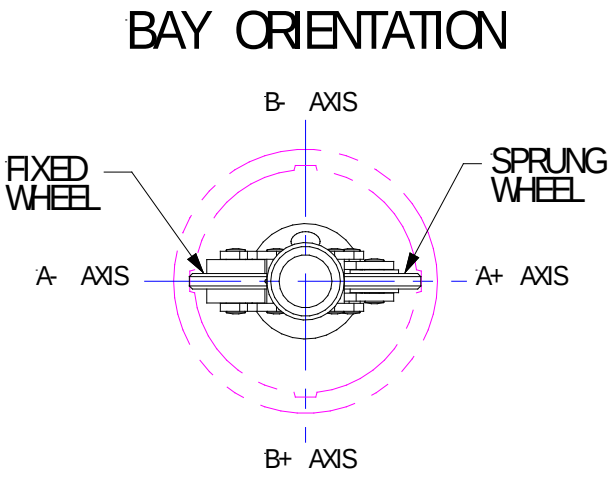

Figure 1: MEMS IPI Orientation

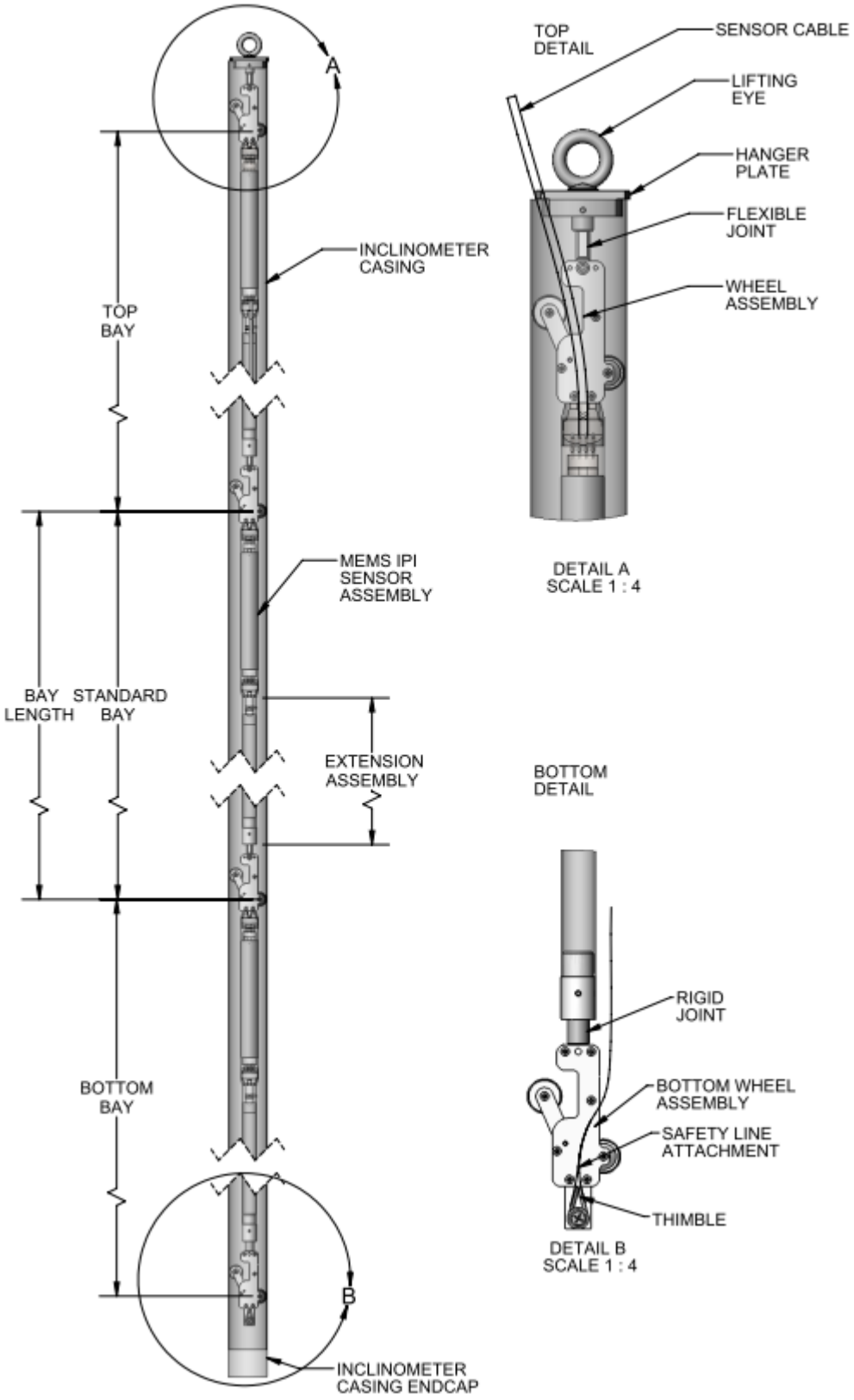

Figure 2: MEMS IPI General Arrangement

4. Slowly lower the Bay into the hole, securing the signal cable to the IPI approximately every meter. Ensure the wheel assembly is aligned with the grooves in the casing and that the signal cable doesn't foul the wheels.

5. When the Bay is protruding 10 cm out of the casing, secure the inclinometer from falling down the hole.
6. Locate the next IPI Bay Length and slide the end of the next bay over the protruding flexible joint of the previously installed bay. Ensure the alignment of the wheel assembly matches the previously installed bay, and then set the screw into place.
7. Slowly lower the assembly into the casing, securing the IPI cables to the IPI with tape (Approx. every 1 m) and ensure the wheels are aligned with the grooves of the inclinometer casing.

> **Note**
> The cables should be secured in a neat and orderly fashion to prevent the cables from crossing or fouling the wheel assemblies.

8. Lower the assembly until the Bay is protruding 10 cm out of the casing.
9. Repeat steps 5-8 until all bays are installed
10. The last bay (with the hanger plate) should be lowered onto the casing with the number of IPI cables split evenly on either side of the hanger plate.
11. Connect the cables to the data logger or RST handheld. Electrical connections are provided in Section 5.

2.2 SS WIRE ROPE SYSTEM

In a case where specific zones are of interest, and not the profile of the entire borehole, a SS Wire Rope System is used. Standard Bay lengths are available with each Bay coupled via a site specific length of SS wire rope. This provides a very flexible and versatile method for coupling the bays as the length of SS rope can be determined and manufactured in the field. Installation is the same as the Standard Bay Installation with respect to orientation and positioning. Each sensor has two wheel trucks per bay and coupling is done in a similar fashion as the standard bays, except with SS wire rope. To modify a SS wire rope for coupling bays together:

1. Determine the length of SS wire rope to be used for coupling IPI bays together (**make sure to allow enough length for making loops at either end**).
2. Use the supplied ***1/8" Wire Rope Clips/Thimble*** to make a loop at either end of the SS wire rope (as per instructions printed on the back of the ***1/8" Wire Rope Clips/Thimble*** packaging).
3. Trim any excess wire rope protruding from the ***Dead End*** of the loop.

Once the SS wire rope couplers are made, the IPI bays can be stringed together, with the wire rope couplers acting as a spacer in between the bays, using the supplied D-Rings (see Figure 3).

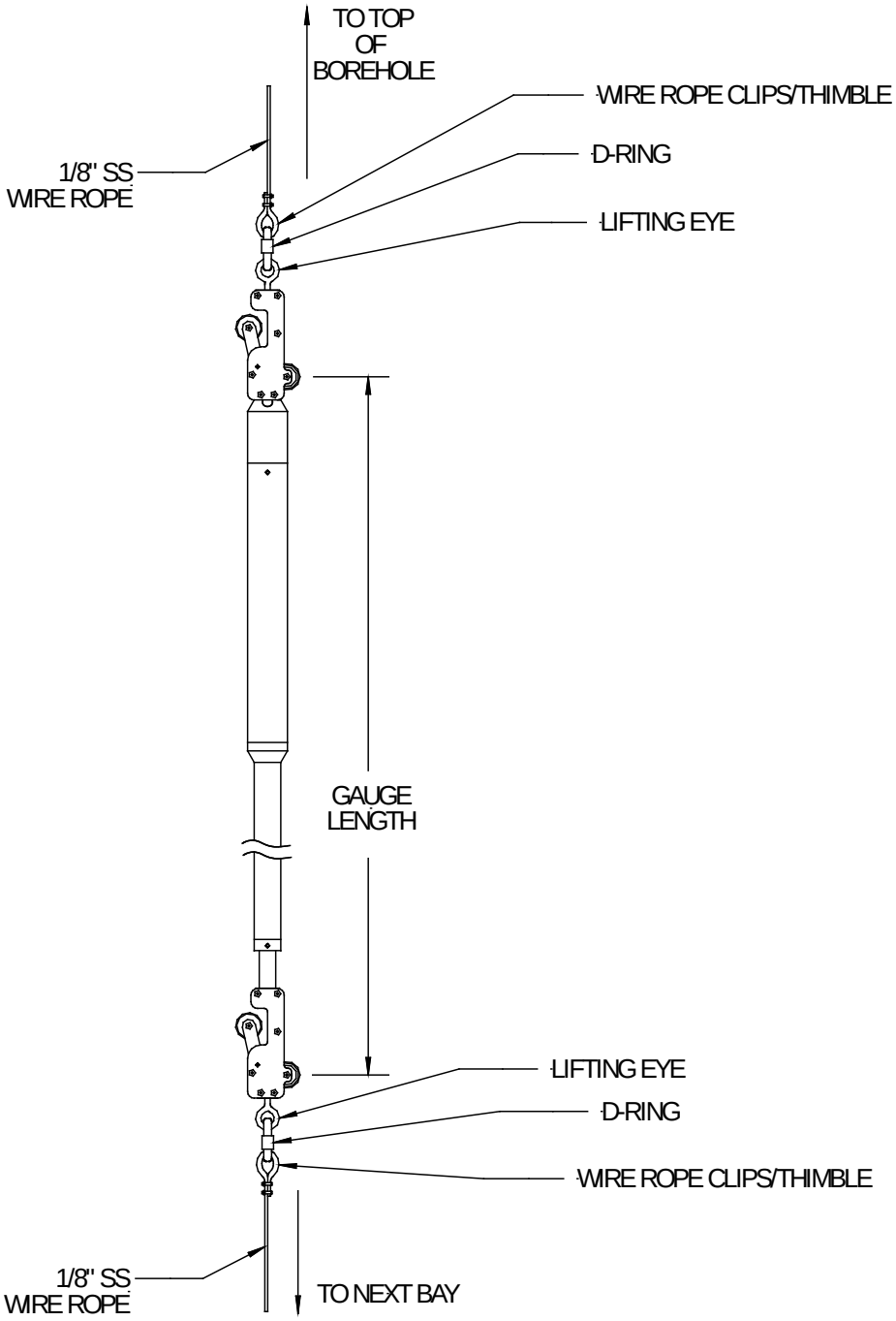

Figure 3: SS Wire Rope Bay Layout

2.3 SINGLE CABLE BUS SYSTEM

Installation is essentially the same as the individual cable system, except that M12 connectors will be used to connect each IPI bay.

With the exception of the top and bottom bay, all bays are identical, and have a cable fitted with a submarine electrical connector protruding from each end of the IPI (see Figure 5). The bottom bay is unique in that the bottom wheel assembly is rigidly fixed to the IPI.

The top bay is readily identified as it is fitted in the factory with a hanger plate.

Install as per the individual cable connector system, taking care to connect each bay's electrical connector prior to inserting into the borehole. To connect the electrical connectors, simply connect the female connector from the top MEMS IPI to the male connector from the bottom MEMS IPI.

WARNING

Failure to follow the instructions below will result in failure of the connector and string.

To ensure connectors are properly sealed, the coupling nuts must be tightened to a tightening torque of 0.6Nm (hand-tight). Then use a 14mm wrench to turn it one notch further to a tightening torque of 1.5Nm (approximate another **1/8** turn using a wrench). To prevent damage on the connectors, only apply torque on the flats of the metal coupling nuts.

Note that the thread will likely still be visible once the connector is properly tightened.

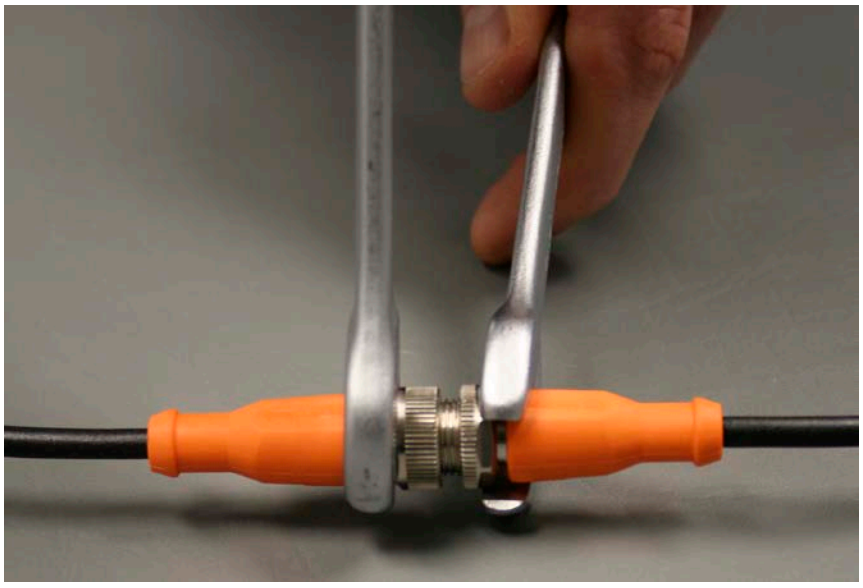

Figure 4: Connecting M12 Connectors

WARNING

Always keep the protective caps on the connectors. Only remove just prior to connecting. See Figure 6.

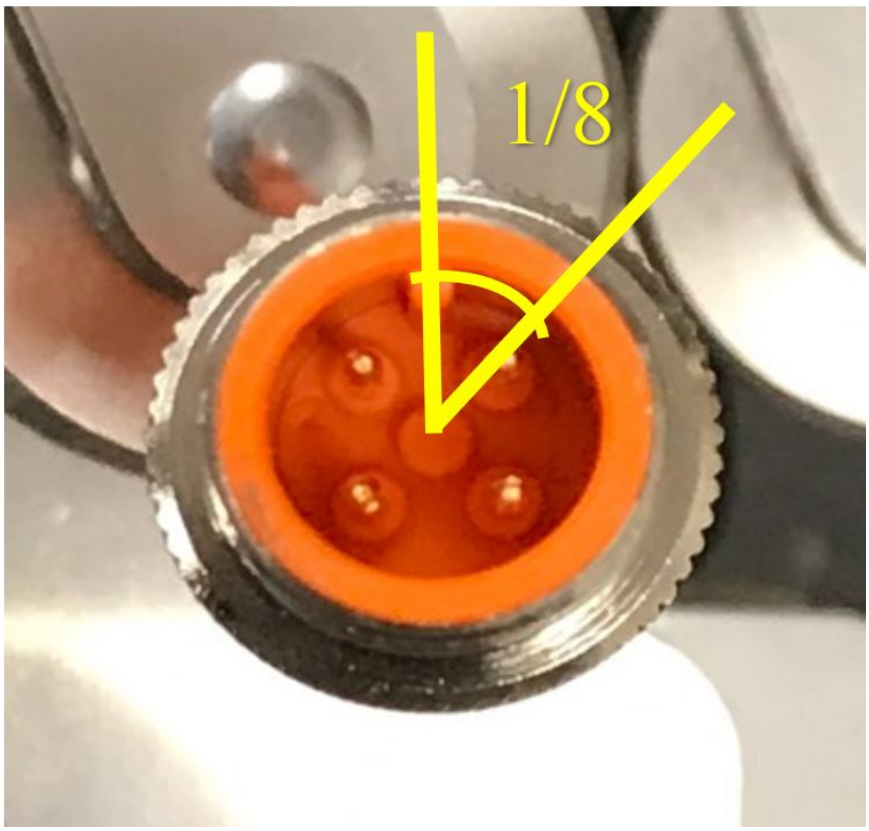

Figure 5: Further Tighten Approximately 1/8 Turn

Figure 6: Ensure Protective Caps are Always on the Connectors

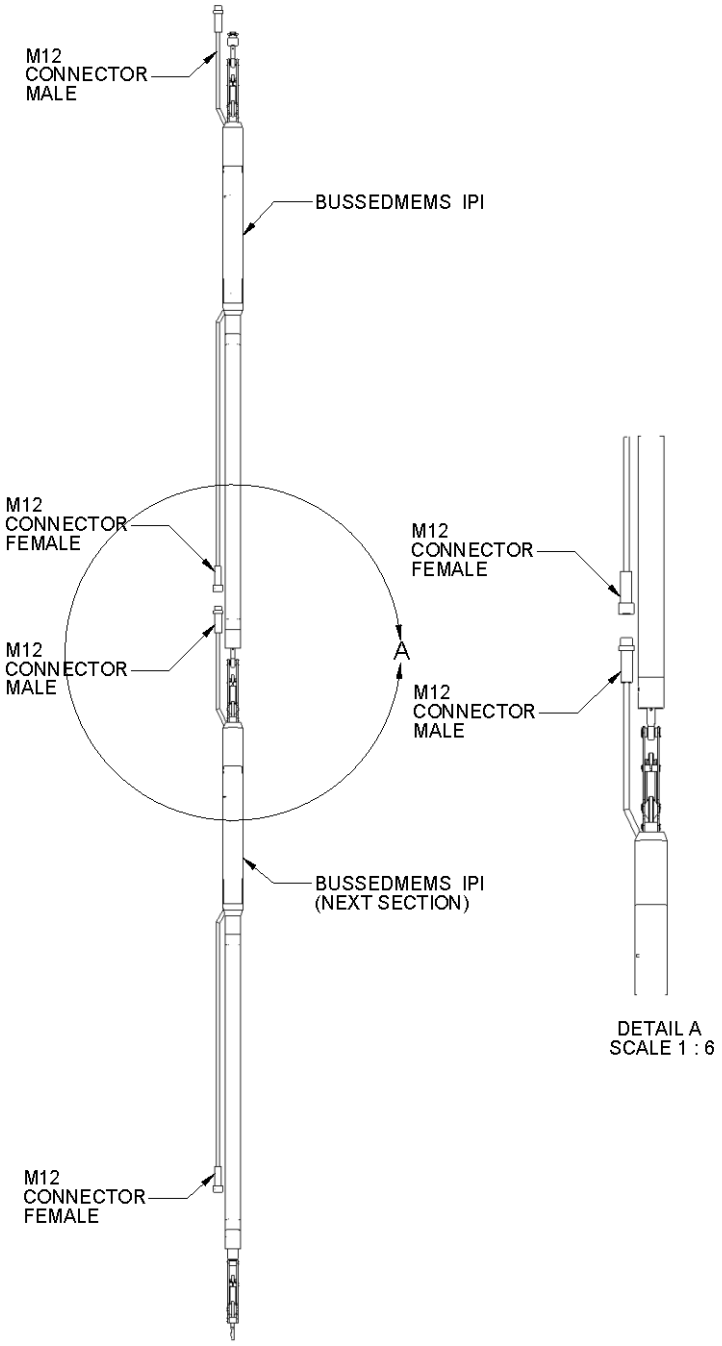

Figure 7: Bussed IPI with M12 Connectors

3 OPERATION

The MEMS In-Place Inclinometers consist of one (uniaxial) or two (biaxial) ±15° sensors mounted inside a 1.25" SS housing. A length of 3 pair cable is supplied with each inclinometer bay. The MEMS IPI sensors output a high level voltage, which is read by a Datalogger or a Handheld (See Section 5 for electrical connection details). Movement of the inclinometer casing will change the angle output of the in-place inclinometers. This angle can be used to calculate the displacement or distance the inclinometer casing has moved. The bottom of the hole is used as the reference. The angle is calculated by converting the mV/V reading to an angle (based on the calibrations) and using the following equation:

$$\Delta d = L \times (\sin \alpha_c - \sin \alpha_I)$$

Equation 1: Tilt Displacement

Δd = Change of displacement
L = length of bay
α_I = Initial tilt (angle)
α_C = Current tilt (angle)

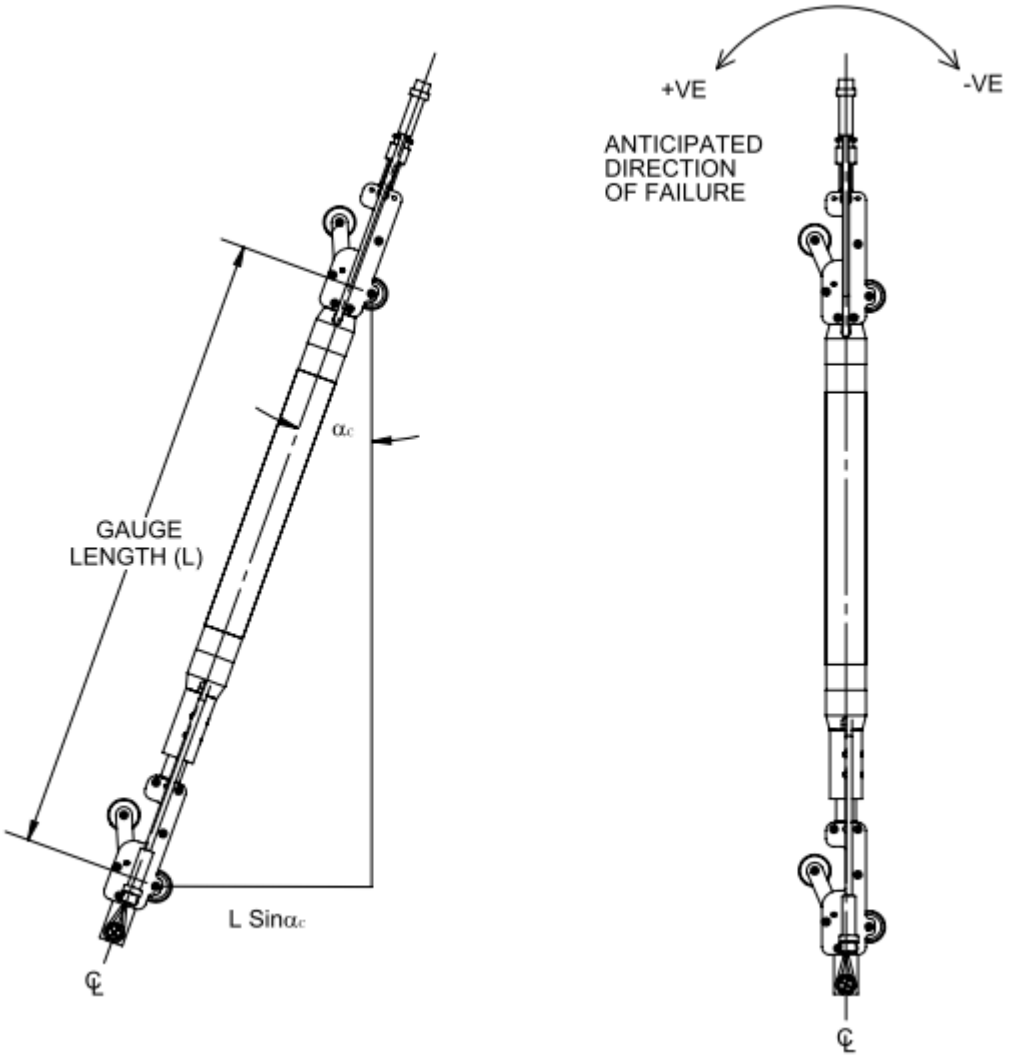

Figure 8: MEMS IPI Reaction

MEMS In-Place Inclinometers should be read during quiet times, not when heavy pile driving or construction activity is present (preferably at night).

3.1 RECORDING INITIAL READINGS

It is important to immediately take an initial reading (α_i) after an installation, as this will be the reference point from which relative displacements will be taken.

1. Record the serial number of the MEMS IPI located at the end of the IPI cable.
2. Record a reading.
3. Repeat steps 1-2 for all MEMS IPI's.

3.2 RECORDING CURRENT READINGS

To find out the amount of tilt (α_c):

1. Record the serial number of the MEMS IPI located at the end of the IPI cable.
2. Record a reading.
3. Repeat steps 1-2 for all MEMS IPI's.

3.3 ANALYZING THE DATA

Each MEMS IPI is identified by a Serial Number, and has a corresponding Calibration Certificate (See Appendix A: Sample Calibration Certificate). The sensing principle of the MEMS IPI is that of an accelerometer with the sensitive axis is oriented. To convert the sensor signal into meaningful data, simply substitute the values from the readings and the Calibration Constants into the following formula:

$$\mathbf{Sin\ \alpha = m(V-b)}$$

Equation 2: Tilt Angle

Where

- **V** is the MEMS IPI Output signal.
- **m** is the predetermined Calibration Constant.
- **b** is the predetermined Calibration Constant.

4 SENSOR SPECIFICATIONS

Environmental	
Operating temperature	-40°C to +80°C
4.1 ELECTRICAL	
Sensor	One/Two MEMS Tilt Sensor(s)
Range	± 15 Degree Standard
Resolution	0.0013 Degree
Null Repeatability	<0.004 Degree
Signal Cable	22 Gauge Shielded Water Blocked 3 Pair Polyurethane Jacketed
4.2 MECHANICAL	
Gauge Length	0.5, 1, 1.5, 2, 2.5, or 3 meters
Housing Diameter	32mm (1 ¼") (sensor)
Wheel Assembly	70 mm (2.75") or 85 mm (3.34")
Extension Rod Diameter	25mm (1")

5 ELECTRICAL CONNECTIONS

1. Under the Color Code Table, look up the lead designations for the type of cable being used.
2. Under the Electrical Connections Table, make the appropriate lead connections, according to the type of system being used. Uniaxial MEMS IPI system only has A axis while Biaxial MEMS IPI system has both A axis and B axis.

5.1 UNIAXIAL/BIAXIAL (ANALOG OUTPUT) MEMS IPI SYSTEM

Wire Color	MEMS IPI	Datalogger
Red	12V	12V
Black	Ground	Ground
Green	A +	xH
White	A -	xL
Orange	B +	yH
Blue	B -	yL

Note: B+ and B- (Blue and Orange) are only for **Biaxial** MEMS IPI System.

5.2 UNIAXIAL/BIAXIAL (DIGITAL OUTPUT) MEMS IPI SYSTEM

Wire Color	MEMS IPI
Red	V+
Black	Gnd
Green	A+
White	B-

5.3 UNIAXIAL / BIAXIAL (DIGITAL OUTPUT) BUSSED MEMS IPI SYSTEM

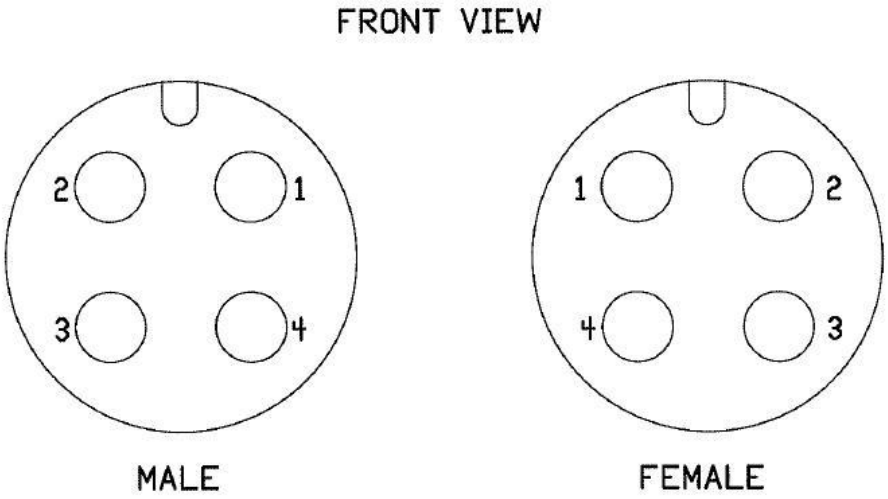

Figure 9: M12 Connectors

PIN	Wire Color	Tiltmeter
1	Brown	12V
2	White	Ground
3	Blue	A+
4	Black	B-

6 APPENDIX A: SAMPLE CALIBRATION CERTIFICATE

Calibration Record

200 - 2050 Hartley Ave., Coquitlam, British Columbia, Canada V3K 6W5
Tel: 604.540.1100 • Fax: 604.540.1005 • Toll Free: 1.800.665.5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Biaxial MEMS In-Place-Inclinometer

Customer: RST
Serial No.: **Bixxxxx**
Date: 29-Apr-08
Model: IC7505
W.O. No.: Q010xxx
Cable Length: 1 m
Cable Type: EL380006
References:
Inclinometer Frame RST-06
Referenced Annually To National Standards.

Wiring

Red	P+	Orange	B+
Black	P-	Blue	B-
Green	A+		
White	A-		

A-Axis

Applied Angle (Deg)	Applied Angle (Sin)	IPI Output (V)	Calculated Angle (Sin)
15	0.2588	3.922	0.2588
10	0.1736	2.560	0.1736
5	0.0872	1.178	0.0871
0	0.0000	-0.214	0.0000
-5	-0.0872	-1.605	-0.0870
-10	-0.1736	-2.988	-0.1736
-15	-0.2588	-4.352	-0.2589

$\sin \alpha =$ **m(V-b)**

m = **0.062578**
b = **-0.21414**

B-Axis

Applied Angle (Deg)	Applied Angle (Sin)	IPI Output (V)	Calculated Angle (Sin)
15	0.2588	4.097	0.2589
10	0.1736	2.737	0.1736
5	0.0872	1.359	0.0871
0	0.0000	-0.028	0.0001
-5	-0.0872	-1.418	-0.0872
-10	-0.1736	-2.795	-0.1736
-15	-0.2588	-4.155	-0.2589

$\sin \alpha =$ **m(V-b)**

m = **0.062746**
b = **-0.02900**

Calibrated By: James

Figure 10: Calibration Certification for Analog Output MEMS IPI

Calibration Record

200 - 2050 Hartley Ave., Coquitlam, British Columbia, Canada V3K 6W5
Tel: 604.540.1100 • Fax: 604.540.1005 • Toll Free: 1.800.665.5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

MEMs Biaxial In-Place Inclinometer - Digital Bus Output

Customer: RST
Work Order Number: Q01xxxx
Model: IC7565
Serial Number: Bixxxx
Date: 30-Mar-10

Wiring:

Colour	Function	Pin
Brown	V+	1
White	Gnd	2
Blue	A+	3
Black	B-	4

References: Inclinometer Frame RST-06
Referenced to National Standards Annually

A-Axis

Face Frame Angle Degrees	A+/-	Sin ⊖	Swing Right Sin ⊖	Swing Left Sin ⊖	Mean Sin ⊖	Error Sin ⊖
15	L	0.25882	0.25882	-0.25880	0.25881	0.00001
10	L	0.17365	0.17364	-0.17365	0.17365	0.00000
5	L	0.08716	0.08715	-0.08716	0.08715	0.00000
0		0.00000	-0.00003	0.00001	-0.00002	0.00002
5	R	-0.08716	-0.08715	0.08714	-0.08715	-0.00001
10	R	-0.17365	-0.17365	0.17366	-0.17365	0.00000
15	R	-0.25882	-0.25882	0.25882	-0.25882	0.00000

B-Axis

Face Frame Angle Degrees	B+/-	Sin ⊖	Swing Right Sin ⊖	Swing Left Sin ⊖	Mean Sin ⊖	Error Sin ⊖
15	L	0.25882	0.25880	-0.25880	0.25880	0.00002
10	L	0.17365	0.17371	-0.17361	0.17366	-0.00001
5	L	0.08716	0.08722	-0.08710	0.08716	0.00000
0		0.00000	0.00009	0.00009	0.00000	0.00000
5	R	-0.08716	-0.08709	0.08720	-0.08715	-0.00001
10	R	-0.17365	-0.17366	0.17368	-0.17367	0.00002
15	R	-0.25882	-0.25884	0.25884	-0.25884	0.00002

Calibrated By: M. Hubbard

Document Number: ICL0042B

Figure 11: Calibration Certification for Digital Output MEMS IPI

7 APPENDIX B: MEMS HORIZONTAL IPI DETAILS

The RST MEMS Horizontal In-Place Inclinometer is simply a uniaxial MEMS IPI internally modified to measure horizontally as opposed to vertically. Construction and electronics are the same as the vertical IPI probes as discussed in this manual.

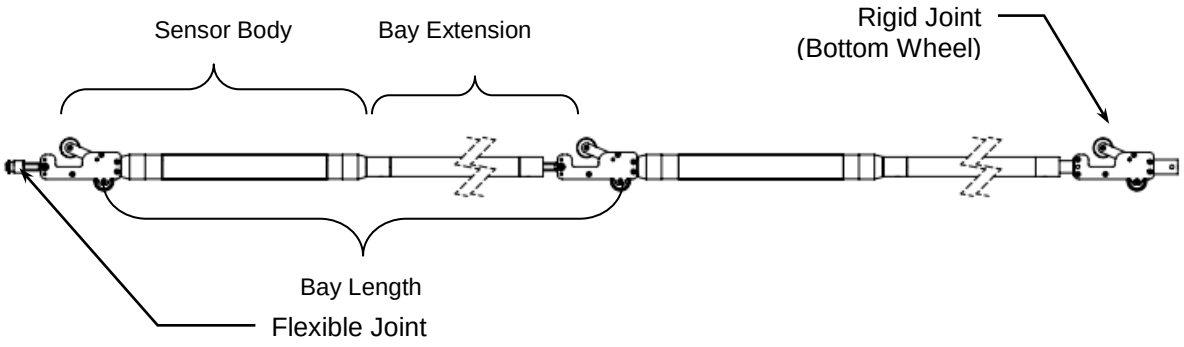

Figure 12: MEMS Horizontal IPI Orientation

Proper orientation places the sprung wheel upwards in the inclinometer casing.

1. Attach a Bottom Wheel Assembly to an Extension Assembly (use setscrews provided and ensure the setscrew bottoms out in the groove of the Wheel Assembly and then loosen ¼ turn to allow the wheel to rotate).
2. Insert the Assembly into the borehole and secure in place, when ready to add a Standard Bay Sensor Assembly.
3. Attach a Standard Sensor Assembly (use setscrews provided and ensure the setscrew bottoms out in the groove of the Sensor Assembly, and then loosen ¼ turn to allow the assembly to rotate).
4. Attach the next Extension Assembly (use setscrews provided and ensure the setscrew bottoms out in the groove of the Sensor Assemblies' Wheel Assembly, and then loosen ¼ turn to allow the assembly to rotate).
5. Repeat steps 2-5, for the remaining Sensor Assemblies, including the Top Bay Sensor Assembly.
6. Attach the Hanger Plate to the last Sensor Assembly and insert into the Casing until the Hanger Plate sockets inside the top of the Casing.

8 ADDENDUM: MODULAR ASSEMBLY OF IPI BAY

1. Attach a Bottom Wheel Assembly to an Extension Assembly (use setscrews provided and ensure the setscrew bottoms out in the groove of the Wheel Assembly, and then loosen ¼ turn to allow the wheel to rotate).
2. Attach a Safety line (with a thimble) around the screw on the Bottom Wheel Assembly.
3. Lower the Assembly into the borehole and secure in place when ready to add a Standard Bay Sensor Assembly.
4. Attach a Standard Sensor Assembly (use setscrews provided and ensure the setscrew bottoms out in the groove of the Sensor Assembly, and then loosen ¼ turn to allow the wheel to rotate).
5. Attach the next Extension Assembly (use setscrews provided and ensure the setscrew bottoms out in the groove of the Sensor Assemblies' Wheel Assembly, and then loosen ¼ turn to allow the wheel to rotate).
6. Repeat steps 3-5, for the remaining Sensor Assemblies, including the Top Bay Sensor Assembly.
7. Attach the Hanger Plate to the last Sensor Assembly and insert into the Casing until the Hanger Plate sockets inside the top of the Casing.