MEMS In-Place Inclinometer System Installation and User Manual

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REVISION HISTORY

Rev.	Revision History	Date	Prepared By	Approved By
J	Content updated for IC27050; revision table added.	2020-Sep-17	MP	AB
K	Replaced sample calibration chart, added a note on p.10 about silicone grease on the connectors.	2023-Apr-28	AV, MP	EG, AV
L	Specifications and formatting update. Added diagrams illustrating axes orientation.	2025-Apr-23	SM	SP, JP, AA

1 Intended Audience

This guide is for the personnel responsible for installing or using the MEMS In-Place Inclinometer System. This manual provides steps for installing the MEMS In-Place Inclinometer System, and how to take readings and interpret them.

2 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.

3 Safety

	**WARNING:** Always follow safety precautions and use proper personal protective equipment (PPE) including safety glasses and high-visibility clothing when working in the field with this equipment.

4 Abbreviations and Acronyms

This section lists abbreviations and acronyms used in the document.

Abbreviation or acronym	Definition
MEMS	Microelectromechanical Systems
IPI	In-Place Inclinometer
HOSS	Heavy Over-hole Suspension System
kgf	Kilogram-force
mm/m	Millimeters per meter
°C	Degrees Celsius
°F	Degrees Fahrenheit
µA	Microamperes
V	Volt

DC	Direct Current
MPa	Megapascal
m	Meter
mm	Millimeter
in	Inch

5 INTRODUCTION

RST's MEMS In-Place Inclinometer (IPI) System is designed to reliably measure lateral movement in and around dams, embankments, landfills, landslides, piles, piers, retaining walls, and abutments, particularly when continuous remote monitoring is required. It provides early movement warning, which is essential forprotecting life and equipment.

Each IPI employs MEMS (micro-electromechanical systems) accelerometer sensors housed inside a 28.1 mm (1.125 in) diameter, water-tight, stainless-steel enclosure. The sensor body is rigidly connected to a 25.4 mm (1.0 in) diameter bay rod, which establishes the length of the IPI. Multiple IPIs are assembled with pivots, allowing for displacement sensing over discreet, configurable intervals. Wheel assemblies centralize the pivot point and establish the azimuth of each IPI. Units are available in sizes to fit 70 mm (2.75 in) or 85 mm (3.34in) OD inclinometer casings.

The sensors are read through a bussed signal cable designed to chain together multiple sensors. A data logger is used to monitor the deflection of each sensor onthe digital bus. If necessary, an alarm can be triggered when movement reaches adesignated threshold rate or magnitude.

5.1 FEATURES

- Up to 70% reduction in installation time compared to previous generation
- IP68 (2 MPa), stainless steel enclosure
- Wet-mate submersible connector
- Precision locking & tools free bay rod connections
- Industry-leading system weight

5.2 APPLICATIONS

The MEMS Digital In-Place Inclinometer System is ideal for monitoring of:

- Stability adjacent to excavations or underground workings
- Dams and embankments
- Landslides
- Deflection of piles, piers, abutments, or retaining walls

Figure 1: Overview of MEMS In-Place Inclinometer System

6 INSTALLATION OF STANDARD IN-PLACE INCLINOMETER SYSTEM

6.1 REQUIRED MATERIALS AND TOOLS

Before installing the IPI System, ensure the following components and tools are present:

- Correct number and length of IPI bay rods
- Correct number of IPI sensors with correct cable length
- Shoulder bolts (2 per bay)
- 3/8” hex wrench
- Electrical tape
- Safety cable assembly: safety cable, clevis pin, locking hair pin, flat washer, D-ring
- Collar hanger
- Cross rod (approximately ½” diameter)
- **Optional:** Heavy Over-hole Suspension System (HOSS)
- Cable bottom plug

6.2 INSTALLATION GUIDELINES

Please refer to Figure 2 and follow the instructions outlined below to correctly install a MEMS IPI.

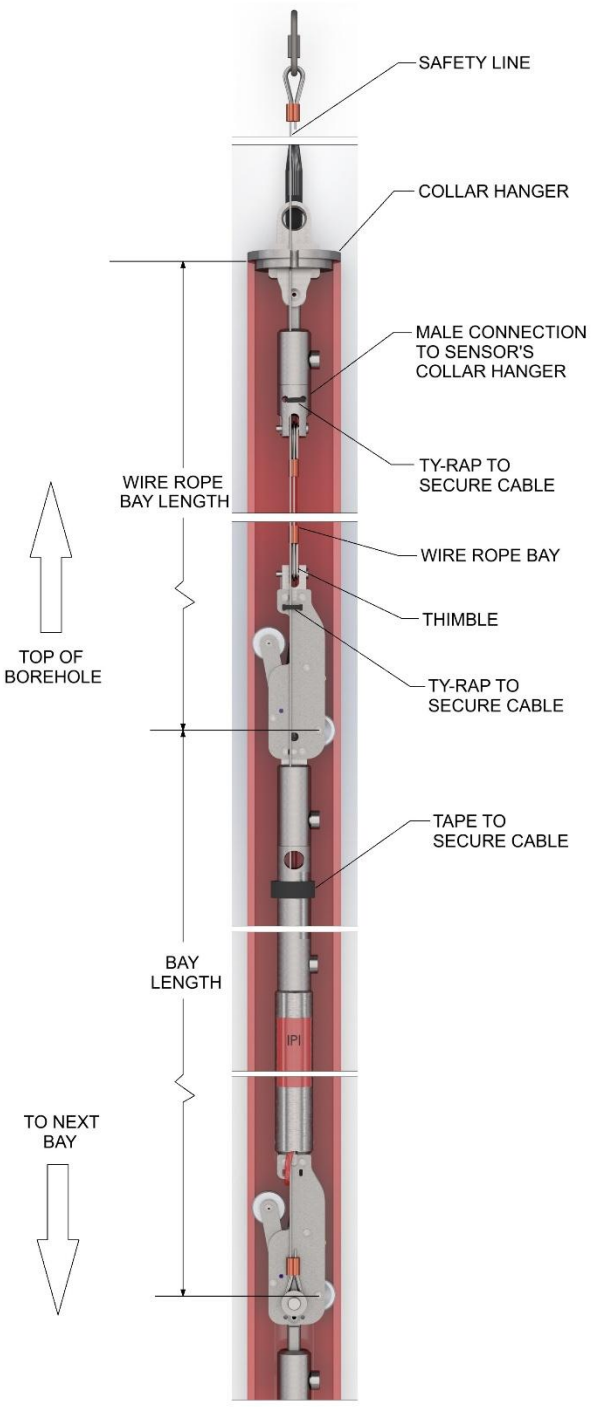


Figure 2: Installation of MEMS IPI

1. Gather the IPI bay rods and sensors.

2. Secure the collar hanger to the top sensor (see Figure 3). Loosen the shoulder bolt at the top of the IPI sensor and slide the sensor into the collar hanger, aligning the shoulder bolt in the j-slot. Twist the sensor counterclockwise into the seat of the j-slot and tighten the bolt.

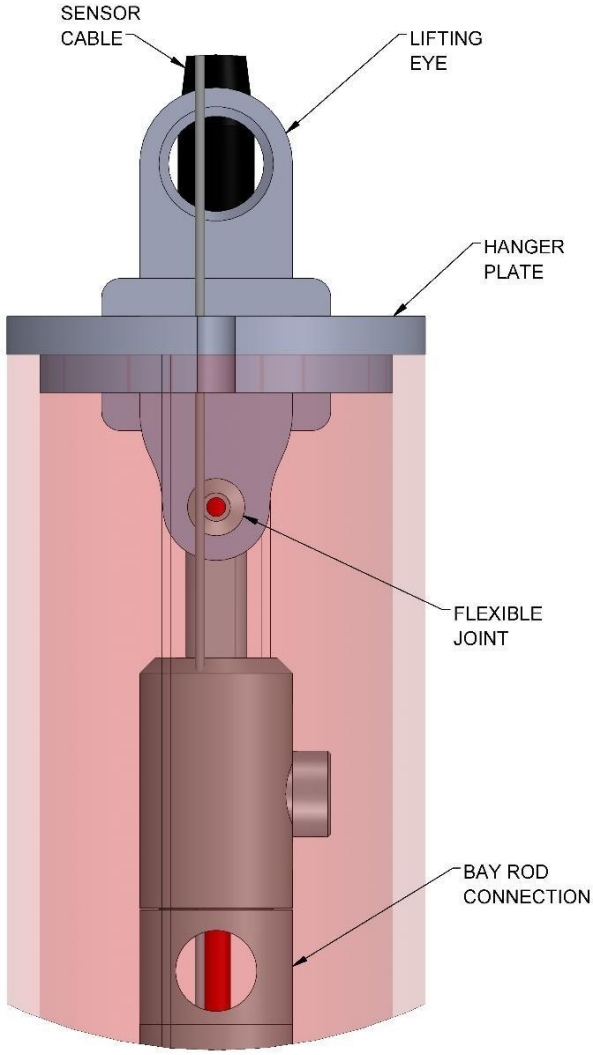


Figure 3: Collar Hanger Secured to Top Sensor

3. Loosen the shoulder bolt at the top of the IPI sensor. Slide the bay rod onto the sensor, aligning the shoulder bolt in the j-slot (see Figure 4, a). Twist the sensor counterclockwise (see Figure 4, b) into the seat of the j-slot and tighten the bolt (see Figure 4, c).

Figure 4: Attaching the Bay Rod

4. Secure one bay rod to each of the remaining sensors, following the instructions outlined in Step 3.

5. Lay sensor and bay rod assemblies in order of installation from the bottom of the borehole to the top. Record the serial number and position of each sensor.

6. Attach a safety line to the bottom wheel assembly (see Figure 5).

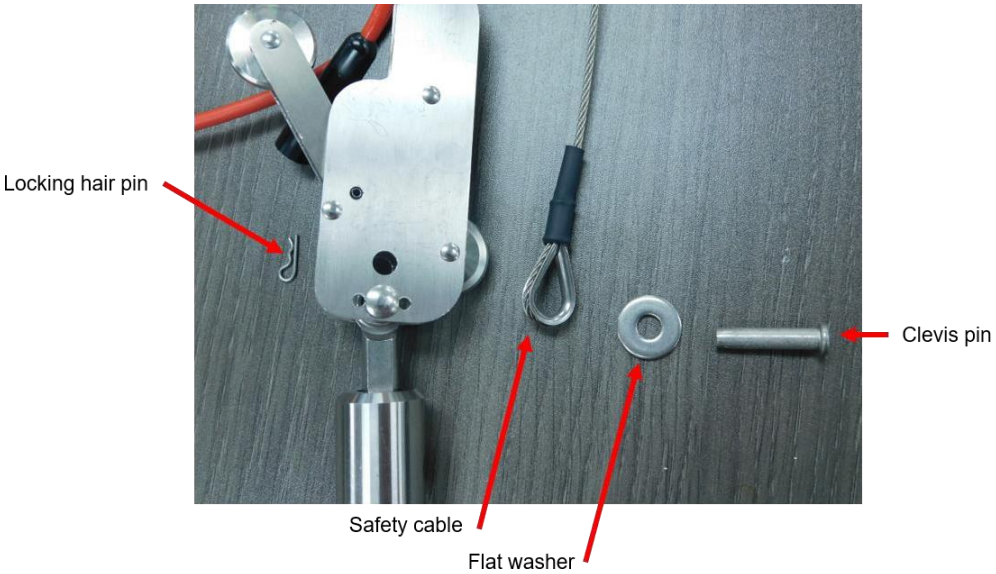


Figure 5: Safety Cable and Hardware

a. Place one end of the safety cable flat against the bottom wheel assembly (see Figure 6).

Figure 6: Place Safety Cable Against Bottom Wheel Assembly

b. Place a washer on top of the thimble on the safety cable and insert the clevis pin through the washer, cable, and wheel assembly (see Figure 7).

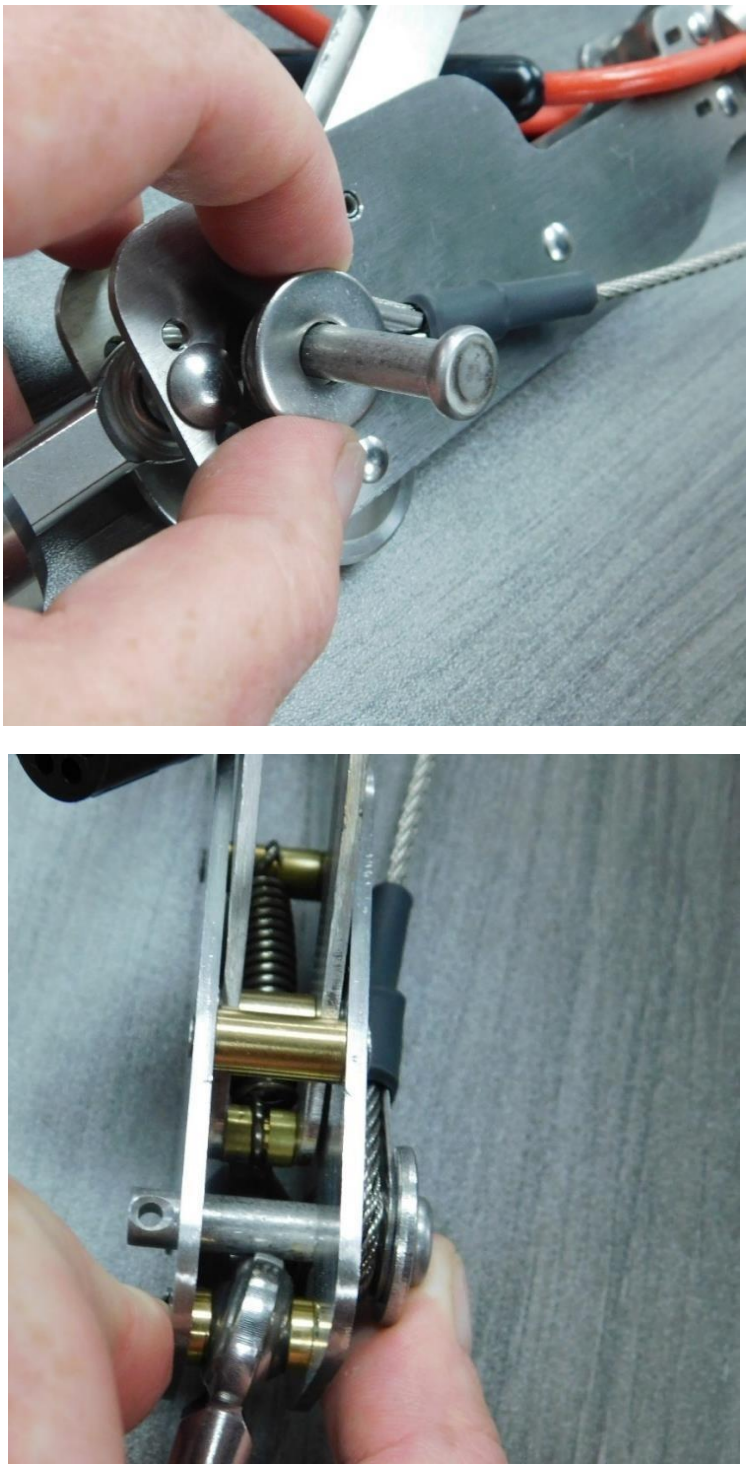


Figure 7: Place Washer (Top Image) and Insert Clevis Pin Through Wheel Assembly (Bottom Image)

c. Secure the clevis pin on the opposite side of the wheel assembly by inserting the hair pin through the clevis pin (see Figure 8).

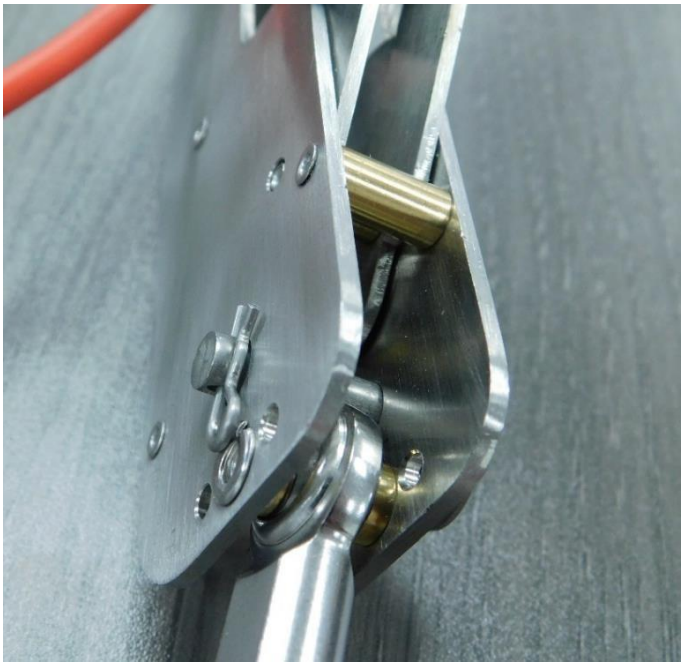


Figure 8: Secure Clevis Pin with Locking Hair Pin

NOTE: Securing the safety link to a winch will maximize control and safety during deep installations. Contact RST for further details.

7. Place the bottom plug onto the bottom sensor cable, as shown in the figure below:

Figure 9: Attach the Bottom Plug onto the Bottom Sensor Cable

NOTE: The orientation of both axes is labelled on each IPI unit, as shown in the image below:

8. 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, as illustrated on the unit's decal.

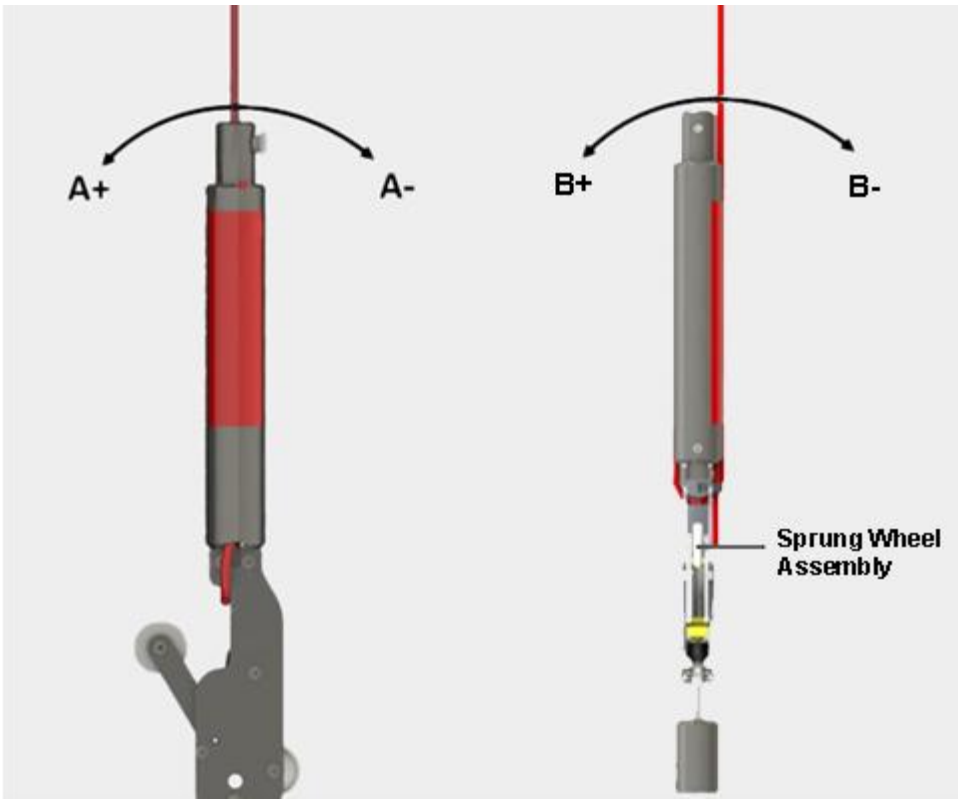


Figure 10: MEMS IPI Axis Orientation

9. Slowly lower the bay assembly into the inclinometer casing, taking care not to twist the wheels out of the grooves (see the figure below). Ensure that the signal cable and safety cable do not obstruct the wheels by securing the cables with Ty-rap and tape, as illustrated in Figure 2.

Figure 11: Lowering the Bay Assembly into the Inclinometer Casing

10. Use the winch on the HOSS or another powered or manual winch to secure the bay assembly from falling downhole. If the installer does not have access to a winch that can slowly and securely lower and raise the IPI string, the cross rod method may be used with any two flat surfaces, such as foldable tables or sawhorses (see Figure 13).

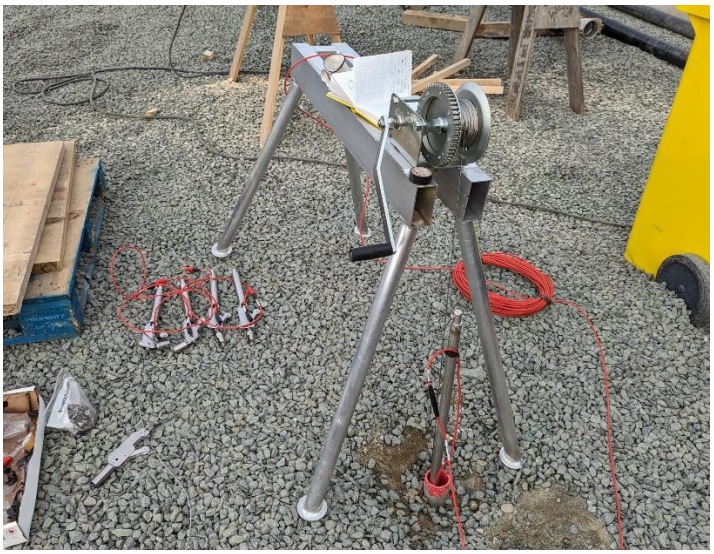


Figure 12: HOSS for Lowering Bay Assembly into the Inclinometer Casing

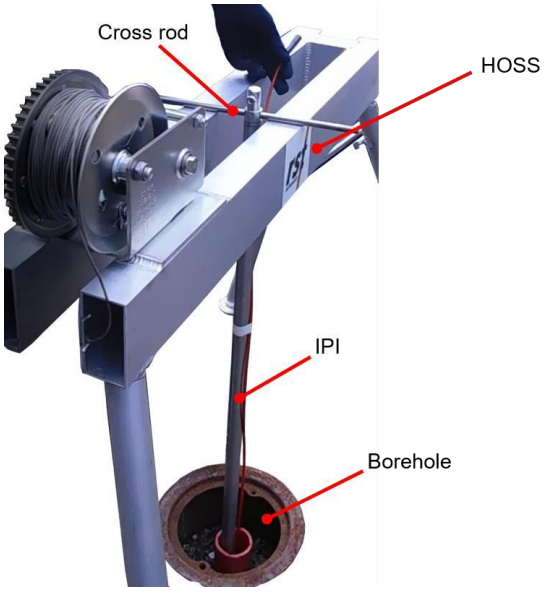


Figure 13: Using the Cross Rod Method as an Alternative to Winch

11. Attach the next section of the assembly using a shoulder bolt, as described in Step 3.

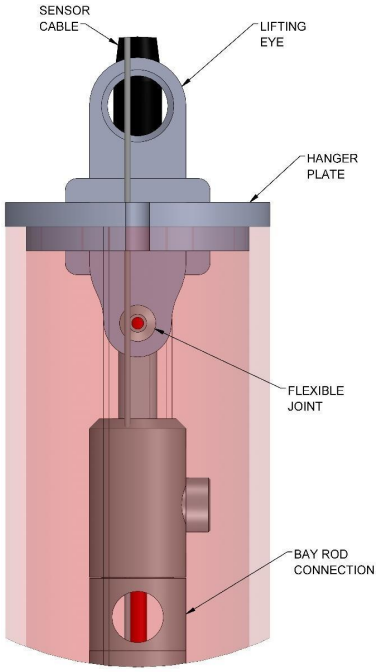
12. Attach the connectors. Wrap a length of tape around the connection to prevent dirt and water ingress. Secure the cable to the lower sensor assembly with tape.

NOTE: The cables should be secured in a neat and orderly fashion to prevent the cables from crossing or obstructing the wheel assemblies.

13. Repeat Steps 9 to 12 for the remaining sensor and bay rod assemblies.

14. Connect the top cable to the top sensor and secure with tape.

15. Insert the collar hanger into the casing, ensuring that the cable exits are aligned with the B-axis grooves of the inclinometer casing. Secure the safety cable.



NOTE: Please ensure that the top cap or hanger does not rest on the safety line and data cable. Instead, route the cables through the notches or grooves in the cap.

16. Connect the signal cable to a datalogger or readout. See Section 6.6 for connection details.

6.3 STAINLESS STEEL WIRE ROPE INTERVAL

A stainless-steel wire rope interval (see Figure 13) may be used in place of a bay rod for cases where specific zones are of interest rather than the entire profile of the borehole.

The wire rope interval takes the place of a sensor bay in the IPI chain. The sensor assembly below the wire rope bay is terminated using a top wheel assembly. The top wheel assembly uses a clevis pin with hair pin locker to secure the wire rope section. The wire rope transitions back to the next sensor assembly or collar hanger using a wireline-to-bay adapter.

Installation is the same as the standard IPI installation with respect to orientation and positioning.

The device is secured with the same clevis and hair pin mechanism as the upper wheel assembly.

The wireline bay adapter includes through holes for insertion of a Ty-Rap to relieve strain on the suspended signal cable.

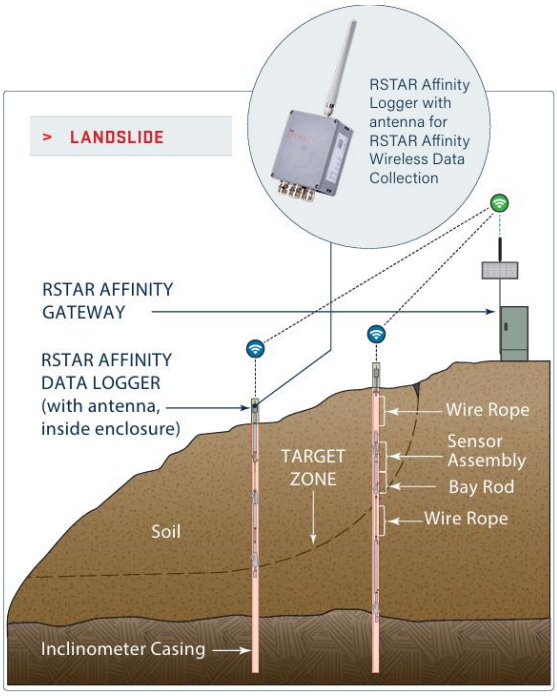


Figure 14: Example Installation Overview with RSTAR Affinity Data Collection Set-Up Showing Wire Rope Locations

NOTE: Automated data collection methods can be made with the use of the RSTAR Affinity Data Logger, RST DT2485 DT-BUS Data Logger, or a FlexDAQ Data Logger System. For incorporating wireless data collection, the DT2485 is RSTAR and DT Link compatible and the RSTAR Affinity Data Logger forms part of the RSTAR Affinity Gateway and Digital Suite.

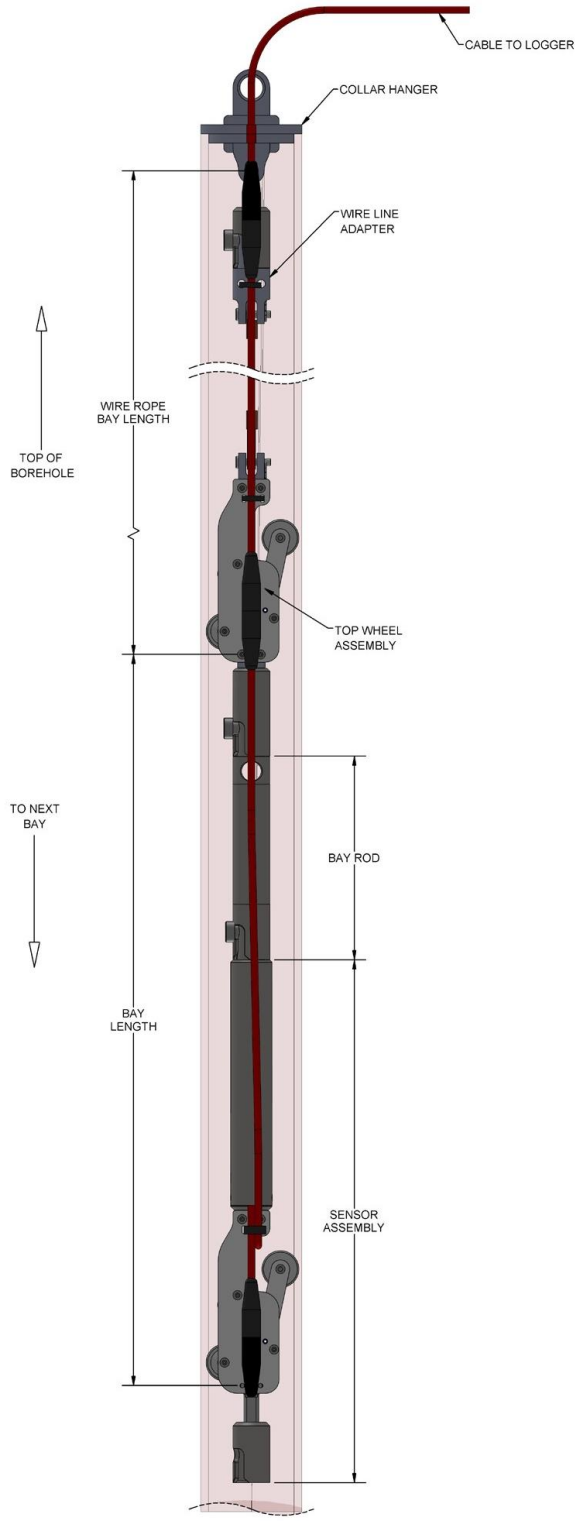


Figure 15: Wire Rope Type System Configuration

6.4 SIGNAL CABLE AND CONNECTORS

RST IPIs connectors are waterproof and are designed to be submerged (IP68, 2 MPa). The connectors must be kept clean and connected only when clean.

Connectors consist of a plug and receptacle. To successfully make a connection, insert the plug into the receptacle and push until fully inserted.

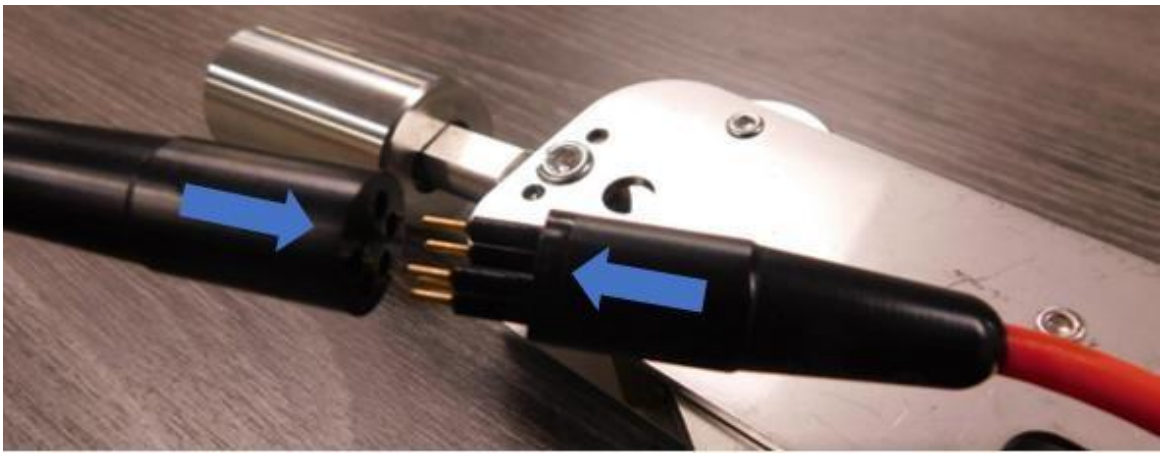


Figure 16: IPI27050 Connectors

CAUTION: Do not twist the connectors.

NOTE: If the connectors are difficult to connect and disconnect, apply a trace amount of silicone-based lubricant to the mating face of the plug connector.

6.5 CLEANING CONNECTORS

It is strongly recommended to keep caps on connectors until mated to the next sensor to prevent contamination. Store the caps in a clean, dry location for future use.

To prevent potential contamination, cover the IPI connectors with the provided connector caps each time the IPI is disassembled (Figure 13). Ensure that protective caps are always on the connectors when the connectors are not in use.

Any dirt within the connectors may cause water ingress and cause an entire string of IPIs to fail.

CAUTION: Do not twist the connectors.

In the event of contamination within the connectors, the connector ends may be flushed with isopropyl alcohol and set aside to dry.

Figure 17: Protective Caps are Placed on the Connectors when not in use

6.6 DIGITAL OUTPUT FOR MEMS IPI SYSTEM

Table 1: Digital Output for MEMS IPI System

Wire Color	MEMS IPI
Red	V +
Black	GND
Green	RS485 A-
White	RS485 B+

6.7 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, remain clean. Refer to Section 6.5 for instructions on cleaning the IPI connectors. Dirt can be removed from the instrument itself with clean water and a damp cloth.

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 reinstallation.

7 MEMS HORIZONTAL IPI DETAILS

The RST MEMS Horizontal In-Place Inclinometer is installed, and measures deflection horizontally as opposed to vertically. Construction and electronics are the same as the vertical IPI probes outlined above.

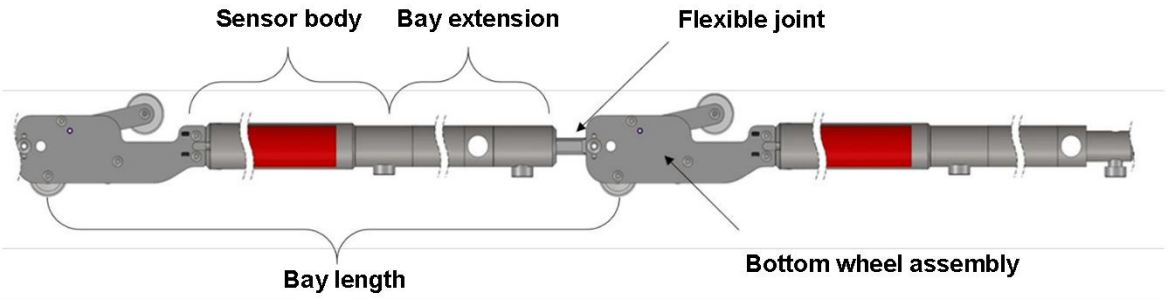


Figure 18: MEMS Horizontal IPI Overview

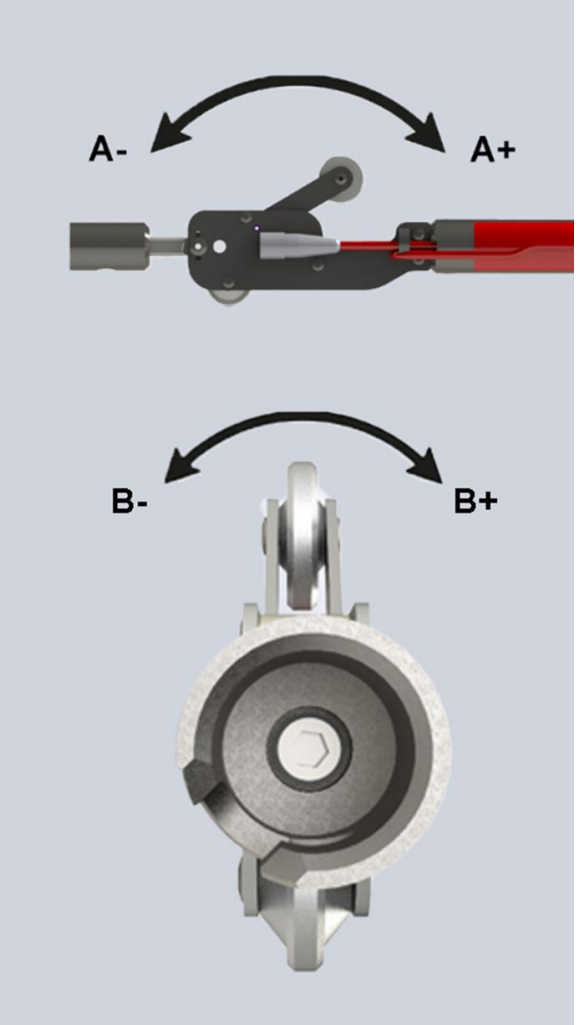


Figure 19: MEMS Horizontal IPI Orientation

7.1 INSTALLATION

The following steps detail the procedure for installing a horizontal IPI.

1. Place the sprung wheel upwards in the inclinometer casing for correct orientation, as illustrated in Figure 14.

2. Follow assembly instructions (steps 1 – 5), as outlined in Section 6.3.

3. Place a bottom cable plug onto the bottom sensor cable.

4. Insert the bottom sensor and bay rod assembly into the borehole with the wheels in the inclinometer casing grooves and the sprung wheel facing up (this aligns the A-Axis wheels with the anticipated failure direction). Secure properly in place.

NOTE: Place the sprung wheel facing upwards in the inclinometer casing for correct orientation.

5. Loosen the shoulder bolt at the top of the installed IPI sensor. Slide the next bay rod and sensor assembly onto the installed sensor, aligning the shoulder bolt in the j-slot. Twist the sensor counterclockwise into the seat of the j-slot and tighten the bolt.

6. Attach the connectors. Wrap a length of length tape around the connection to prevent dirt and water ingress. Secure the cable from the lower sensor assembly with tape.

7. Repeat steps 3 – 5 for the remaining sensor and bay rod assemblies, including the top bay rod and sensor assembly.

8. Secure the hanger plate to the top sensor (see Figure 3). Loosen the shoulder bolt at the top of the IPI sensor and slide the sensor into the collar hanger, aligning the shoulder bolt in the j-slot. Twist the sensor counterclockwise into the seat of the j-slot and tighten the bolt. Insert into the casing until the hanger plate sockets inside the top of the casing.

8 OPERATION

The MEMS In-Place Inclinometers measure tilt in two planes with two MEMS accelerometers arranged at 90°. Both axes are calibrated across a ±30° range.

8.1 INITIAL READINGS

NOTE: Since IPIs are relative movement devices, it is critical to record initial readings. RST recommends surveying the inclinometer with the RST Digital Inclinometer System prior to installing the IPI. Contact RST for further information.

For each IPI sensor on the string, record measurements for tilt in the A axis, tilt in the B axis, and temperature.

NOTE: RST recommends performing a manual Inclinometer survey prior to installation of IPIs to have as back up survey results if needed in the future.

Readings are obtained from each IPI by interrogating the Serial number via the designated Data logger or readout.

RST devices and Data Loggers can assign the required MODBUS addresses to receive readings from the sensors.

For further information, please refer to the following manual:

https://rstinstruments.com/wp-content/uploads/IPI-Setup-Utility-Manual.pdf

9 CALCULATIONS

IPIs are relative measurement devices. To calculate the displacement of the instrument over time, the initial tilt reading is subtracted from the current tilt reading and multiplied by the gauge length.

The device output is reported in sine of the angle from vertical (tilt), using the following equation:

$$\boldsymbol{d = L(\sin(\theta) - \sin(\theta_i))}$$

Equation 1: Calculation of Tilt Displacement Over Time

$where$:

$d = displacement$
$L = gauge\ length$
$\sin(\theta) = current\ device\ output$
$\sin(\theta i) = initial\ device\ output$

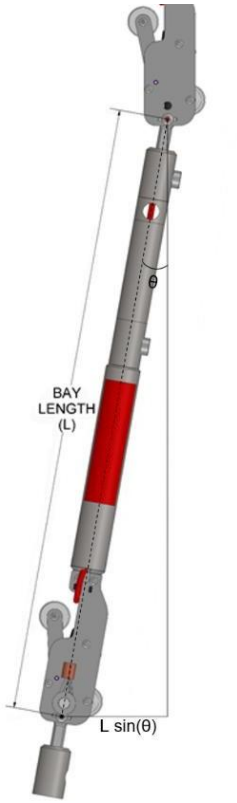


Figure 20: MEMS IPI Reaction

10 PRODUCT SPECIFICATIONS

Table 2: MEMS In-Place Inclinometer System Specifications

Item	Specification
Sensor	
Range	±30°
Resolution	0.0002° (0.004 mm/m)
System Precision	±0.5 mm for 30 m IPI (15 sensors at 2 m, 6 months, repeatability conditions in borehole)
Sensor 24 h Stability	±0.03 mm/m[1] ±0.01 mm/m[2]
Sensor Precision	±0.0013° (0.02 mm/m)[1] ±0.0005° (0.01 mm/m)[2]
Sensor	MEMS Accelerometer
Temperature Dependent Uncertainty	±0.016 mm/m/°C (±0.001°/°C), for ±5° from vertical ±0.033 mm/m/°C (±0.002°/°C), for ±15° from vertical
Temperature Accuracy	±0.5°C (0°C to 60°C) ±1.0°C (-40°C to 60°C)
Temperature Resolution	±0.06°C
Electrical	
Supply Voltage	5 to 15V DC
Operating Current	490 µA (Reading Average, per sensor)
Standby Current	<20 µA (per sensor)
Signal Output	RS485 Digital Bus (MODBUS RTU Protocol)
Operating Temperature	-40 to 60°C (-40 to 140°F)
Mechanical	
Ingress Protection	IP68 (2 MPa)
Gauge Length	0.5 – 3 m
Sensor Diameter	28.6 mm (1.125 in)
Bay Rod Diameter	25.4 mm (1.0 in)
Wheel Assembly	70 mm (2.75 in) 85 mm (3.34 in)
System Maximum Weight	180 kgf

Sensor and Bay Rod Assembly Weight (Dry, submerged H_2O)	0.5 m: 1.25, 1.00 kgf 1.0 m: 1.63, 1.12 kgf 1.5 m: 2.00, 1.24 kgf 2.0 m: 2.37, 1.36 kgf 3.0 m: 3.11, 1.60 kgf

Table 3: MEMS In-Place Inclinometer System Weight Table

Maximum System Weight					
180 kgf					
Assemblies	**Length (m)**	**Mass (kg)**	**Max Sensors (Dry)**	**Submerged Weight (kgf)**	**Max Sensors Submerged**
0.5m	0.5	1.252	143	1	180
1m	1	1.625	110	1.121	160
1.5m	1.5	1.999	90	1.241	145
2m	2	2.372	75	1.362	132
3m	3	3.118	57	1.603	112
3 ft	0.991	1.619	111	1.118	160
5 ft	1.524	2.016	89	1.247	144
10 ft	3.048	3.154	57	1.615	111

NOTE: For deeper installations it is recommended to use a winch-type system like the HOSS shown in Figure 12 for an easier installation process.

11 SERVICE, REPAIR AND CONTACT INFORMATION

This product does not contain any user-serviceable parts. Contact RST for product services or repairs.

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

RST Canada Office (Head Quarters)

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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

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

APPENDIX A: SAMPLE CALIBRATION CERTIFICATE FOR DIGITAL OUTPUT MEMS IPI

Monitor with Confidence

Calibration Record

RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
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

Serial Number: BI0000083891
Calibration Date: April 7, 2021
Inclinometer Frame: RST07
Referenced to National Standards Annually

Wiring

Colour	Function	Pin
Red	Voltage +	1
Black	Ground	2
Green	RS485 A+	3
White	RS485 B-	4
Bare	Shield	5

A-Axis

Applied Degrees	Applied Sin	Displayed Sin	Error Sin
-30	-0.50000	-0.50000	0.00000
-25	-0.42262	-0.42262	0.00000
-20	-0.34202	-0.34201	0.00001
-15	-0.25882	-0.25881	0.00001
-10	-0.17365	-0.17364	0.00001
-5	-0.08716	-0.08714	0.00001
0	0.00000	0.00000	0.00000
5	0.08716	0.08715	0.00000
10	0.17365	0.17364	0.00001
15	0.25882	0.25882	0.00000
20	0.34202	0.34202	0.00000
25	0.42262	0.42263	0.00001
30	0.50000	0.50000	0.00000

B-Axis

Applied Degrees	Applied Sin	Displayed Sin	Error Sin
-30	-0.50000	-0.49998	0.00002
-25	-0.42262	-0.42260	0.00002
-20	-0.34202	-0.34199	0.00003
-15	-0.25882	-0.25880	0.00002
-10	-0.17365	-0.17364	0.00001
-5	-0.08716	-0.08716	0.00000
0	0.00000	-0.00000	0.00000
5	0.08716	0.08715	0.00001
10	0.17365	0.17364	0.00001
15	0.25882	0.25881	0.00001
20	0.34202	0.34201	0.00001
25	0.42262	0.42261	0.00001
30	0.50000	0.50000	0.00000

Calibrated By: HB **Date:** 07/04/2021
Checked By: Sa[illegible]iani **Date:** 21/04/2021

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