

MEMS Vertical IPI Serial Sensors

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SLOPE INDICATOR

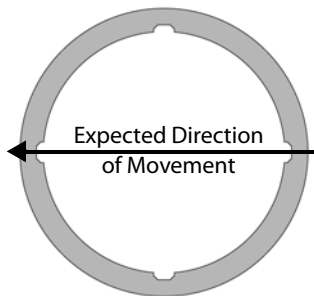
12123 Harbour Reach Drive
Mukilteo, Washington, USA, 98275
Tel: 425-493-6200 Fax: 425-493-6250
E-mail: solutions@slope.com
Website: www.slopeindicator.com

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Introduction

Vertical In-Place Inclinometers



Casing should be installed with one set of grooves aligned with the expected direction of movement.

The wheels of the sensors are inserted in these grooves.

The in-place inclinometer system consists of inclinometer casing and a string of in-place inclinometer sensors.

The inclinometer casing provides access for subsurface measurements, controls the orientation of the sensors, and moves with the surrounding ground.

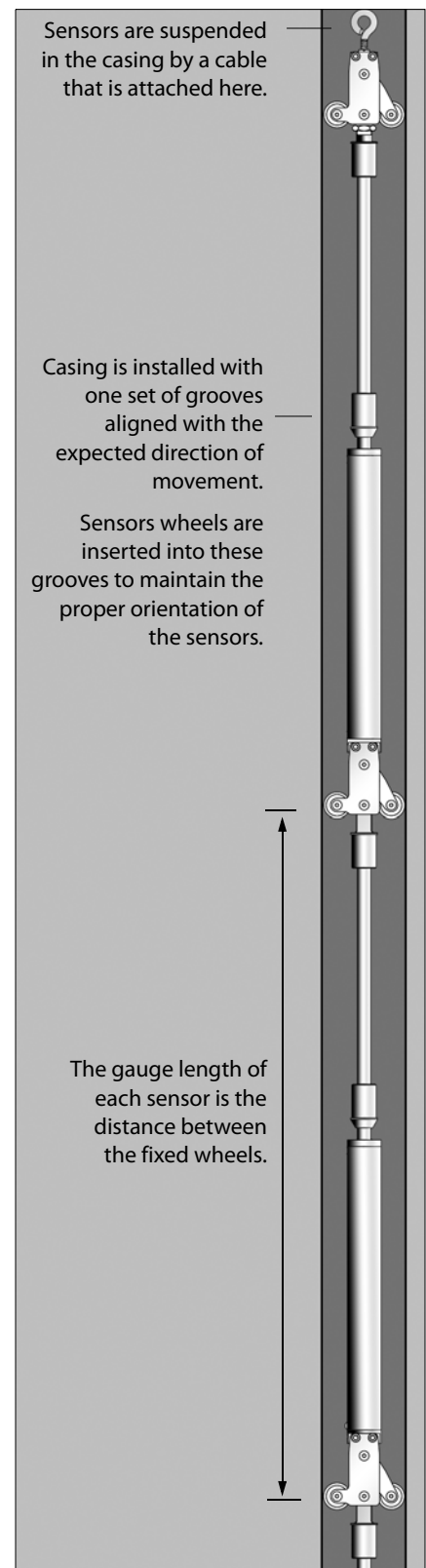
In vertical installations, the casing is installed in a borehole that passes through a suspected zone of movement into stable ground below. One set of grooves in the casing is aligned with the expected direction of movement, as shown in the drawing at left.

The grooves in the casing control the orientation of the in-place sensors. A stainless steel cable keeps the sensors at the required depth.

The sensors measure inclination from vertical. As ground movement occurs, the casing moves with it, changing the inclination of the sensors inside the casing.

The inclination measurements are then processed to provide displacement readings in mm or inches.

In most applications, sensors are connected to a data acquisition system and data processing is completed by a computer program.



Sensor Components

In-place sensors can be installed as a single sensor or as a string of linked sensors. The drawing at right shows both.

An individual sensor includes a sensor body, a gauge tube, a top wheel, and a bottom wheel.

A string of linked sensors includes n sensor bodies, n gauge tubes, a top wheel, a bottom wheel, and $n-1$ middle wheels.

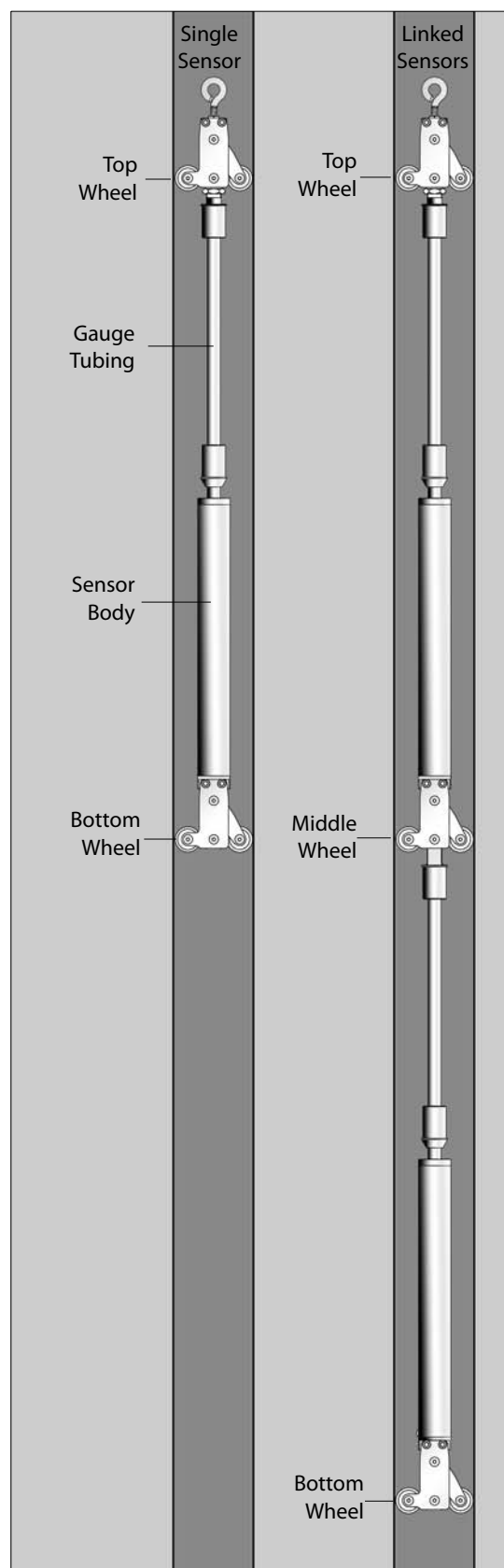
Sensor bodies can contain uniaxial or biaxial sensors, but look the same.

Gauge tubes are sized to make gauge lengths of 1, 2, or 3 m (or 3, 5, and 10') when joined to a sensor body and wheels.

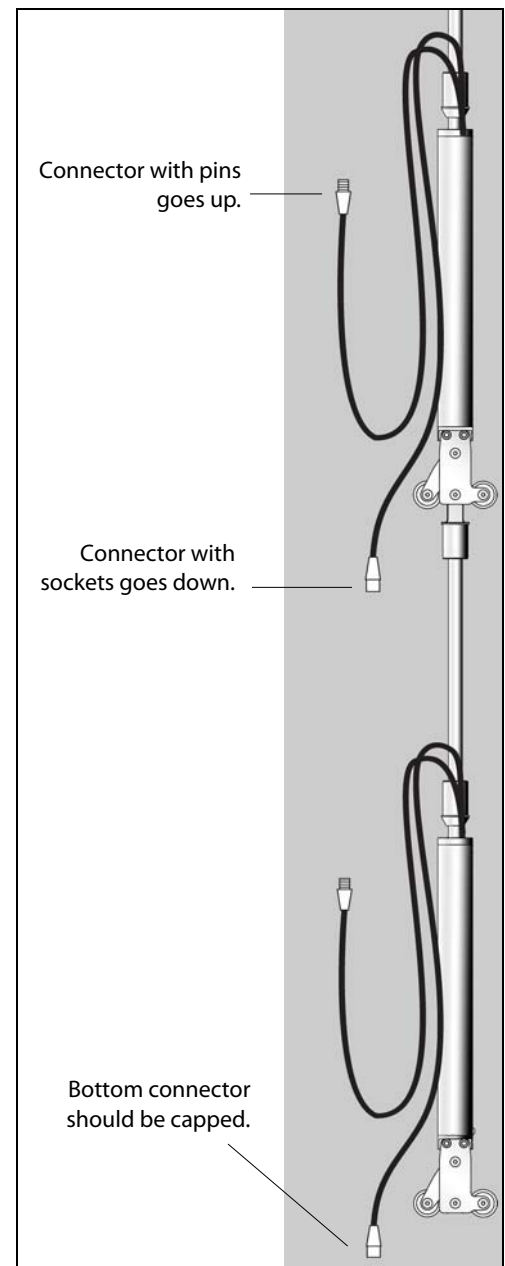
Top wheels have an eyelet for attaching a stainless steel suspension cable. They also have a socket for connecting to a gauge tube.

Bottom wheels attach directly to the bottom of the sensor. They have no socket.

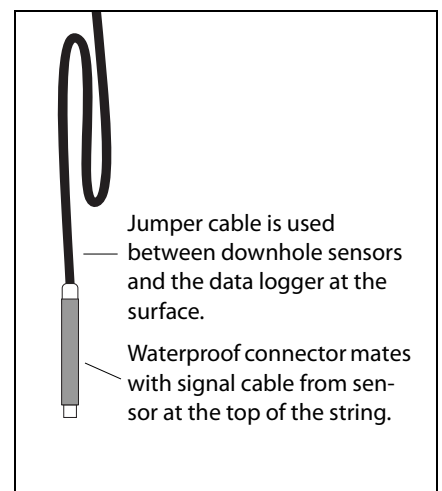
Middle wheels are used to link sensors. The middle wheel attaches directly to the bottom of the sensor sensor and has a socket for connecting to the gauge tube from the sensor below.



Serial Sensor Cable Connections



Other Components

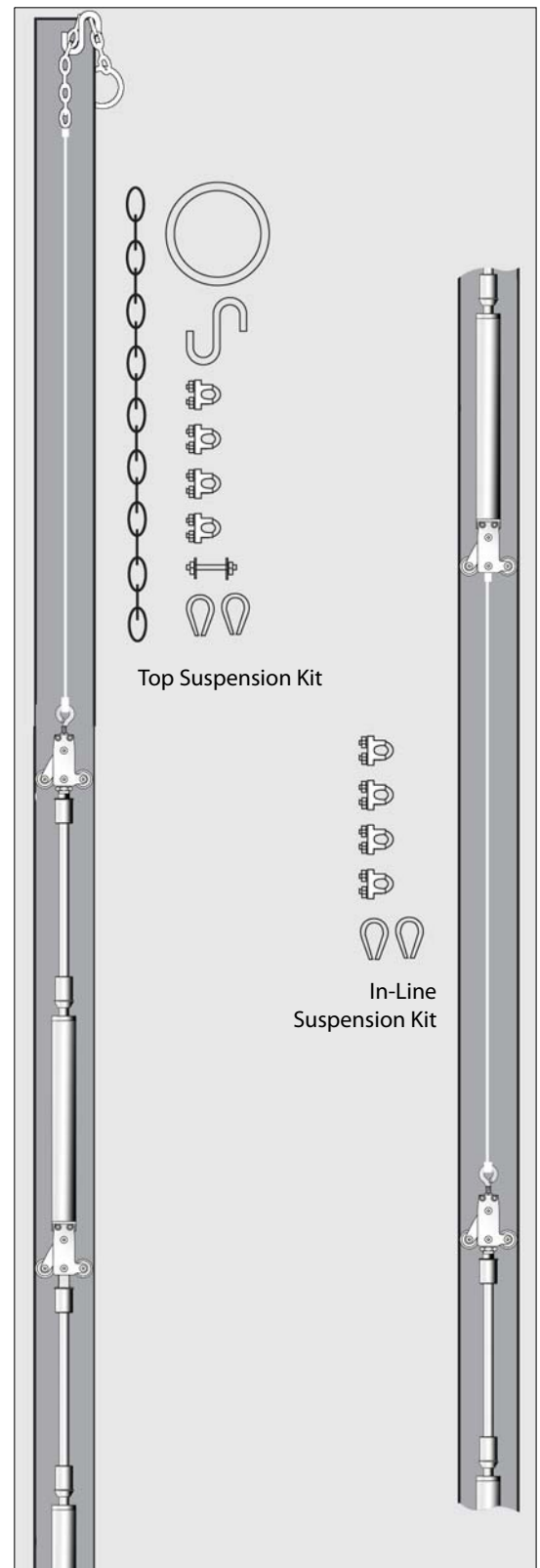


Suspension Kits

Top Suspension Kit is used to suspend the IPI sensors from the top of the casing. Stainless steel cable is ordered separately.

In-Line Suspension Kit is used to suspend a string of deeper sensors from a string of shallower sensors. This allows economical monitoring of two or more separate zones of interest.

Safety Cable (not shown) is sometimes attached to the bottom sensor and used to prevent loss of sensors downhole during installation. A safety cable is also helpful when sensors are withdrawn from the casing.



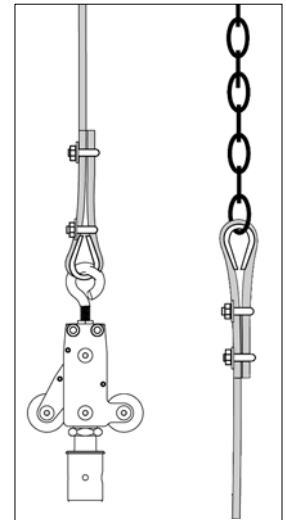
Preparations for Installation

Check Sensors

1. Check each sensor.
2. Identify the bottom sensor for each string. The bottom sensor will require a plug for the bottom connector.
3. Make a note of the serial number of each sensor and its intended depth of installation.
4. Mark sensors for order of installation.
5. Check length of jumper cable to make sure it will run from the top sensor to the datalogger.

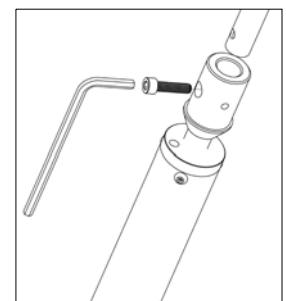
Prepare Suspension Cable

1. Check project specifications for intended depth of top sensor.
2. Determine the required depth of the top wheels of the top sensor.
3. Determine the distance between the top wheels and the top of the casing. Cut the stainless steel suspension cable to this length.
4. Connect suspension cable to top wheel as shown in the drawing.
5. Connect suspension cable to the chain as shown in the drawing.



Attach Gauge Tubing

1. Remove screw from socket.
2. Align hole in gauge tube with hole in socket, then insert gauge tube into socket.
3. Insert screw and tighten to secure the gauge tube.
4. No further pre-assembly is recommended.



Gather Tools

- Vice grips (clamping pliers) for holding gauge tubing while connecting adjacent sensors.
- Allen wrench for screws that securing gauge tubing.
- Cable ties or vinyl tape to secure cable to gauge tubing.
- Optional: safety cable connected to bottom sensor to prevent loss of sensors down hole. The safety cable is also helpful when the sensors are withdrawn from the casing.

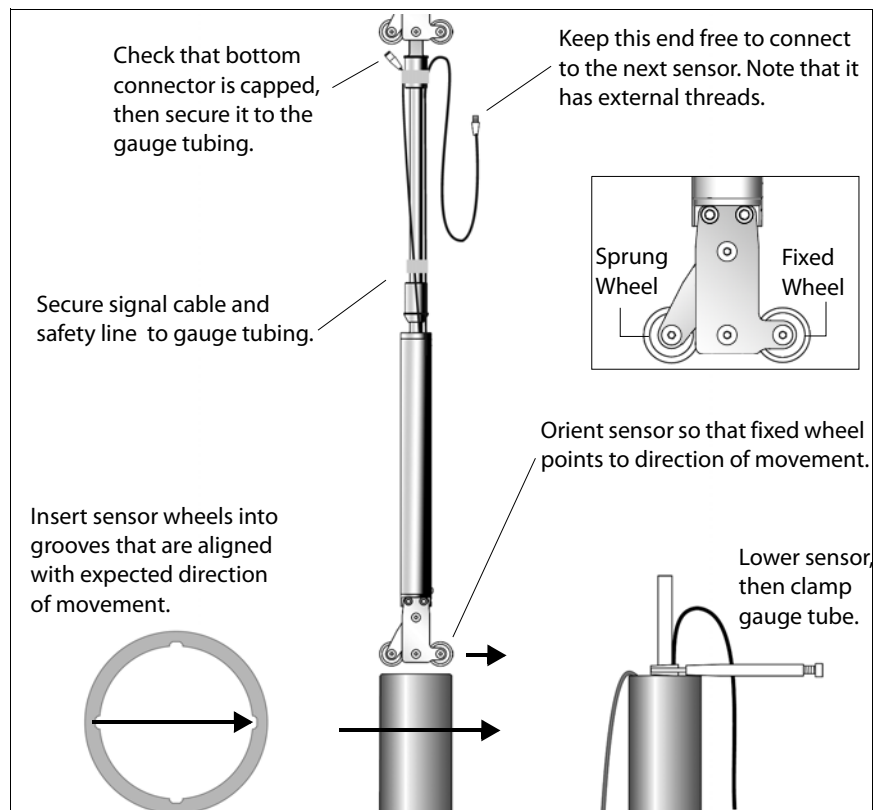
Installation

Installation Overview

1. Lay out sensors in order of installation.
2. Connect cap to end of cable connection on first sensor. Attach safety cable to first sensor (optional), then insert the first sensor into the preferred set of grooves.
3. Lower the sensor into the casing. Clamp the top of the gauge tube to hold the sensor while you connect the next sensor.
4. Align the next sensor with the preferred set of grooves as in step 2, and connect it to the gauge tubing of the downhole sensor.
5. Lower the two sensors. Repeat steps 4 and 5 until all sensors have been installed.
6. Connect the top wheel and suspension kit and lower the sensors to their final elevation.

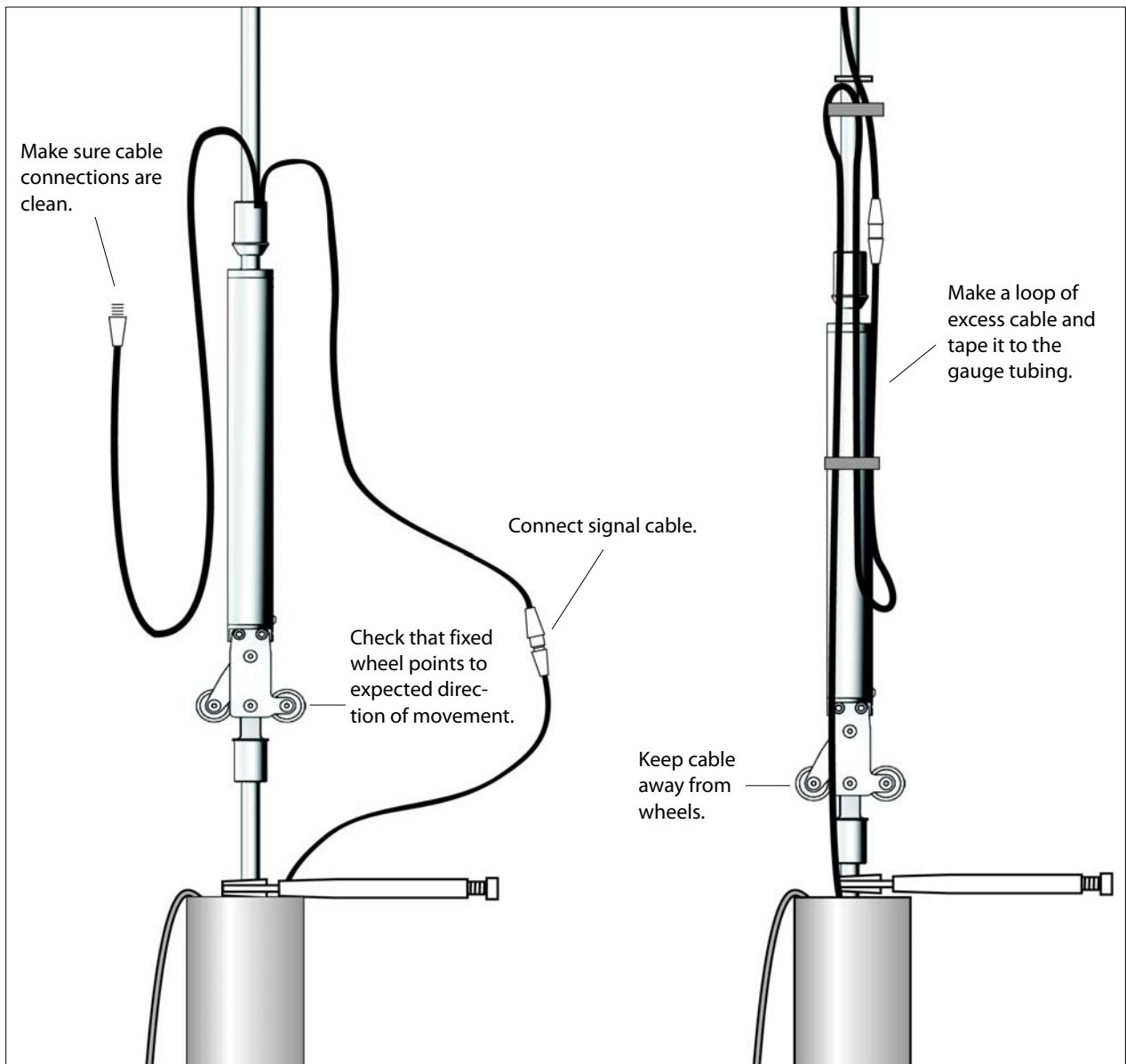
Install the First Sensor

1. Attach safety cable to bottom sensor. Secure the safety cable. Insert first sensor in selected set of grooves. The fixed wheel should point to the expected direction of movement.
2. Secure signal cable to gauge tubing and then lower sensor into casing. Clamp the top of gauge tubing to hold it at the top of the casing.



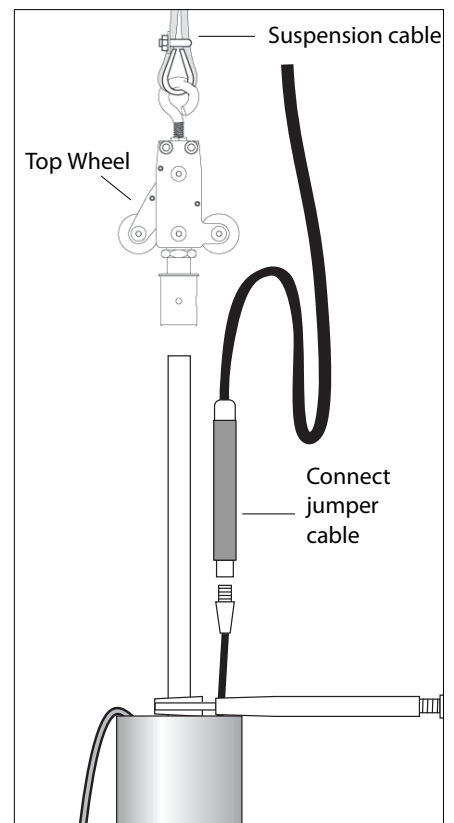
Install the Next Sensor

1. Make sure connections are clean, then connect signal cables. Make a loop with the excess cable and secure it to the gauge tubing with tape or a cable tie.
2. Connect next sensor to the gauge tubing of the sensor below, as shown in the drawing. Continue adding sensors until the sensor string is complete. Keep the following points in mind:
 - Do not allow the installed sensor to twist in the casing, as this may damage the wheels or pop them out of the grooves.
 - When you lower the sensor into the casing, check that the fixed wheel is aligned in the proper direction.
 - Secure cables neatly, so that they do not cross each other.



Install the Install Top Wheel

1. Jumper cable runs from down-hole sensors to data logger. Connect jumper cable to signal cable from top sensor.
2. Attach top wheel from suspension kit or placement kit.
3. Connect top wheel to gauge tubing.
4. Check that suspension cable is attached securely.



Suspend the Sensors

1. Check that suspension cable is securely clamped.
2. Use the chain and S-hook to make fine adjustments to the final depth of the sensors.



Note on Retrieving Sensors

When you withdraw the sensors, you must disassemble the string and remove sensors one at a time from the casing. Otherwise there is a good chance that sensor wheels and gauge tubes will be damaged.

1. Draw each sensor upwards.
2. Clamp the gauge tube of the sensor below
3. Disconnect the sensor, and repeat. If you intend to reinstall the sensors, check that they are still numbered for order of installation

Data Reduction

Introduction Data reduction is usually automated because it involves a large number of readings and a large number of calculations.

Here, we explain how to use the sensor calibration record and provide an example of converting a single reading in volts to tilt in mm per meter and tilt in degrees.

Calibration Record A calibration record is provided with each sensor. Use sensor serial numbers to match sensors with their calibrations. Calibrations are unique for each sensor.

The sensor calibration record provides two sets of factors. One set lists factors to convert readings in volts to tilt in mm per meter and also includes factors to calculate temperature corrections.

The other set lists factors to convert readings in volts to tilt in degrees and also includes factors to calculate temperature corrections.

Factors for A-axis sensors have a `_A` suffix. Factors for B-axis sensors have a `_B` suffix.

The bottom section of the calibration record shows how the factors are applied.

Converting Volts to Tilt To convert a reading in volts to mm/m or degrees of tilt, use the following formula:

$$\text{Tilt} = C3 \times \text{Volts}^3 + C2 \times \text{Volts}^2 + C1 \times \text{Volts} + C0$$

Where:

Tilt is a value in mm/m or degrees, depending on the factors used.

C3...C0 are factors for A-axis or B-axis.

Volts is the sensor reading in volts.

Correcting for Temperature The formula below shows how to adjust the tilt value for temperature:
Temp-Corrected Tilt = Tilt - (T1 × TdegC + T0)

Where:

Tilt is the value calculated above.

T1 and T0 are temperature factors for mm/m or degreesC .

TdegC is the temperature in degrees C at the time of reading.

Example: Sensor 14295 gives an A-axis reading of 2.3V at 18C. The calibration factors are: C3_A = -1.2508E-2, C2_A = -3.6652E-2, C1_A = 7.2839E1, and C0_A = -3.9469. Use these factors in the formula from the previous page:

$$\text{Tilt} = \mathbf{C3 \times Volts^3 + C2 \times Volts^2 + C1 \times Volts + C0}$$

$$\text{Tilt}_{\text{mm/m}} = -1.2508\text{E-}2 \times 2.3^3 + -3.6652\text{E-}2 \times 2.3^2 + 7.2839\text{E}1 \times 2.3 + -3.9469$$

$$\text{Tilt}_{\text{mm/m}} = 163.24$$

The same sensor has temperature factors T0_A = -3.3162E-1 and T1_A = 2.4139E-2. Use these factors to adjust for temperature.

$$\text{Temp-Corrected Tilt} = \text{Tilt} - (\mathbf{T1 \times TdegC + T0})$$

$$\text{Temp-Corrected Tilt}_{\text{mm/m}} = 163.24 - (-3.3162\text{E-}1 \times 18 + 2.4139\text{E-}2)$$

$$\text{Temp-Corrected Tilt}_{\text{mm/m}} = 162.65$$

Example: Sensor 14295 gives a reading of 2.3V at 18C. The calibration factors are: C3_A_deg = -3.0241E-3, C2_A_deg = -2.7405E-3, C1_A_deg = 4.1733E0, and C0_A_deg = -2.2612E-1. Use these factors in the formula from the previous page:

$$\text{Tilt} = \mathbf{C3 \times Volts^3 + C2 \times Volts^2 + C1 \times Volts + C0}$$

$$\text{Tilt}_{\text{deg}} = -3.0241\text{E-}3 \times 2.3^3 + -2.7405\text{E-}3 \times 2.3^2 + 4.1733\text{E}0 \times 2.3 + -2.2612\text{E-}1$$

$$\text{Tilt}_{\text{deg}} = 9.3635$$

The same sensor has temperature factors T0_A_deg = -1.9109E-2 and T1_A_deg = 1.3911E-3. Use these factors to adjust for temperature.

$$\text{Temp-Corrected Tilt} = \text{Tilt} - (\mathbf{T1 \times TdegC + T0})$$

$$\text{Temp-Corrected Tilt}_{\text{deg}} = 9.2972 - (-1.9109\text{E-}2 \times 18 + 1.3911\text{E-}3)$$

$$\text{Temp-Corrected Tilt}_{\text{deg}} = 9.3611$$

Calculating Deviation

To calculate deviation over the gauge length of the sensor, use either formula below:

$$\text{Deviation}_{\text{mm}} = \text{Tilt}_{\text{mm/m}} \times \text{gauge_length}_{\text{m}}$$

or

$$\text{Deviation}_{\text{mm}} = \sin(\text{Tilt}_{\text{deg}}) \times \text{gauge_length}_{\text{mm}}$$

Example: Sensor 14295 has a gauge length of 2 meters. The examples below use the temperature corrected tilt values.

Calculating Deviation

$$\text{Deviation}_{\text{mm}} = 162.65_{\text{mm/m}} \times 2 \text{ m}$$

$$\text{Deviation}_{\text{mm}} = 325.30$$

$$\text{Deviation}_{\text{mm}} = \sin(9.3611) \times 2000 \text{ mm}$$

$$\text{Deviation}_{\text{mm}} = 325.31$$

Calculating Displacement

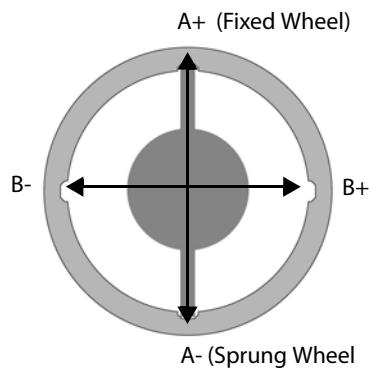
Displacement (movement) is the change in deviation:

$$\text{Displacement} = \text{Deviation}_{\text{current}} - \text{Deviation}_{\text{initial}}$$

Direction of Tilt & Displacement

Uniaxial sensors respond to tilt in the plane parallel to the wheels of the sensor. This plane is called the A axis. A-axis readings may be positive or negative. Positive readings indicate that the sensor is tilted in the direction of the fixed wheel. Negative readings indicate that the sensor is tilted in the direction of the sprung wheel.

Biaxial sensors respond to tilt in the plane of the wheels (A-axis) and the plane rotated 90 degrees to the wheels (B-axis). Positive A-axis readings show tilt in the direction of the fixed wheels. Positive B-axis readings show tilt in the direction rotated 90 degrees clockwise. Displacement directions follow the same convention. In the drawing below, the sensor is viewed from the top.



Connection to Data Loggers

CR10X or CR1000 These instructions provide information needed for reading uniaxial and biaxial IPIs with the Campbell Scientific CR1000 datalogger system.

Sample Program: A sample CR1000 monitoring program is available at the Slope Indicator website. Go to www.slopeindicator.com. Then navigate to Support -> TechNotes -> DataLoggers, and look for sample programs.

Wiring Diagrams: The wiring diagram below shows how to connect serial IPIs to the Campbell Scientific CR1000 datalogger. Uniaxial and Biaxial connections are identical.

Wiring Diagram

