

# MEMS Horizontal In-Place Inclinometer

## Applications

The remote, continuous, and automatic monitoring of...

- The stability of structures, underground openings, and foundations
- The stability of tank foundations and subway tunnels
- Ground movements and differential settlements in, around and above tunnels and underground openings



• Installation detail with a cutout section of the Model 6155 Inclinometer Casing.



• Model 6155 MEMS Horizontal In-Place Inclinometer.

## Operating Principle

The Model 6155 MEMS In-Place Inclinometer consists of a string of MEMS (Micro-Electro-Mechanical Systems) tilt sensors mounted on lengths of stainless steel tubing which are linked together by universal joints. The string of sensors is installed inside the casing with all the sensor cables passing to the surface where they are connected to Terminal Boxes or Dataloggers.

Movements of the ground deflect the casing causing one or more of the inclinometer segments (length L) to undergo changes of inclination ( $\Delta\theta$ ). Summation of all these tilts in the form  $\Sigma L \sin\theta$ , are plotted to give profiles of vertical deflection. Each tilt sensor contains a thermistor to permit temperatures to be recorded.

## Available Versions

Several versions are available allowing for optimal configuration based on application and site specifics:

### 6155A | Standard, Analog Sensor

This is the classic configuration in which uniaxial or biaxial MEMS tilt sensors are mounted on lengths of stainless steel tubing to provide customer specific gauge lengths, and linked together by universal joints. Spring-loaded wheel assemblies are located at each joint and allow the sensor string to positively engage in the grooves of conventional inclinometer casing. Each sensor uses its own cable (up to 305 m (1000 ft) in length), each of which are routed to the top of the casing. Output is  $\pm 4V$  at  $\pm 15^\circ$ . The maximum number of sensors that can be used in this configuration is 24

(Uniaxial) or 16 (Biaxial) in 70 mm (2.75") inclinometer casing and 42 (Uniaxial) or 28 (Biaxial) in 85 mm (3.34") casing. Readout is achieved using the RB-500 (manual readings) or with the Model 8600 Series Dataloggers.

### 6155B | Standard, Analog Sensor, Addressable

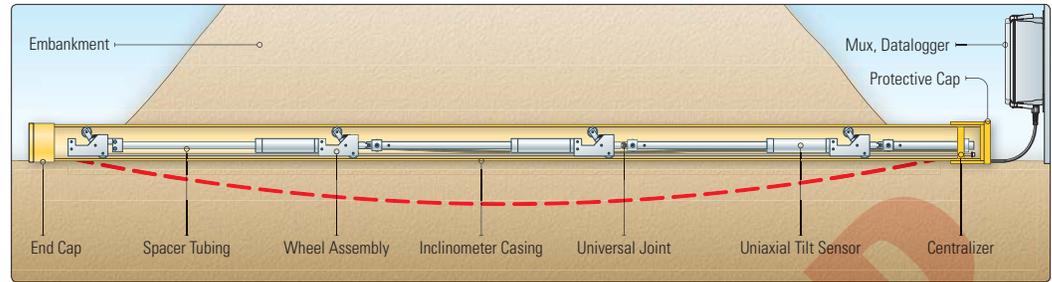
Similar to the above but with all the sensors connected together on a single 6-pair cable that is permanently attached to the sensor as part of a string with the cable going in and out of the top of the sensor; one to the sensor above, the other to the sensor below. Each string is custom made with requisite cables according to customer specifics. The maximum number of sensors that can be used in this configuration is 16 and the maximum cable length is 305 m. This assembly operates in much the same way as a multiplexer and is read using the Model 8600 Series Dataloggers.

### 6155C | Digital Sensor, Addressable

Similar to the above but with digital MEMS sensors connected to a 2-conductor Frequency Shift Keying (FSK) trunk line via waterproof connectors. In this configuration sensors are built and stocked with short pigtail cables and only the trunk cable is made according to customer specifics. Readout is accomplished using the Model 8600 Series Dataloggers via a modem interface (each modem is capable of supporting up to 6 IPI sensor strings). The maximum number of sensors that can be used in this configuration is 32. Digital systems offer greater noise immunity than analog types, and are capable of signal transmission over cables up to 305 m in length.



• Model 8600-1 Datalogger.



• Typical application to monitor the settlement of an embankment.

### 6155E | RS-485 Versions\*

Similar to the 6155C and 6155D described above, but with a 4-conductor cable and RS-485 output allowing for direct connection to a variety of dataloggers and the GeoNet Wireless Datalogger System. (\*In development.)

### Advantages and Limitations

MEMS tilt sensors have many advantages. They have a wide range combined with high sensitivity, which makes them ideally suited for use in installations which deviate excessively from the horizontal. Their long-term stability is excellent and they are immune to shock loading. Sensor outputs are compatible with most data acquisition systems and optional serial systems are available for multiplexed installations using a single cable.

Limitations include cost which, even though comparable to or less than other systems, may limit the number of sensors in any one installation. Because of this, the deflection profile obtained may not be as detailed as profiles obtained with conventional inclinometer probes.

Costs can be controlled by limiting the tilt sensor placement only to those zones where the largest deflections are anticipated.

### System Components

Components of the MEMS Horizontal In-Place Inclinometer are shown above. The tilt sensors may be either uniaxial or biaxial, with wheel assemblies and universal joints separated by spacer tubing of various lengths determined by the required interval between the tilt sensors.

The outer end of the system is terminated in a manhole, or other structure, and blind ended systems are available allowing the instruments to be "pulled" into the casing.

### Data Acquisition

For automatic monitoring, readout is best accomplished using the 8600 Series dataloggers or any other datalogger capable of reading  $\pm 5$  volt sensors or accepting RS-485 signals (Campbell Scientific CR1000, Data Electronics Datataker 600, Geomatic Model 2380, etc.).

### Technical Specifications

	6155A-1/2	6155B-1/2	6155C-1	6155E-1
Standard Range <sup>1</sup>	$\pm 15^\circ$	$\pm 15^\circ$	$\pm 15^\circ$	$\pm 15^\circ$
Resolution	$\pm 0.02$ mm/m ( $\pm 4$ arc seconds)	$\pm 0.02$ mm/m ( $\pm 4$ arc seconds)	$\pm 0.02$ mm/m ( $\pm 4$ arc seconds)	$\pm 0.02$ mm/m ( $\pm 4$ arc seconds)
Sensor Accuracy <sup>2</sup>	$\pm 0.05$ mm/m ( $\pm 10$ arc seconds)	$\pm 0.05$ mm/m ( $\pm 10$ arc seconds)	$\pm 0.05$ mm/m ( $\pm 10$ arc seconds)	$\pm 0.05$ mm/m ( $\pm 10$ arc seconds)
Sensor Voltage (Nom)	12 V DC ( $\pm 3$ V)	12 V DC ( $\pm 3$ V)	12 V DC (10.8-15 V)	12 V DC ( $\pm 3$ V)
Sensor Output	$\pm 4$ V @ $\pm 15^\circ$	$\pm 4$ V @ $\pm 15^\circ$	Digital	Digital
Materials	304 SS	304 SS	304 SS	304 SS
Cable (Uniaxial)	3 pair	6 pair	n/a	n/a
Cable (Biaxial)	6 pair	6 pair	1 pair	2 pair
Temperature Range <sup>1</sup>	$-20^\circ\text{C}$ to $+80^\circ\text{C}$	$-20^\circ\text{C}$ to $+80^\circ\text{C}$	$-20^\circ\text{C}$ to $+80^\circ\text{C}$	$-20^\circ\text{C}$ to $+80^\circ\text{C}$
Thermistor Accuracy	$\pm 0.5^\circ\text{C}$	$\pm 0.5^\circ\text{C}$	$\pm 0.5^\circ\text{C}$	$\pm 0.5^\circ\text{C}$
Sensor (L x Ø)	219 x 32 mm	362 x 32 mm	362 x 32 mm	362 x 32 mm
Sensor Weight	0.4 kg	0.4 kg	0.4 kg	0.4 kg
Max Cable Length	305 m	305 m	305 m	TBD (in development)
Max Sensors per String	24-42; 16-28 <sup>3</sup>	16	32	TBD (in development)

<sup>1</sup>Other ranges available on request. | <sup>2</sup>Established under laboratory conditions. | <sup>3</sup>Maximum number of Sensors per String is dependent on Casing diameter, as follows: Casing OD: 70 mm (2.75"): 24 (Uniaxial), 16 (Biaxial); Casing OD: 85 mm (3.34"): 42 (Uniaxial), 28 (Biaxial).