



Monitor
with
Confidence

MEMS In-Place Inclinometer System Instruction Manual

CE

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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 (uniaxial) or two (biaxial) MEMS sensors. 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 pre-set critical rate.

1.1 CONNECTORS

RST In-Place Inclinometers are IP68 rated. It is recommended that the IPI connections be made in an area free of dirt and water. The IPI connectors must be kept clean and connected only when clean. The connectors should be threaded correctly to prevent any moisture ingress or tightening issues.

Ensure the threads and O-ring inside the connectors are free of dirt and moisture. Any dirt within the connectors may cause water ingress and cause an entire string of IPIs to fail.



CAUTION: ANY CONTAMINANT, SUCH AS DIRT OR WATER, IN THE IPI THREADS OR CONNECTORS COULD CAUSE AN ENTIRE STRING OF IPIs TO FAIL.

Store the IPI connector caps somewhere clean and dry for future use. To prevent potential contamination, cover the IPI connectors with the provided connector caps each time the IPI is disassembled. Refer to Figure 1-1.

Ensure the connectors are clean before reinstalling the IPI. Refer to Section 1.2 for cleaning instructions.



FIGURE 1-1 **ENSURE PROTECTIVE CAPS ARE ALWAYS ON THE CONNECTORS**

1.2 **CLEANING THE IPI**

It is strongly recommended that the IPI string is assembled prior to installation in the field. This will reduce the chances of contaminants entering the connectors.

In the event of contamination within the connectors, the connector ends may be dipped in isopropyl alcohol and set aside to dry. Once dry, compressed air may be used to blow dirt out of the connectors. Take care not to blow the O-ring out of the connector.

O-ring lube should be applied to the male end of the connector (opposite the O-ring end) when connecting cleaned, dried connectors.

2 **INSTALLATION OF STANDARD IPI**

2.1 **REQUIRED MATERIALS AND TOOLS**

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

- Correct number of IPI Bays:
 - One Top Bay,
 - One Bottom Bay,

- Residual number of Standard Bays to make up the total number of bays corresponding to their respective boreholes,
- Correct length of cable attached to IPI instruments;
- Set of metric hex head wrenches;
- Can of compressed air;
- Isopropyl alcohol;
- O-ring lube;
- Tape for securing the IPI cable and safety line.

2.2 PRE-INSTALLATION

It is recommended to prepare and assemble the IPI off-site when possible, such as in an office or similar setting. This will ensure a clean installation site and minimize any chance of dirt or water contaminating the connectors or threads.

Off-site assembly will also allow the IPI connectors to be properly tightened as installation may be hindered or rushed on-site.

2.3 INSTALLATION

- 1 Install, align, and grout the appropriate size inclinometer casing.
- 2 Gather the in-place inclinometer bays. Lay them in order of installation from the bottom of the borehole to the top.
- 3 Attach a safety line to the bottom wheel assembly. Refer to Figure 2-2.
 - It is recommended to secure the safety link to a winch for best control and safety on deep installations. Contact RST for further details.
- 4 Install bay number one (with the longest cable) first.
- 5 Align the A-Axis wheels with the anticipated failure direction. Insert the wheels in the inclinometer casing grooves. The A+ (sprung wheel) should be oriented towards the anticipated movement. Refer to Figure 2-1.
- 6 Slowly lower the bay assembly into the borehole while securing the signal cable to the IPI with tape approximately every meter. Ensure the wheel assembly is aligned with the grooves in the casing and that the signal cable doesn't cross or obstruct the wheels.
- 7 Secure the inclinometer from falling down the borehole when the bay is protruding 10 cm out of the inclinometer casing.

BAY ORIENTATION

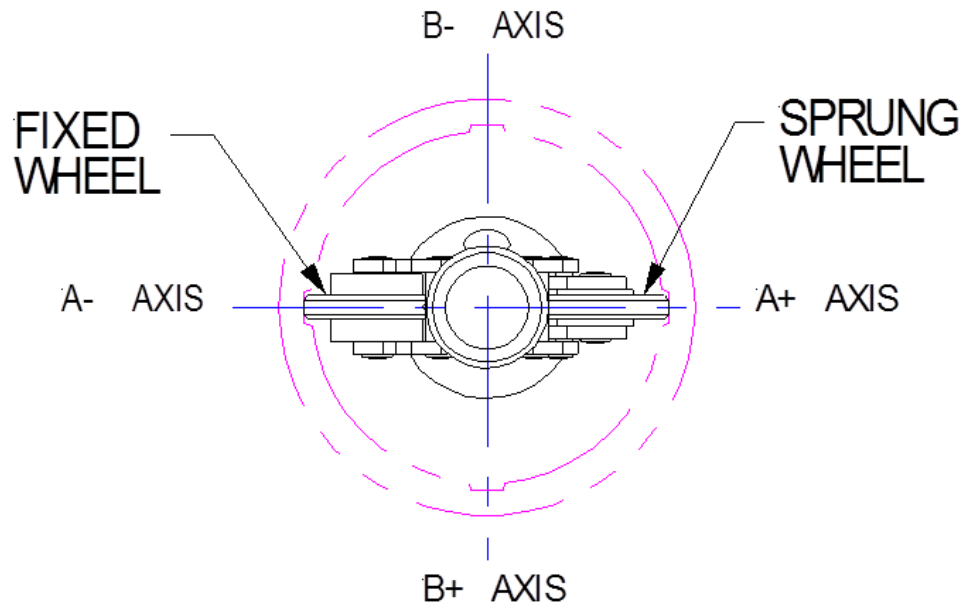


FIGURE 2-1 MEMS IPI ORIENTATION

- 8 Locate the next IPI bay and slide the end over the protruding flexible joint of the previously installed bay. Ensure the alignment of the wheel assembly matches the previously installed bay before setting the screw into place.
- 9 Slowly lower the bay assembly into the casing. Secure the IPI cables to the IPI with tape approximately every meter. Ensure the wheel assembly is aligned with the grooves in the casing and that the signal cable doesn't cross or obstruct the wheels.



NOTE: THE CABLES SHOULD BE SECURED IN A NEAT AND ORDERLY FASHION TO PREVENT THE CABLES FROM CROSSING OR OBSTRUCTING THE WHEEL ASSEMBLIES.

- 10 Lower the bay assembly until it is protruding 10 cm out of the inclinometer casing.
- 11 Repeat steps 5-8 until all bays are installed.
- 12 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.
- 13 Connect the cables to a data logger or Ultra-Rugged Field PC2. Refer to Section 5 for electrical connections.

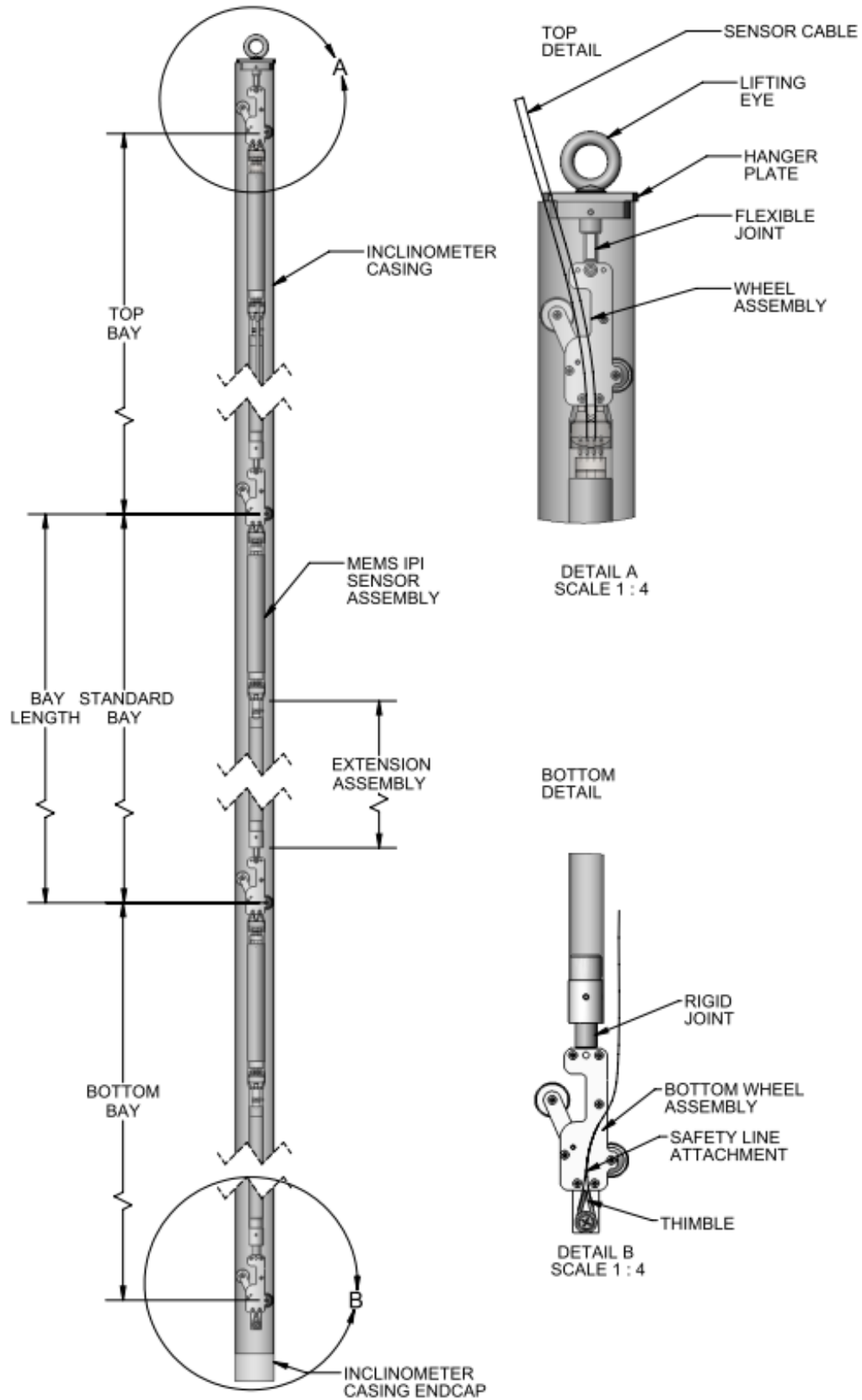


FIGURE 2-2 MEMS IPI GENERAL ARRANGEMENT

2.4 STAINLESS STEEL WIRE ROPE SYSTEM

A stainless steel wire rope system may be used for cases where specific zones are of interest, rather than the profile of the entire borehole.

Standard bay lengths are available with each bay coupled via a site specific length of stainless steel wire rope. This provides a very flexible and versatile method for coupling the bays as the length of stainless steel rope can be determined and manufactured in the field.

Installation is the same as the standard IPI installation with respect to orientation and positioning. Each sensor has two wheel trucks per bay. Coupling is completed in a similar fashion as the standard bays, except with stainless steel wire rope.

The following steps outline the instructions to modify a stainless steel wire rope for coupling bays together:

- 1 Determine the length of stainless steel wire rope to be used for coupling IPI bays together. Ensure there is enough length to make loops at either end.



NOTE: MEASURE EXTRA LENGTH OF STAINLESS STEEL WIRE ROPE TO MAKE LOOPS AT EITHER END.

- 2 Use the supplied **1/8" Wire Rope Clips/Thimble** to make a loop at either end of the stainless steel wire rope as per the 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.

The IPI bays can be strunged together when the stainless steel wire rope couplers are made. The couplers act as a spacer in between the bays using the supplied D-rings. Refer to Figure 2-3.

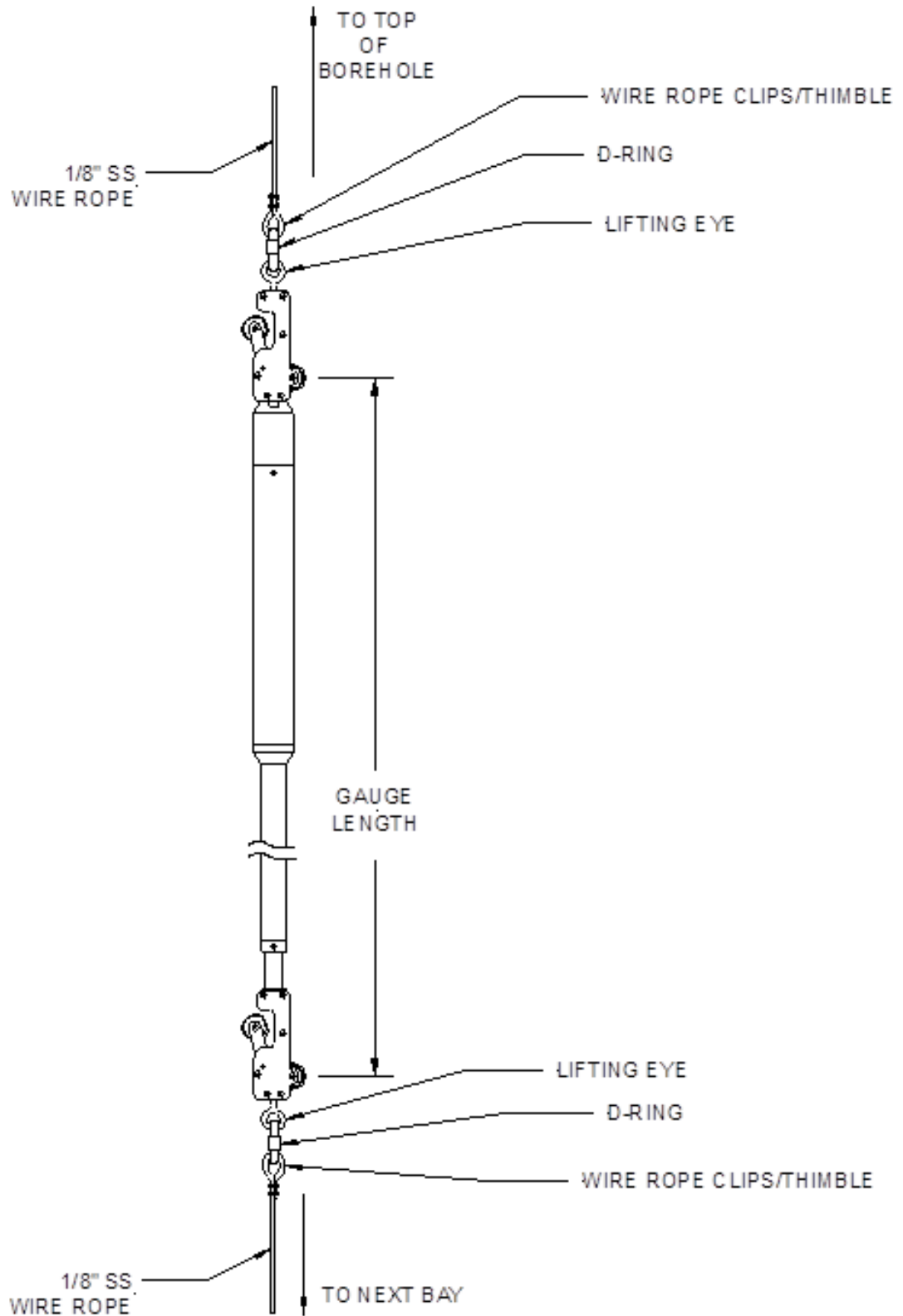


FIGURE 2-3 SS WIRE ROPE BAY LAYOUT

2.5 SINGLE CABLE BUS SYSTEM

Installation of a single cable bus system is similar to the standard IPI installation except M12 connectors will be used to connect each IPI bay.

All bays are identical with the exception of the top and bottom bays. The top bay is fitted with a hanger plate in the factory. The bottom bay differs from a standard IPI bottom bay as the bottom wheel assembly is rigidly fixed to the IPI. A cable fitted with a submarine electrical connector will protrude from each end of the IPI. Refer to Figure 2-5.

Installation of the single cable bus system is similar to the installation of the individual cable connector system. The electrical connectors for each bay will need to be connected prior to inserting the assembly into the borehole.

Ensure all caps stay on the connectors until it is time to connect the connectors. Refer to Figure 2-6. The following steps outline the instructions to connect the electrical connectors for a single cable bus system:

- 1 Connect the female connector of the top IPI to the male connector of the subsequent IPI.



CAUTION: FAILURE TO FOLLOW THE INSTRUCTIONS BELOW WILL RESULT IN FAILURE OF THE CONNECTOR AND STRING.

NOTE THAT THE THREAD WILL LIKELY STILL BE VISIBLE ONCE THE CONNECTOR IS PROPERLY TIGHTENED.

- Hand-tighten the coupling nuts. Use 14 mm wrenches to further tighten the coupling nuts one extra notch (one click). The torque on the tightened nuts should be between 0.6 Nm and 1.5 Nm. Only apply torque on the flats of the metal coupling nuts. Refer to Figures 2-4 and 2-5.



CAUTION: ONLY APPLY TORQUE ON THE FLATS OF THE METAL COUPLING NUTS TO PREVENT DAMAGE ON THE CONNECTORS.

- 2 Wrap tape around the secured connectors to prevent dirt ingress.



NOTE: THE THREAD ON THE CONNECTORS WILL LIKELY STILL BE VISIBLE ONCE THE CONNECTER HAS BEEN PROPERLY TIGHTENED.

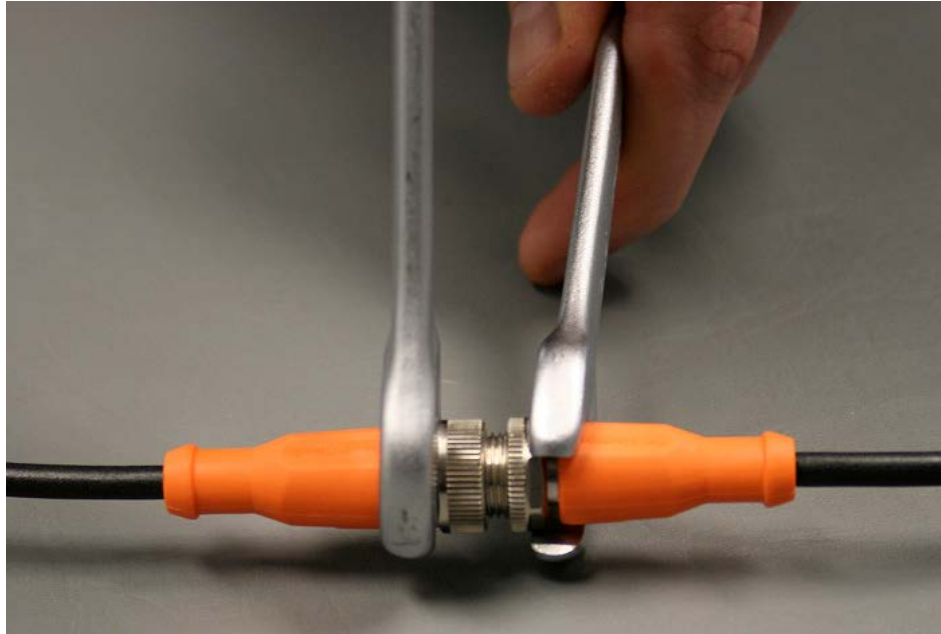


FIGURE 2-4 CONNECTING M12 CONNECTORS



CAUTION: ALWAYS KEEP THE PROTECTIVE CAPS ON THE CONNECTORS. ONLY REMOVE THEM JUST PRIOR TO CONNECTING. REFER TO FIGURE 2-5.



FIGURE 2-5 ENSURE PROTECTIVE CAPS ARE ALWAYS ON THE CONNECTORS

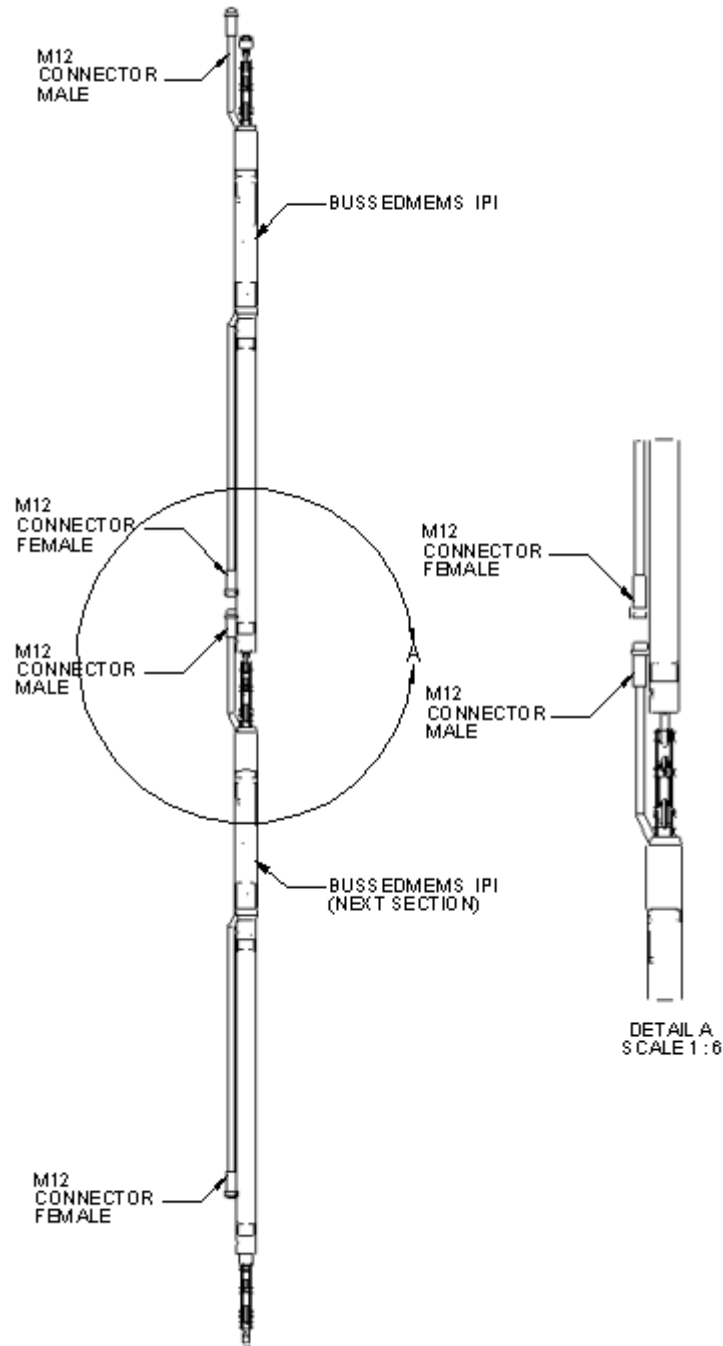


FIGURE 2-6 BUSSE IPI WITH M12 CONNECTORS

2.6 REINSTALLATION

IPIs may be reused for different sites. In the case of removing a previously installed IPI and reinstalling elsewhere, ensure the IPI, especially the connectors, stay clean. Refer to Section 2.2 for instructions on properly cleaning the IPI and connectors.

Always keep the connector caps on when the inclinometers are not in use. Always clean the connectors after detaching the IPIs. Ensure the IPIs and connectors are clean and dry before reinstalling elsewhere.

3 OPERATION

The MEMS In-Place Inclinometers consist of one (uniaxial) or two (biaxial) $\pm 15^\circ$ 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 6 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 3-1

TILT DISPLACEMENT

Δd = Change of displacement

L = length of bay

α_i = Initial tilt (angle)

α_c = Current tilt (angle)

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

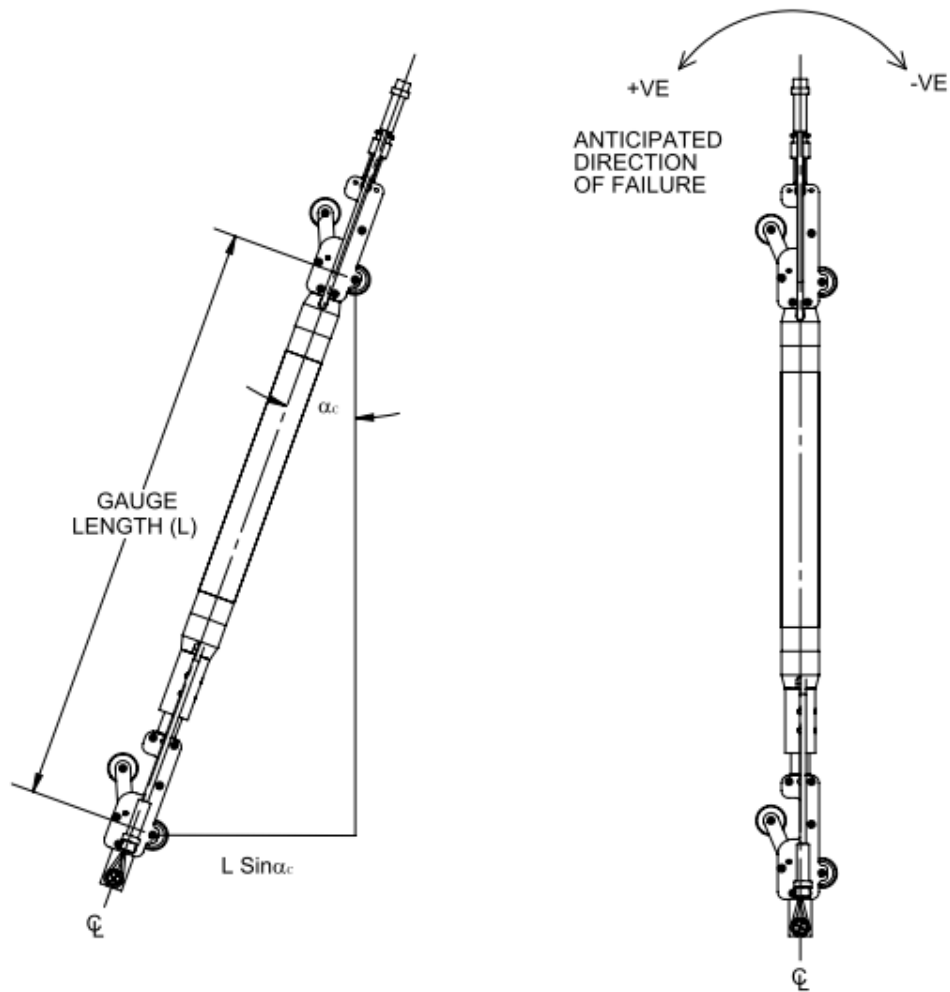


FIGURE 3-1 MEMS IPI REACTION

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:

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

EQUATION 3-2 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

TABLE 4-1 SENSOR SPECIFICATIONS

Environmental	
Operating Temperature	-40°C to +80°C
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
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

TABLE 5-1 UNIAXIAL/BIAXIAL (ANALOG OUTPUT) MEMS IPI SYSTEM

Wire Color	MEMS IPI	Data Logger
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

TABLE 5-2 UNIAXIAL/BIAXIAL (DIGITAL OUTPUT) MEMS IPI SYSTEM

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

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

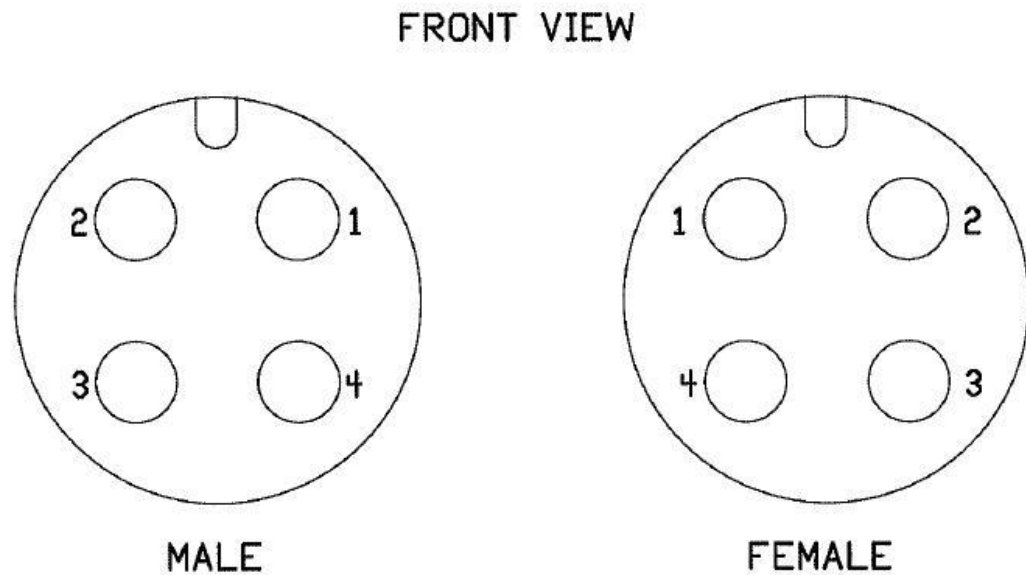


FIGURE 5-1 M12 CONNECTORS

TABLE 5-3 M12 CONNECTORS

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

6 SERVICE AND REPAIR

The product contains no user-serviceable parts. Contact RST for product service or repair not covered in this manual.

Appendix A SAMPLE CALIBRATION CERTIFICATE 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

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

Appendix B SAMPLE CALIBRATION CERTIFICATE FOR DIGITAL 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 \ominus	Swing Right Sin \ominus	Swing Left Sin \ominus	Mean Sin \ominus	Error Sin \ominus
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 \ominus	Swing Right Sin \ominus	Swing Left Sin \ominus	Mean Sin \ominus	Error Sin \ominus
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

Appendix C 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.

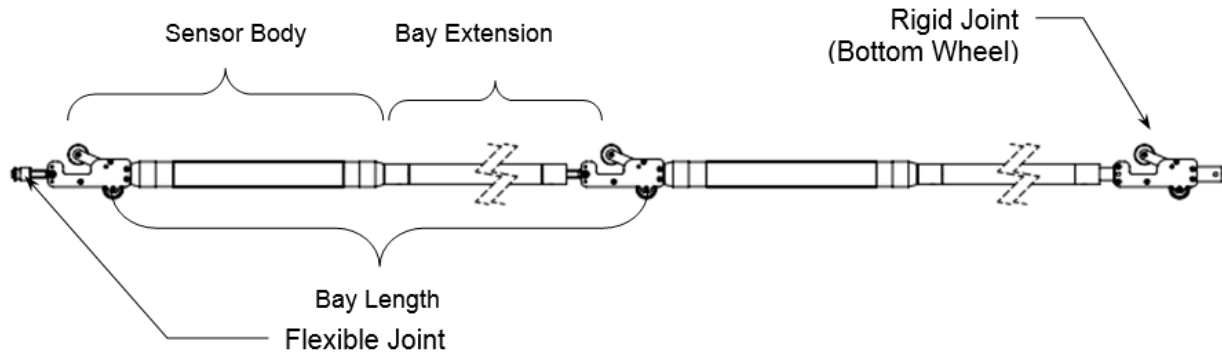


FIGURE C-1

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 $\frac{1}{4}$ 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 $\frac{1}{4}$ 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 $\frac{1}{4}$ 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.

Appendix D **MODULAR ASSEMBLY OF IPI B AY**

- 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 $\frac{1}{4}$ 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 $\frac{1}{4}$ 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 $\frac{1}{4}$ 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.