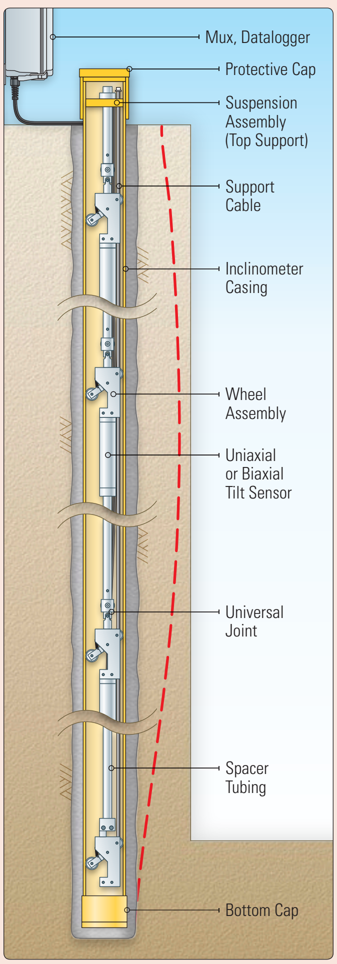
MEMS In-Place Inclinometer Systems

Applications

The remote, continuous, and automatic monitoring of…

- The stability of natural slopes, landslides and embankments
- The stability of slurry walls, sheet piling and tieback walls around excavations
- Lateral ground movements and differential settlements in, around and above tunnels and underground openings



Typical application to monitor the stability of a foundation wall.

Model 6150 MEMS In-Place Inclinometer. Inset photo reveals installation detail with section of Model 6400 Inclinometer Casing removed.

Operating Principle

The Model 6150 MEMS In-Place Inclinometer consists of a string of MEMS (Micro-Electro-Mechanical Sensor) tilt sensors mounted on lengths of stainless steel tubing which are linked together by universal joints. The string of sensors is inserted inside a pipe, or a casing installed in a borehole in the ground, with the sensor cable(s) 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 Σ L sinθ, are plotted to give profiles of lateral 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:

6150A | 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 gage 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 ±4V at ±15°. 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 Micro-1000 or Micro-800 Dataloggers.

6150B | 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 Micro-1000 or Micro-800 Dataloggers.

6150C | 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.

● *Model 6150D Digital Sensor, Wheelless, Addressable, MEMS In-Place Inclinometer.*

● *Closeup of Model 6150D sensor, stainless steel tubing and universal joint.*

Readout is accomplished using the Micro-1000 or Micro-800 Datalogger 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 16. Digital systems offer greater noise immunity than analog types, and are capable of signal transmission over cables up to 305 m in length.

6150D | Digital Sensor, Wheelless, Addressable
Similar to the above but with sensors flexibly linked with tubing (to provide customer specific gage lengths: 0.5, 1, 2 or 3 m) and fixed U-joints, which prevent rotation. Intended for use in standard 2" PVC pipe (without grooves), hence the wheelless design. Two versions of this configuration are available; one with customer specific interconnecting cables to match the sensor spacing, and another with sensors fitted with short pigtail cables that connect the sensors to each other.

6150E | RS-485 Versions*
Similar to the 6150C and 6150D 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.
*Available Fall 2015.

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 vertical. Their long-term stability is excellent and they are highly resistant to shock loading.

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 In-Place Inclinometer for use in conventional inclinometer casing are shown at left. 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 upper end of the system is suspended from a top support and the lower end requires a special bottom wheel assembly to which a support cable is attached.

Data Acquisition

For automatic monitoring, readout is best accomplished using the Micro-1000 datalogger or any other datalogger capable of reading ±5 volt sensors or accepting RS-485 signals (Campbell Scientific CR1000, Data Electronics Datataker 600, Geomation Model 2380, etc.).

Technical Specifications

	6150A-1/2	6150B-1/2	6150C-1	6150D-1	6150E-1
Standard Range[1]	±15°	±15°	±15°	±15°	±15°
Resolution	±4 arc seconds (±0.02 mm/m)	±4 arc seconds (±0.02 mm/m)	±4 arc seconds (±0.02 mm/m)	±4 arc seconds (±0.02 mm/m)	±4 arc seconds (±0.02 mm/m)
Sensor Accuracy[2]	±10 arc seconds (±0.05 mm/m)	±10 arc seconds (±0.05 mm/m)	±10 arc seconds (±0.05 mm/m)	±10 arc seconds (±0.05 mm/m)	±10 arc seconds (±0.05 mm/m)
Sensor Voltage (Nom)	12 V DC	12 V DC	12 V DC	12 V DC	12 V DC
Sensor Output	±4 V @ ±15°	±4 V @ ±15°	Digital	Digital	Digital
Materials	304 SS	304 SS	304 SS	304 SS	304 SS
Cable (Uniaxial)	3 pair	6 pair	n/a	n/a	n/a
Cable (Biaxial)	6 pair	6 pair	1 pair	1 pair	2 pair
Temperature Range[1]	–20° to +80°C	–20° to +80°C	–20° to +80°C	–20° to +80°C	–20° to +80°C
Thermistor Accuracy	±0.5°C	±0.5°C	±0.5°C	±0.5°C	±0.5°C
Sensor (L × Ø)	219 × 32 mm	362 × 32 mm	362 × 32 mm	362 × 32 mm	362 × 32 mm
Sensor Weight	0.4 kg	0.4 kg	0.4 kg	0.4 kg	0.4 kg
Max Cable Length	305 m	305 m	305 m	305 m	TBD *(Fall 2015)*
Max Sensors per String	24-42; 16-28[3]	16	16	16	TBD *(Fall 2015)*

[1]Other ranges available on request. | [2]Established under laboratory conditions. | [3]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).*

GEOKON
The World Leader in Vibrating Wire Technology™

Geokon, Incorporated
48 Spencer Street
Lebanon, NH 03766
USA

1 • 603 • 448 • 1562
1 • 603 • 448 • 3216
geokon@geokon.com
www.geokon.com