I N S T R U C T I O N   M A N U A L

MEMS Vertical In-Place Inclinometer - IPI

GEOSENSE

UK CA CE

TABLE OF CONTENTS

1. VERSION CONTROL

Version	Date	Author	Approved	Issued
V1.0 – V1.2	2013 - 2022	MC	MC	GC
V1.3	2023	TB	TC	GC

2. INTRODUCTION

This manual is intended for all users of **Geosense®** In-Place Inclinometers (IPIs) manufactured by Geosense and provides information on their installation, operation and maintenance.

It is VITAL that all personnel responsible for the use of IPI Instruments READ and UNDERSTAND this manual, prior to working with the equipment

2.1. General Description

The Geosense® In-Place Inclinometer (IPI) equipment is an environmentally sealed assembly that is used to register changes of inclination within specialist inclinometer casing. The assemblies are commonly interlinked and intended to remain static within the inclinometer casing.

In-Place Inclinometers can be installed or included in many types of monitoring regime and can be linked to various types of readout and recording equipment.

The primary uses of IPIs are:

- Measurement of rotation within a vertical installation
- Measurement of rotation within an inclined or horizontal installation

With applications such as, but not limited to, the following:

- Embankment stability and safety monitoring
- Stability of retaining walls
- Dam monitoring
- Horizontal pile testing
- Slope stability monitoring

Particular features of Geosense IPIs are:

- Reliable long-term performance
- Ruggedness; suitable for demanding environments
- Simple, cable free interconnection
- High accuracy
- Digital output, therefore insensitive to long cable lengths and joints

The Geosense® IPI is based upon micro-electromechanical systems technology (MEMS). The MEMS sensors employed in the IPI is an accelerometer that is configured to measure changes in rotation (tilt or inclination). IPI sensor modules can be configured to include a Uni-axial sensor or a Bi-axial sensor, where the two sensors detect inclination in perpendicular directions (A axis and B axis).

Electronic circuitry within each IPI module interrogates its sensor and the corresponding output is converted from an Analogue to a Digital signal, making it particularly suitable for the demanding environments of geotechnical and civil engineering applications. Digital signals are capable of long transmission distances without degradation.

Each Geosense® IPI has a unique identification number, thereby simplifying the interconnection using 4 wire digital protocols.

Geosense® IPIs are supplied in various configurations to suit a range of installations. In most applications they are installed in 'strings' where each IPI is connected to its neighbour by a 'universal joint'.

A typical IPI string comprises the following components:

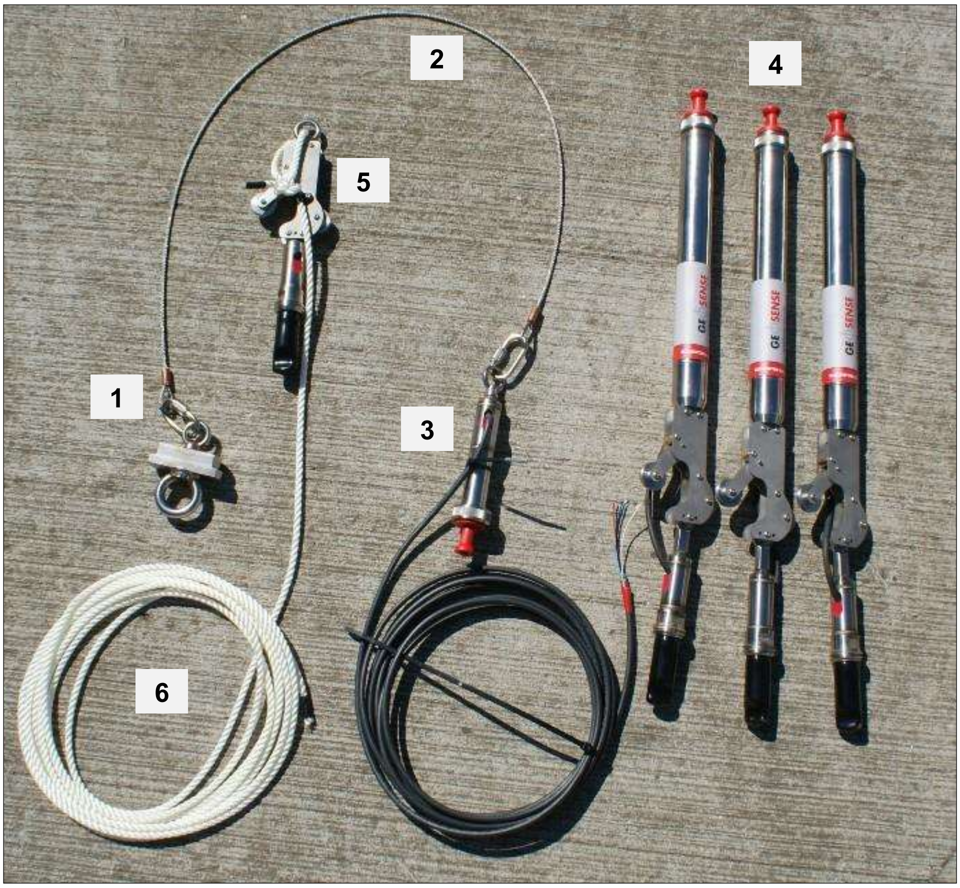


Figure 1: A string of 3 IPIs laid out showing the main components

1) **Top hanger** - used to suspend the complete IPI string
2) **Wire hanger extension** - used to position the first IPI
3) **Top fly lead assembly** - top suspension adaptor and cable connector
4) **In-Place Inclinometer probe** - measures tilt in uniaxial or biaxial axes
5) **Bottom wheel/termination assembly** - base reference wheel & RS-485 end termination
6) **Support rope** - used to support the IPI string from the base

2.2. Theory of Operation

inclinometer casing is a specially machined plastic tube that is installed in, or fixed to, a structure. The tube has 4 equally spaced, parallel 'keyways' in its inner surface, into which wheeled probes can be inserted, thereby maintaining their orientation. The inclinometer casing is designed to move with the structure into which, or onto which, it is fixed, if the structure changes shape.

In order to detect any changes in the horizontal direction (vertical or inclined access tubes) or vertical direction (horizontal access tubes), an inclinometer system is inserted into the inclinometer casing.

An inclinometer system comprises a wheeled probe that runs in the inclinometer casing keyways and includes very sensitive electronic tiltmeter(s), a connecting cable and a readout.

Portable inclinometer systems are commonly used where monitoring is to be in-frequent or manual monitoring is in-expensive. These systems are used to determine the inclination of an inclinometer casing at 0.5m intervals along it length. This information is processed to generate a profile of the inclinometer casing, with respect to vertical and sequential profiles being compared with each other to detect changes.

Geosense® In-Place Inclinometers (IPIs) are intended to remain 'in-place' within the inclinometer casing and are employed where continuous or frequent monitoring is required. The completed installation is, in effect, a string of interconnected, inclinometer probes, separated by rods or wires and suspended in the inclinometer casing.

Each **Geosense® IPI** sensor module includes a very sensitive Micro Electro-Mechanical System (MEMS) tiltmeter. The device is extremely sensitive and is detects changes in the angle of the module if the surrounding inclinometer casing moves. Installations close to vertical can measure movements in 2 directions, whereas

Since they are digital, the cable from the IPI modules can be connected together in a 'string', thereby minimising the cables from each installation.

In most cases, **Geosense® IPIs** are mechanically inter-connected using 'Universal joints' so as to maintain a physically connected profile of measurement. This is critical if a 'truly accurate' profile of the inclinometer casing is to be measured. (Where steel rope is used to interconnect the IPI modules, a true profile cannot be measured).

In addition, it is vital that the IPI modules are suspended between the walls of the inclinometer casing and do not touch them at any time during the monitoring period.

Once installed and suspended in the inclinometer casing, the IPI sensors can be interrogated by various means. The readings from each module will be the angle of the sensors, with respect to vertical, in either degrees or 'sine of the angle' units and the temperature of the module.

2.3. Measurement of Tilt

When installed within inclinometer casing and viewed from the top, the wheels of the inclinometer are engaged into the grooves within the casing.

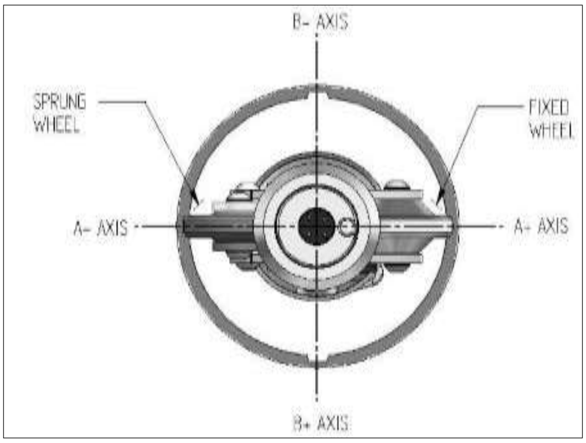
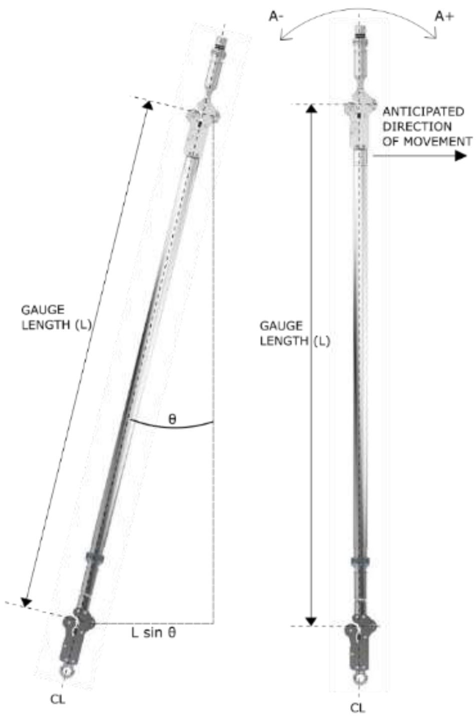


Figure 2: Top down view of IPI within Geosense inclinometer casing

The A axis is the primary axis and the B axis is the secondary axis. Uni-axial IPI sensors only detect changes in the A axis.

After their installation, the vertical profile of the inclinometer casing is established from the readings of individual IPI sensors. Changes to the verticality of a vertical or inclined inclinometer casing (changes in the horizontal plane) are detected by the sensor and the magnitude of the change is simply computed from the equation ‘current reading - initial reading’. Horizontal IPI’s detect vertical movement of the inclinometer casing.



3. VARIANTS

There are two variants of the **Geosense®** In-Place Inclinometer:

- Vertical In-Place Inclinometer
- Horizontal In-Place Inclinometer

There are two types of deployment method for **Geosense®** IPIs:

- Rigid Rod
- Wire Rope (vertical only)

There are two sensor options for **Geosense®** IPI sensors:

- Uniaxial
- Biaxial

System specifications can be found for each system in the relevant datasheets. For more information, please contact **Geosense®** on sales@geosense.co.uk

4. CONFORMITY

Geosense Ltd
Nova House
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United Kingdom

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www.geosense.co.uk

EU Declaration of Conformity

We Geosense Ltd at above address declare that the equipment detailed below, complies with the requirements of the following EU Directives: -

- Electromagnetic Compatibility Directive **2014/30/EU**
- Waste electrical and electronic equipment (WEEE) **2012/19/EU**
- Restriction on the use of certain Hazardous Substances **RoHS2 2011/65/EU**

Equipment description:	**MEMS Digital In-Place Inclinometer**
Make/Brand:	**Geosense**
Model Numbers:	**IPI-V-1, IPI-V-2, IPI-I-1, IPI-I-2, IPI-H-1, IPI-H-2**

Compliance has been assessed with reference to the following standard:

EN 61326-1:2021 Electrical equipment for measurement, control and laboratory use. EMC requirements. General requirements.

EN 61010-1:2010+A1:2019 Safety requirements for electrical equipment for measurement, control, and laboratory use. General requirements.

A technical file for this equipment is retained at the above address.

Tim Clegg

Director
24/04/2023

GQF/037 V2

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www.geosense.co.uk

UK Declaration of Conformity

We Geosense Ltd at above address declare that the equipment detailed below, complies with the requirements of the following UK regulations: -

- Electromagnetic Compatibility Regulations 2016
- The Waste Electrical and Electronic Equipment Regulations 2013 (as amended)
- The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2012

Equipment description:	**MEMS Digital In-Place Inclinometer**
Make/Brand:	**Geosense**
Model Numbers:	**IPI-V-1, IPI-V-2, IPI-I-1, IPI-I-2, IPI-H-1, IPI-H-2**

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Tim Clegg

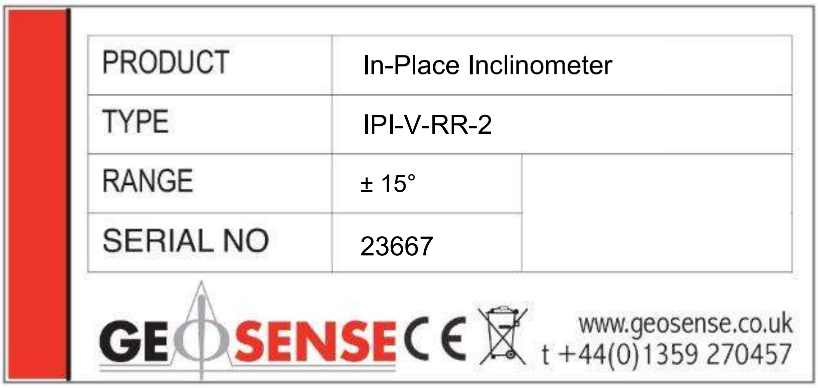
Director
24/04/2023

GQF/037C V2

5. MARKINGS

Geosense® Vertical In-Place Inclinometers are labelled with the following information:

- Manufacturers name & contact details
- Product type
- Model
- Range
- Orientation
- Input signal
- Output signal
- Serial number
- CE mark / UKCA mark
- WEEE mark



6. DELIVERY

This section should be read by all users of equipment manufactured by **Geosense®.**

6.1. Packaging

Geosense® IPI's are packed for transportation to site. Packaging is suitably robust to allow normal handling by transportation companies. Inappropriate handling techniques may cause damage to the packaging and the enclosed equipment. The packaging should be carefully inspected upon delivery and any damage MUST be reported to both the transportation company and **Geosense®**.

6.2. Handling

Whilst they are a robust devices, **Geosense®** IPI's are precision measuring instruments. They, and their associated equipment, should always be handled with care during transportation, storage and installation.

Once the shipment has been inspected (see below), it is recommended that IPI's remain in their original packaging for storage or onward transportation.

Cable should also be handled with care. Do not allow it to be damaged by sharp edges, rocks for example, and do not exert force on the cable as this may damage the internal conductors and could render an installation useless.

6.3. Inspection / Functionality Check Readings

It is important to check all the equipment in the shipment as soon as possible after taking delivery and well before installation is to be carried out. Check that all the components detailed on the documents are included in the shipment. Check that the equipment has not been physically damaged.

ALL **Geosense®** IPI's carry a **unique** identification serial number which is included on the labels on the IPI body (see right). All IPI's are supplied with individual calibration sheets that include their serial numbers and these are shipped with the equipment.

Wherever possible, it is suggested that the IPI's should be functionally checked soon after arrival to ensure they have not been damaged during transportation. This is a basic 'out of the box' functional check. Ensure that the IPI's have been stored in a reasonably stable temperature for at least 60 minutes prior to carrying out a functional check.

6.4. Storage

All equipment should be stored in an environment that is protected from direct sunlight. It is recommended that cables be stored in a dry environment to prevent moisture migrating along inside them in the event of prolonged submersion of exposed conductors.

Storage areas should be free from rodents as they have been known to damage connecting cables.

No other special requirements are needed for medium or long-term storage although temperature limits should be considered when storing or transporting associated components, such as readout equipment.

Calibration Sheets contain VITAL information about The IPI's. We suggest that only COPIES of calibration certificates should be taken to site

The original certificates should be stored safely

7. CALIBRATION

All **Geosense®** IPI instruments are supplied with a calibration sheet like the example below.

GEOSENSE QUALITY FORM	
GQF-148	
ISS. 6	
DATE : OCT 21	
SIG. GC	

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Website: www.geosense.co.uk

Vertical MEMS In Place Inclinometer Digital Bus CALIBRATION

Model:	**IPI-V-1-RR**	**Cal Date:**	**24/01/2023**	**Serial No:**	**26158**
Cable Length:		**Range ±:**	**15**	**Temp °C:**	**19**
Rotary Table:	**SN: AT50/7/71**	**Orientation:**	**Vertical**		

A-Axis

Applied Angle (Deg)	Applied Angle (Sin(x))	Output (Sin(x))	Relative Error (Sin(x))
15.00	0.25882	0.25882	0.00000
11.25	0.19509	0.19510	0.00001
7.50	0.13053	0.13053	0.00001
3.75	0.06540	0.06541	0.00001
0.00	0.00000	-0.00001	0.00001
-3.75	-0.06540	-0.06539	0.00002
-7.50	-0.13053	-0.13051	0.00002
-11.25	-0.19509	-0.19510	0.00001
-15.00	-0.25882	-0.25884	0.00002
		Max Error:	0.00002

THE EQUIPMENT USED IN THE CALIBRATION OF THE PRODUCT DETAILED ABOVE IS TRACEABLE TO NATIONAL/INTERNATIONAL STANDARDS

CALIBRATED TO UKAS TRACEABLE STANDARD - ISO 9001:2015

THIS IS AN ELECTRONIC CERTIFICATE AND IS VALID WITHOUT A SIGNATURE

8. INSTALLATION

This section of the manual is intended for all installers of **Geosense**® IPI's and is intended to provide guidance with respect to their installation.

It must be remembered that no two installations will be the same and it is inevitable that some 'fine tuning' of the following procedures will be required to suit specific site conditions.

It is VITAL that personnel responsible for the installation and use of the piezometers READ and UNDERSTAND the manual, prior to working with the equipment.

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As stated before, it is VITAL to check all the equipment in the shipment soon after taking delivery and well before installation is to be carried out. Check that all components that are detailed on the shipping documents are included.

8.1. Preparation for Installation

IPI's are designed to be installed within specialist inclinometer casing. The casing must be either installed in a borehole of fixed firmly to a structure. Prior to installation of an IPI, it is essential to establish and confirm details of the installation to be carried out. Some of the main considerations are listed below:

8.1.1. *Intended elevation and length of each IPI segment*

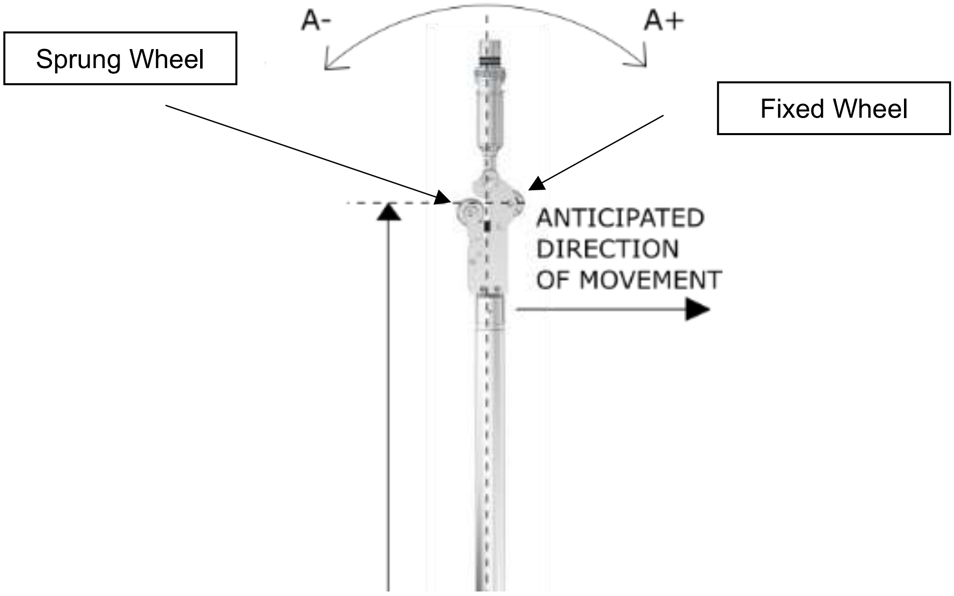
An IPI comprises a series of interconnected elements. The uppermost wheel set must be located a minimum of 250mm from the top of the inclinometer casing so as to accommodate the support and cable connection components. This distance can be varied by adjusting the length of the wire hanger extension (stainless steel rope).

The IPI probes are the measuring elements and the separation between the IPI probes (referred to as the 'Gauge Length) is maintained by extension rods. Standard extension rods are available to provide 1, 2 and 3 metre gauge lengths and the gauge lengths can vary within a single installation.

For example, an IPI installed in an inclinometer casing in a landslip might use 3m gauge lengths in its upper zone (within the slip body) and 1m gauge lengths in the slip zone.

8.1.2. *Directional Orientation*

The primary measuring axis of the IPI is A+ / A- which is the same orientation as the wheels. The A+ direction corresponds to the direction of the FIXED WHEEL and, consequently, A - is in the direction of the SPRUNG WHEEL.



8.1.3. *Cable*

Cables should be marked with a unique identification system. Where multiple cables are to be grouped together along one route, markings should be repeated at regular intervals along the cable, so that in the event of cable damage, there may be a chance that the identification could be exposed and the cables re-joined. Multiple cable marks are particularly important close to the ends of the cables. The spacing of markings can vary according to specific site requirements. As a guide, 5m to 10m is commonly applied, but closer spacing nearer the ends.

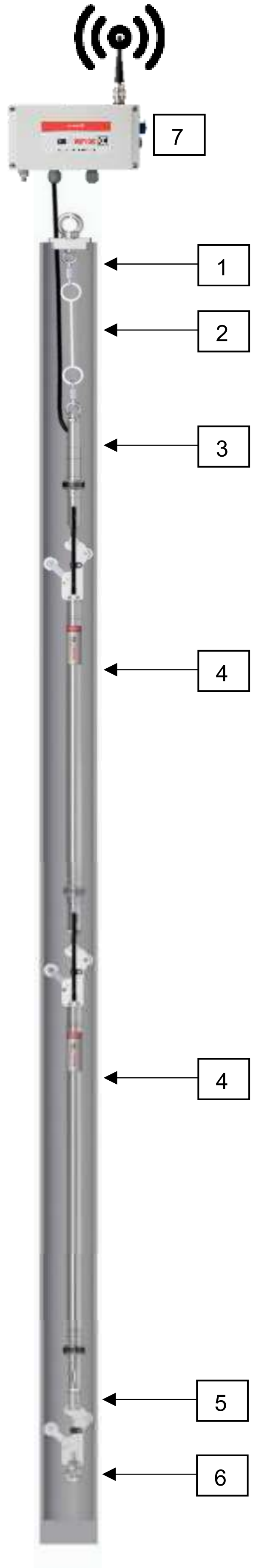
8.1.4. *Tools*

Obtain any tools necessary to carry out the installation. The following is a brief list of tools typically used during the installation of In-Place Inclinometers. Some variation and addition may be necessary for different types of application.

- Fibre measuring tape with a weight added to the end for borehole depth measurement
- Installation fork
- Support rope
- Suitable readout
- Lifting equipment (for deep installations) which must meet all local safety requirements

8.2. System Components – Rigid Rod Variant

Illustrated right are the typical components of a Rigid Rod IPI installation



1) **TOP HANGER** - Used to suspend the complete IPI string. Placed on the top of the 70mm inclinometer casing

   INSTALLATION FORK - (not shown)
   Used to support the IPI string during installation. It fits into two slots on top of the IPI sensor and is placed on top of the inclinometer casing

2) **TOP STEEL WIRE BOND** - A 3mm wire suspension rope used to position the first sensor at the required depth and is connected to the top collar hanger and the IPI top fly lead assembly (G86-502). Available either as pre-assembled lengths (1, 2, 3, 4m) or supplied as site adjustable

3) **IPI TOP FLY LEAD ASSEMBLY** - A universal component which acts as top suspension and cable connector. Fitted as standard with 4.5m of digital BUS cable for connection to a readout or data logger. Other cable lengths available on request.

4) **IN-PLACE INCLINOMETER PROBE (IPI)** - Instrument fitted with one (Uniaxial) or two (Biaxial) MEMS sensors. It is mounted within a watertight stainless steel tube fitted with two wheel sets that run in the internal grooves of inclinometer casing. One set has a fixed wheel and the other is sprung loaded. The output from the sensors is digital RS-485 BUS so that several IPIs can be connected together on one single cable

5) **BOTTOM WHEEL/TERMINATION ASSEMBLY** - Fitted with a rigid joint, the bottom wheel assembly acts as the base reference from which all other readings are taken. It is fitted with an integral end termination resistor which is required at the end of the RS-485 string

6) **BASE EYELET** – Connection for installation and recovery lifting rope to attach (rope provided by customer)

7) **WI-SOS 480 WIRELESS DIGITAL NODE** – Can log up to 50 IPI sensors in a single string.

8.2.1. *Installation into Inclinometer Casing*

1) Make sure all the connectors are protected by the shipping plugs before taking the equipment to site. They can be removed for delivery testing, and should be refitted for transport and setup on site.

Figure 3: Connector Protective Caps

2) Before the installation is started, it is recommended to lay out all the IPI components on a clean dry surface. If the ground is not clean and free from debris, it is STRONGLY recommended that a thick layer of clean plastic sheeting is laid down, with cover from the weather above. Leave the connector covers in place for now.

Figure 4: All equipment laid out prior to install

If the string is to made up of different lengths of sensors, it is a good idea to lay the sensors out in the order they will be put into the hole, to make installation easier and quicker.

3) Connect your support rope to the eyelet at the base of the bottom wheel assembly. The is supplied by the end user and needs to be strong enough to support the entire weight of the string of IPI's. Polypropylene or steel wire rope is normally used. Use the cable clip to secure the rope to ensure it does not fowl the wheel set on deployment or recovery.

Figure 5: Polypropylene rope connected and secured to eyelet on the base of the bottom wheel assembly

It is CRITICAL that the support rope is used to raise and lower the IPI string. NEVER use the top fly lead connection to life the string, this will cause damage

4) It is recommended to use a static fixed point to suspend the support rope from. A winch is required for deeper installations where the weight of the IPI string will become unmanageable for a person to hold by hand. Normal systems used are man recovery frames (tripods) fitted with a winch. These are commonly available from plant hire companies.

5) In a clean and dry area, remove the connector protective caps, and connect the first “lead” sensor to the bottom wheel assembly. Make sure the segment is in the same “fixed” wheel orientation as the bottom wheel assembly. Connectors have an alignment pin. Alignment of the connectors are marked by red marker dots. This designates the orientation of the connectors when they are pushed together.

Figure 6: Alignment pin and marker dot

6) Gently push the two connectors together, noting the alignment. Make sure the connectors are clean and dry. The connectors are coated with a small amount of silicone grease to lubricate the o-ring seals. Make sure the connector is pushed together aligned and in-line with the other connector (i.e. not at any angle). If grit has got stuck to the silicone grease, the connector MUST be cleaned and relubricated before being pushed together. Failure to do so may cause the connector to leak and will potentially damage the sensor.

Figure 7: IPI male and female connectors being pushed together

7) Once the connectors are mated, rotate the threaded collar to lock to two segments together. Once the locking collar has been screwed on enough, the retaining ring or “snap clip” should be able to be engaged.

Figure 8: Retaining ring or "snap ring" engaged into recess, locking the threaded collar and stopping it rotating

It is VITAL that the connections are clean, clear from debris and water before connection. Failure to ensure the seals are lubricated and free from debris will risk the connector watertight integrity.

8) If the connectors need to be undone, the retaining ring will need to be undone before the collar can be unscrewed, this can be done with a small flat head screwdriver.

Figure 9: Retaining ring levered out of the recess using a screwdriver

9) Insert the first length, with the bottom wheel assembly connected, into the top of the inclinometer casing. Confirm the direction of expected movement and ensure the keyways of the inclinometer casing a correctly aligned. See section 8.1.2.

   Make sure the wheels are fully engaged into the keyways.

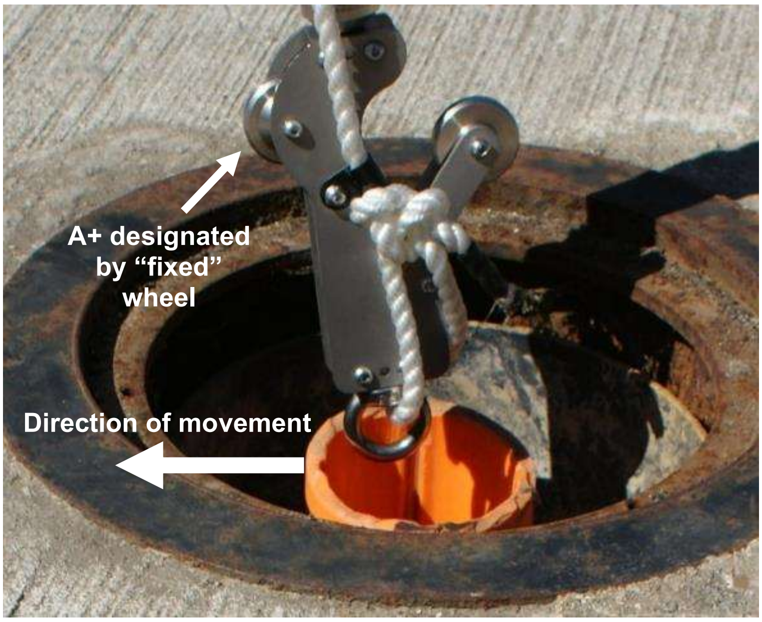


Figure 10: Bottom wheel assembly entering the inclinometer casing first, showing orientation

10) Record the serial number of the first segment that goes in. It is important to have an accurate record of which serial numbers are in each hole, and their order. The order of the string is critical in computing the displacement over the length of the instrumented range.

11) Using the support rope and a hand to steady the inclinometer, gently lower the bottom wheel assembly and the segment into the casing.

12) Lower the rope to allow the sensor string to slide into the inclinometer casing, until you reach the top of sensor just added to the string.

13) Insert the installation fork to lock off and support the string whilst the next sensor is added. The fork is provided with an eyelet should it need to be secured to stop it from falling.

Figure 11: Installation fork locked off on the flats of the sensor, supporting the weight of the half installed string whilst the next sensor is prepared and added onto the top of the locked off sensor

14) Add the next sensor, record the serial number and the position in the string, and continue adding sensors until you have added all sensors required for the install.

Figure 12: Sensors being added and locked off each time with the installation fork. The weight of the string when being lowered is held by the support rope. The sensor entering the hole can be aligned and held steady with a hand.

15) When adding sensors, make sure to only remove the dust caps right before installation.

16) Once you reach the final sensor to enter the inclinometer casing, lock the top of it off with the installation fork.

17) Connect the top fly lead assembly using the same connection method as has been used for all the IPI segments. Take extreme care not to damage the cable attached to the top fly lead.

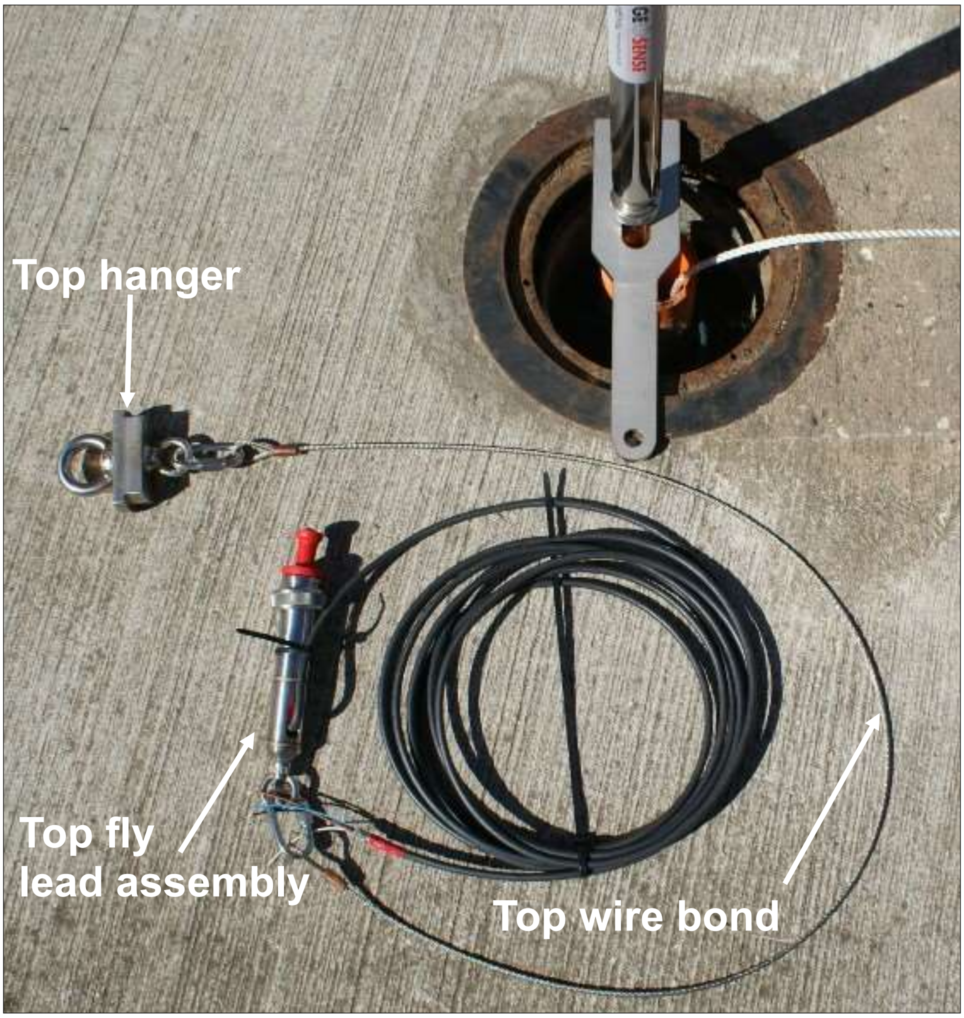


Figure 13: Top fly lead assembly prior to installation

18) Lower the string of IPI's down into the inclinometer hole slowly, allowing the top fly lead assembly to enter the casing. Keep the steel wire hanger and the cable taught by hand as you lower, to stop them falling down into the casing and fowling the wheel sets.

Figure 14: IPI string with top fly lead assembly fitted, being lowered into the casing

19)Slowly lower the string into the casing using the support rope, making sure to keep the top hanger steel wire and cable taught during installation.

Figure 15: String lowered into hole with only top hanger, wire rope, support rope and cable visible

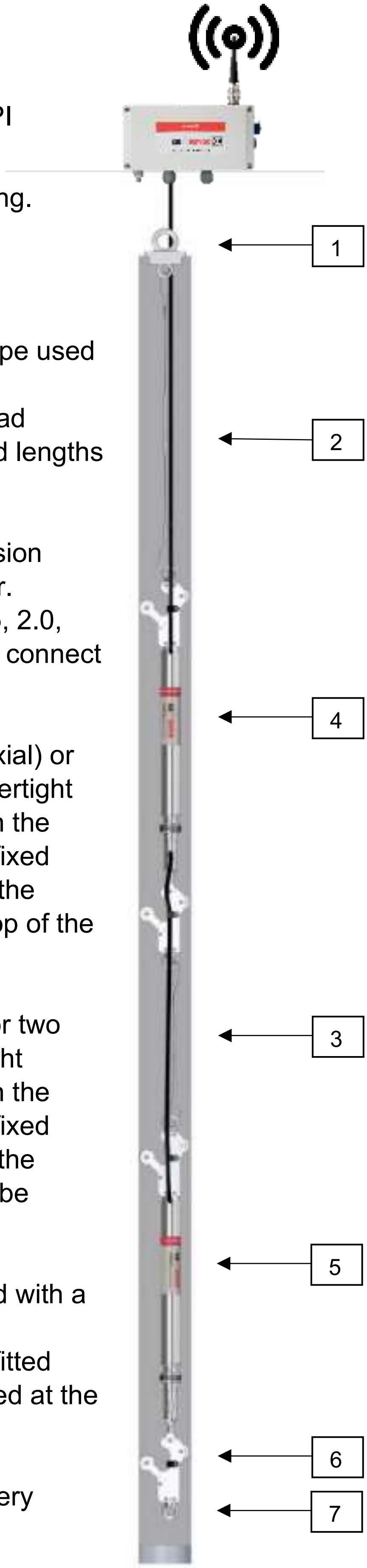
20)Lower down the string until the hanger assembly rests securely on the top of the inclinometer casing. The casing should be cut flat at the top to allow secure seating of the hanger.

21)It is good practice to mark the location of the top hanger on the top of the inclinometer casing, so it can be relocated again if removal occurs at any point.

IPI Assemblies should always hang (once deployed), they should NEVER sit on the bottom of the hole

8.3. System Components – Wire Rope Variant

Illustrated right are the typical components of a Wire Rope IPI installation



1) **TOP HANGER** - Used to suspend the complete IPI string. Placed on the top of the 70mm inclinometer casing

   INSTALLATION FORK - (not shown)

2) **TOP STEEL WIRE BOND** - A 3mm wire suspension rope used to position the first sensor at the required depth and is connected to the top collar hanger and the IPI top fly lead assembly (G86-502). Available either as pre-assembled lengths (1, 2, 3, 4m) or supplied as site adjustable

3) **INTERMMEDIATE WIRE BOND** - A 3mm wire suspension rope used to suspend and connect each IPI-WR sensor. Available either as pre-assembled lengths (0.5, 1.0, 1.5, 2.0, 2.5m) or supplied as site adjustable. These are used to connect each IPI sensor together

4) **IPI-WR TOP PROBE -** Instrument fitted with one (Uniaxial) or two (Biaxial) MEMS sensors. It is mounted within a watertight stainless steel tube fitted with two wheel sets that run in the internal grooves of inclinometer casing. One set has a fixed wheel and the other is sprung loaded. The output from the sensors is digital RS-485 BUS and it is located at the top of the IPI string.

5) **IPI-WR PROBE -** Instrument fitted with one (Uniaxial) or two (Biaxial) MEMS sensors. It is mounted within a watertight stainless steel tube fitted with two wheel sets that run in the internal grooves of inclinometer casing. One set has a fixed wheel and the other is sprung loaded. The output from the sensors is digital RS-485 BUS so that several IPIs can be connected together on one single cable

6) **BOTTOM WHEEL/TERMINATION ASSEMBLY** - Fitted with a rigid joint, the bottom wheel assembly acts as the base reference from which all other readings are taken. It is fitted with an integral end termination resistor which is required at the end of the RS-485 string

7) **BASE EYELET** – Connection for installation and recovery lifting rope to attach (rope provided by customer)

8.3.1. *Installation into Inclinometer Casing*

1) Make sure all the connectors are protected by the shipping plugs before taking the equipment to site. They can be removed for delivery testing, and should be refitted for transport and setup on site.

Figure 16: Connector Protective Caps

2) Before the installation is started, it is recommended to lay out all the IPI components on a clean dry surface. If the ground is not clean and free from debris, it is STRONGLY recommended that a thick layer of clean plastic sheeting is laid down, with cover from the weather above. Leave the connector covers in place for now.

Figure 17: All equipment laid out prior to install

If the string is to made up of different lengths of sensors, it is a good idea to lay the sensors out in the order they will be put into the hole, to make installation easier and quicker.

3) Connect your support rope to the eyelet at the base of the bottom wheel assembly. The is supplied by the end user and needs to be strong enough to support the entire weight of the string of IPI's. Polypropylene or steel wire rope is normally used. Use the cable clip to secure the rope to ensure it does not fowl the wheel set on deployment or recovery. For the wire rope deployment, the rope will not be used in the same way as the rigid rod installation. However, it needs to be fitted prior to beginning the install.

Figure 18: Polypropylene rope connected and secured to eyelet on the base of the bottom wheel assembly

4) Make sure the rope is terminated at the surface somewhere where it cannot fall back down the installation casing, as this will fowl the wheelsets in the casing and make recovering the system difficult.

5) In a clean and dry area, remove the connector protective caps, and connect the first "lead" sensor to the bottom wheel assembly. Make sure the segment is in the same "fixed" wheel orientation as the bottom wheel assembly. Connectors have an alignment pin. Alignment of the connectors are marked by red marker dots. This designates the orientation of the connectors when they are pushed together.


Figure 19: Alignment pin and marker dot

6) Gently push the two connectors together, noting the alignment. Make sure the connectors are clean and dry. The connectors are coated with a small amount of silicone grease to lubricate the o-ring seals. Make sure the connector is pushed together aligned and in-line with the other connector (i.e. not at any angle). If grit has got stuck to the silicone grease, the connector MUST be cleaned and relubricated before being pushed together. Failure to do so may cause the connector to leak and will potentially damage the sensor.

Figure 20: IPI male and female connectors being pushed together

7) Once the connectors are mated, rotate the threaded collar to lock to two segments together. Once the locking collar has been screwed on enough, the retaining ring or “snap clip” should be able to be engaged.

Figure 21: Retaining ring or "snap ring" engaged into recess, locking the threaded collar and stopping it rotating

It is <u>VITAL</u> that the connections are clean, clear from debris and water before connection. Failure to ensure the seals are lubricated and free from debris will risk the connector water tight integrity.

8) If the connectors need to be undone, the retaining ring will need to be undone before the collar can be unscrewed, this can be done with a small flat head screwdriver.

Figure 22: Retaining ring levered out of the recess using a screwdriver

9) Insert the first length, with the bottom wheel assembly connected, into the top of the inclinometer casing. Confirm the direction of expected movement and ensure the keyways of the inclinometer casing a correctly aligned. See section 8.1.2.

   Make sure the wheels are fully engaged into the keyways.

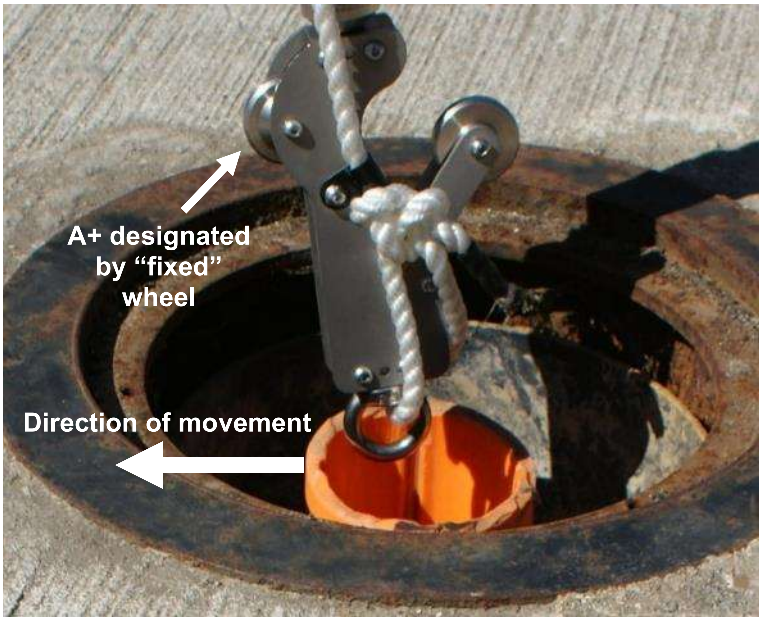


Figure 23: Bottom wheel assembly entering the inclinometer casing first, showing orientation

10) Record the serial number of the first segment that goes in. It is important to have an accurate record of which serial numbers are in each hole, and their order. The order of the string is critical in computing the displacement over the length of the instrumented range.

11) Using the support rope and a hand to steady the inclinometer, gently lower the bottom wheel assembly and the segment into the casing.

12) Lower the rope to allow the sensor string to slide into the inclinometer casing, until you reach the top of sensor just added to the string.

13) Once the top of the assembly nears the top of the casing, place the installation fork into the slots on the top of the connector to support the assembly ready for the next part of the installation.

14) Connect the Rapid Link on one end of an intermediate wire rope support onto the top of the IPI sensor.

15) Lift the string slightly and remove the installation fork.

16) Continue to lower the assembly into the casing and repeat for all intermediate wire bonds and sensors.

17) Once you reach the last sensor to enter the hole (i.e. the top sensor) connect one end of the top steel wire bond to the sensor, and the other end to the top hanger, using the Rapid Links

18) Lower the string of IPI's down into the inclinometer hole slowly. Keep the steel wire hanger and the cable taught by hand as you lower, to stop them falling down into the casing and fowling the wheel sets.

19)Slowly lower the string into the casing using the support rope, making sure to keep the top hanger steel wire and cable taught during installation.

Figure 24: String lowered into hole with only top hanger, wire rope, support rope and cable visible

20)Lower down the string until the hanger assembly rests securely on the top of the inclinometer casing. The casing should be cut flat at the top to allow secure seating of the hanger.

21)It is good practice to mark the location of the top hanger on the top of the inclinometer casing, so it can be relocated again if removal occurs at any point.

IPI Assemblies should always hang (once deployed), they should NEVER sit on the bottom of the hole

8.4. Wiring

8.4.1. *Colour Coding*

Core Colour	Function
Brown	V+
White	Ground
Blue	A+
Black	B-

8.4.2. *WI-SOS 480 Digital Node*

The **Geosense® In-Place Inclinometer (IPI)** is fully compatible with the WI-SOS 480 Digital Node and is wired as shown below. (Please refer to the WI-SOS 480 manual for further details on configuration)

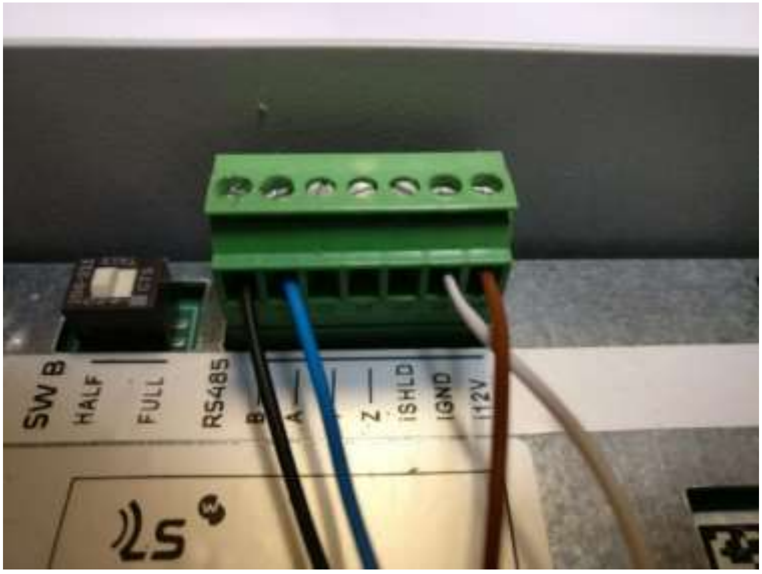


Figure 25: WI-SOS 480 Digital Node with an IPI wired in. Please note - the braid of the sensor must be terminated into either the shield "SHLD" or the housing of the logger using an EMC cable gland

IPI conductor colour	Digital Node colour IN
V+ (Volt)	12V
A +	A+
B-	B-
Ground	GND
Shield	SHLD / EMC cable gland

8.4.3. *RS-485 to RS-232 Interface*

Depending on what type of readout (Windows tablet) or datalogger (e.g. Campbell Scientific) being used with the Geosense IPI, an RS-485 to RS-232 Interface module may be required (Figure 26: Geosense RS-485 to RS-232 Interface)

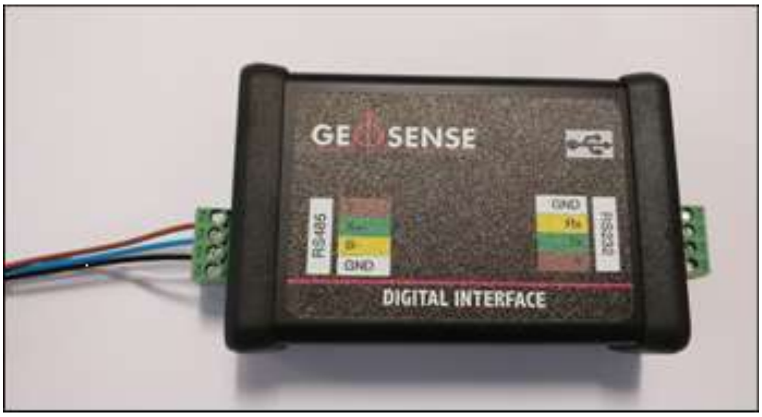


Figure 26: Geosense RS-485 to RS-232 Interface

Various types of screened cables are available, and the Interface has been designed to be used with DIN 47100 colour coding.

IPI conductor colour	RS-485 colour IN	RS-232 colour OUT
V+ (Volt)	V	V
A +	A+	Tx
B-	B-	Rx
Ground	GND	GND

9. DATA HANDLING

9.1. Taking Readings

9.1.1. *Geosense G-Tilt Software*

Geosense® IPI's are excited and interrogated using RS-485 digital protocols. A digital interface unit is required to connect from a standard RS-232C connection (as used by dataloggers, tablets, PCs, Notebooks or similar). Geosense® supply a dedicated RS232 to RS485 interface to be used with a Windows based device.

Once the installation has been carried out and all the thermal gradients have been removed, it is important to establish the initial reading for each of the IPI's. Depending upon the reading method adopted, the initial readings may either be in degrees or sine of angle.

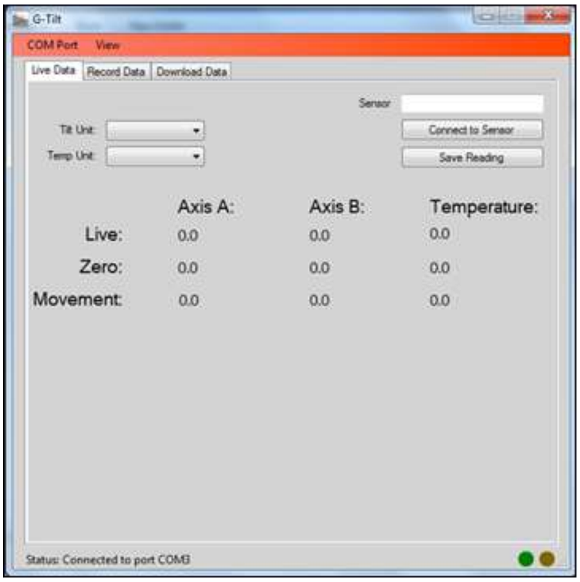
The G-Tilt IPI software is only suitable for use on a Microsoft Windows based PC, Notebook, Tablet or Smart Phone

Do not connect the Digital Interface before installing the software

1 Install G-Tilt.

G-Tilt is available from the Geosense website or alternatively by contacting our Support team.

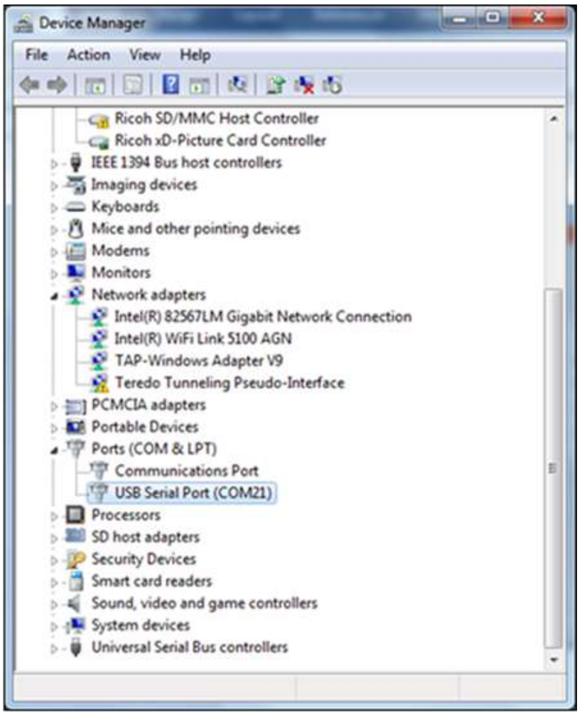
2 Start G-Tilt



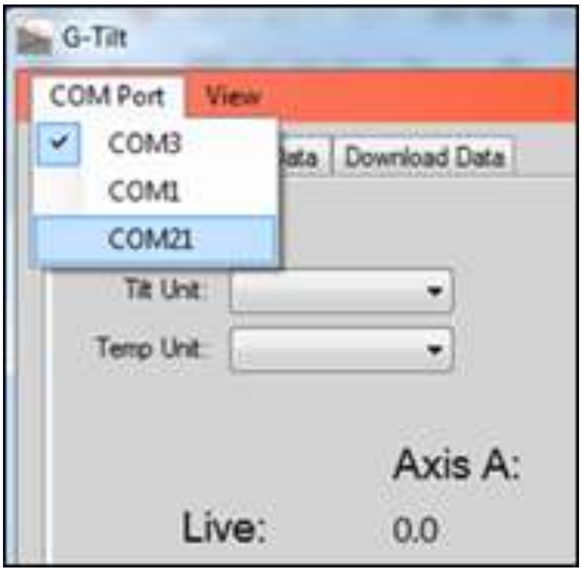
3 Connect the **USB cable** from the **RS485 interface** to the machine running G-Tilt

If Windows does not automatically install the device drivers for the Digital Interface, it may be necessary to perform a Windows Update to locate the drivers from the internet

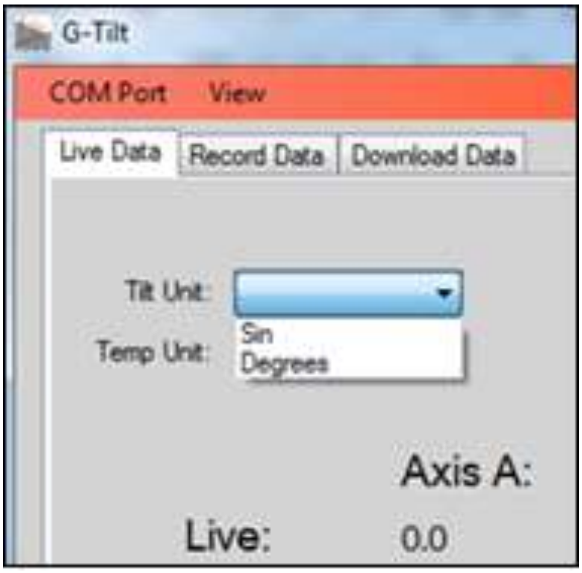
4 Identify the **COM port** which the interface is attached to. Device Manager in Windows can be used.



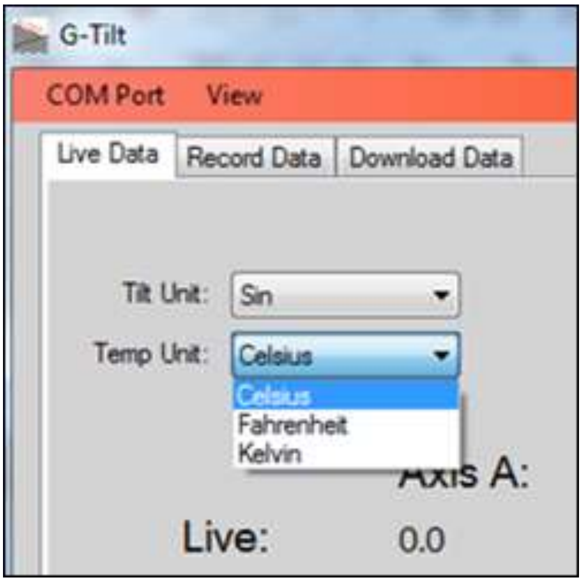
5 Within G-Tilt, select the **COM port** identified in the previous step



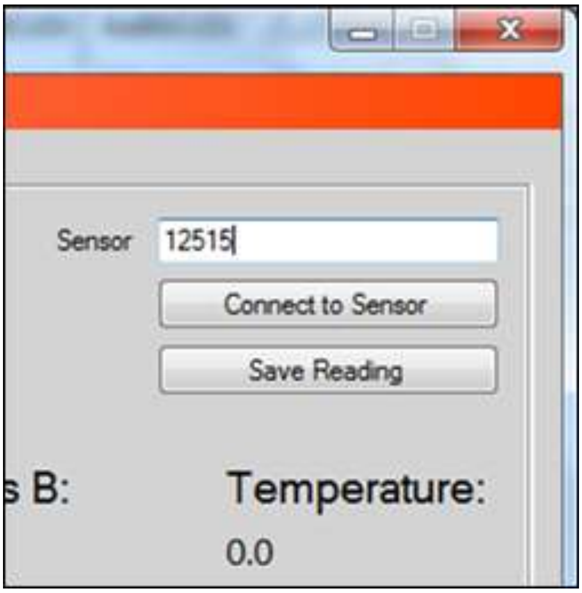
6 Select the preferred angle units (**sin or degrees**) from the drop down list.



Select the preferred temperature units (**Celsius, Fahrenheit or Kelvin**) from the drop down list

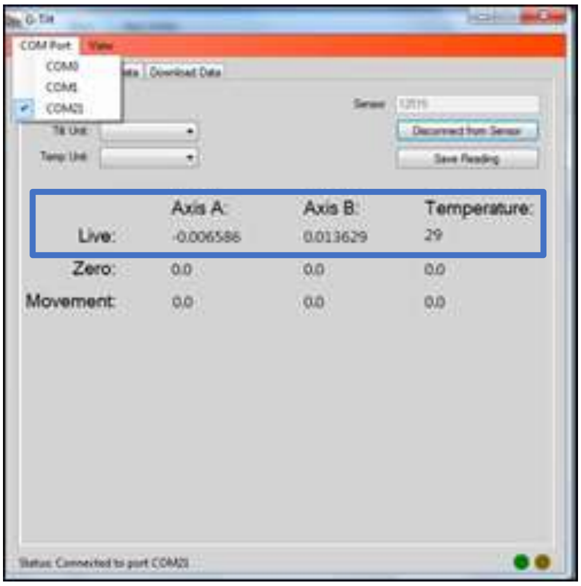


Enter the Serial number of the sensor to be interrogated and press **Connect to Sensor**



Once connected, the current reading will be displayed in the window, in the units selected.

These values must be referred to initial readings to assess any changes in rotation.



9.1.2. *Third Party Loggers*

For other types of logger/interfaces that work with the **Geosense®** IPI sensors, please refer to relevant manuals or contact **Geosense®** for more support.

10. DATA REDUCTION

10.1. Angle and Displacement Calculations

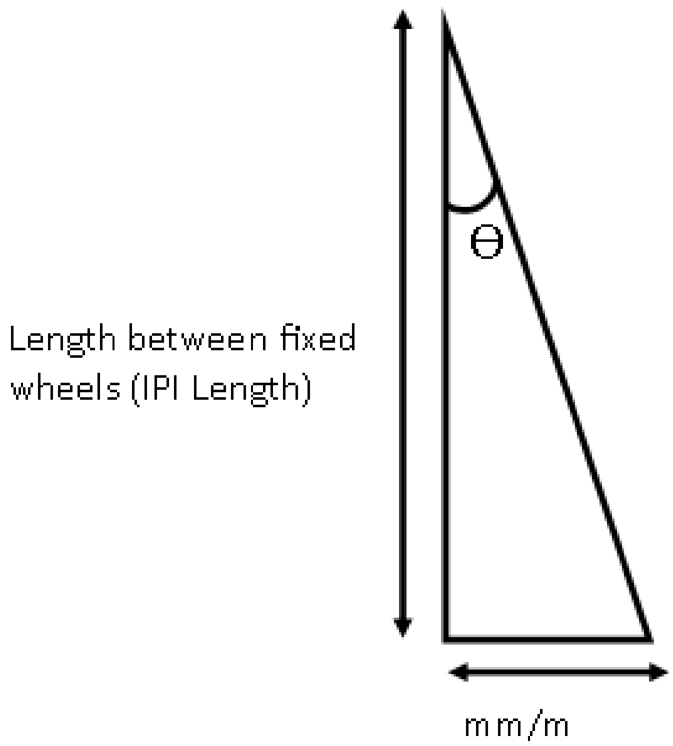
Geosense® Digital IPI's output a reading in sin of the angle. This reading can be converted to engineering units in a number of ways which are explained in this section.

Note:

Angle [degrees]	Angle [radians]	SIN Output
-15	-0.2618	-0.2588
0	0	0
+15	0.2618	+0.2588

Geosense® Digital IPI's are connected via an RS485 Bus system meaning that all sensors are interconnected along a single cable. Each sensor has its own unique ID (its serial number). When the datalogger requests the data from the sensor the sensor takes a reading and the datalogger stores it.

It is very important to understand where each sensor is within in the string for data reduction.



YOU SHOULD ENSURE THAT YOU ALWAYS HAVE A BASE READING AS EVERYTHING IS MEASURED RELATIVE TO THIS. IT IS THE CHANGE IN READING THAT IS IMPORTANT

Geosense® digital IPI's are relative movement sensors and therefore it is critical to record base readings. It is recommended to survey the inclinometer with a portable inclinometer before installing the IPI's to get an understanding of the inclinometer casing. Base readings should be taken once the sensors are within the borehole and believed to be in a stable condition.

You should take base readings of the A axis, B axis and Temp.

REMEMBER: READINGS FROM THE IPI WILL BE IN SINE OF THE ANGLE

Sine of angle to degrees

Example

$$\Delta Angle = sin^{-1}(current\ reading) - sin^{-1}(base\ reading)$$

$$\Delta Angle = sin^{-1}(0.17364818) - sin^{-1}(0.08715574)$$

$$\Delta Angle = (10°) - (5°)$$

$$\Delta Angle = 5.000°$$

Sine of angle to mm displacement

Example

$$\Delta Displacement = L \times (\sin(\theta) - \sin(\theta_b))$$

$$\Delta Displacement = L \times (0.17364818\ -\ 0.08715574)$$

$$\Delta Displacement = 1000 \times (0.08649244)$$

$$\Delta Displacement = 86.49244mm$$

Where

$L = gauge\ length\ in\ mm$
$sin(\theta) = initial\ reading\ (in\ sine)$
$\sin(\theta_b) = base\ reading\ (in\ sine)$

10.2. Temperature Considerations

Geosense® has carried out significant research into temperature effects on the IPI and has found that the thermal effects are very small.

Where the IPI is installed in an inclinometer access tube in a borehole or other subsurface structure, there is usually little variation in temperature, so thermal effects will be small and corrections will not be necessary.

However, if an IPI is suspended in a inclinometer an access tube in a location where there is significant groundwater movement, for example, the sensors may be affected by seasonal changes in the temperature of the water. In this instance, temperature corrections may become necessary, depending upon the range of the change.

Thermal influences on an IPI readings can be complex. The effect of temperature changes on the MEMS are insignificant, but this relates purely to the 'sensor' inside the module. Effects on the body of the sensor module and the structure into (onto) which it is installed will be very complicated and difficult to quantify.

Therefore, in order to correct for in-situ temperature changes, it is first necessary to establish the effects of temperature changes on a particular sensor in-situ at a particular location and the effects on the structure in which it is installed. Ideally this would be over a full annual cycle, but this is often un-achievable. Efforts should be made to quantify both the seasonal and daily thermal affects by observational methods.

It may then be possible to carry out mathematical corrections at the time of data processing.

11. MAINTENANCE

The **Geosense®** IPI is a maintenance free device for most applications. This is because it is intended for sub-surface installation and would normally be suspended in access tubes within boreholes or attached to structures.

IT IS CRITICAL THAT THE CONNECTORS ON THE TOP AND BOTTOM OF IPIs AND ALL O-RINGS ARE KEPT CLEAN, DRY AND FREE OF DEBRIS

12. TROUBLESHOOTING

12.1. Unstable Readings

In almost all cases, a fluctuating reading is a sign of a faulty signal from the sensor. The fault could be in either the sensor, the connecting cable, any switch boxes, the digital interface, or the readout. The best way to fault find an individual sensor is to isolate it from all others in a string and any connections. Where possible begin fault finding from the sensor or end of a string of sensors.

An additional resistance diagnostic check routines are also included to help identify problems with cables.

Fault finding assistance from the Digital Interface manual:

Typically any failure or error in communication is due to the RS485 sensor being read and not the RS485—RS232/USB interface. However the interface can be checked by sending the command “menu” when it is first powered up. See the interface manual for assistance with this procedure.

Table 1: Troubleshooting symptoms, causes and remedy

Symptom	Possible cause	Possible remedy
No Connection to the Interface	Incorrect wiring	Check wiring diagram for the RS232 or USB side.
No Connection to the Interface	Incorrect Settings - see the Interface manual	Settings on readout Baud rate: 115200 Data Bits: 8 Stop Bits: 1 Parity: None
No Connection to a Sensor	Incorrect wiring	Check wiring diagram for the RS485 side.
No Connection to a Sensor	Incorrect Sensor Settings	Interface only supports baud rates of 9600 (RS485 side)
No Connection to a number of Sensors	Maximum Current Limited Exceeded	Supply RS485 sensor(s) externally
No Connection to a Sensor	Incorrect Command	Check RS485 Sensor manual for correct command structure

Fault finding assistance for the cabling :

Using a Resistance meter or Electrical Multi-meter set to measure resistance, check the resistance between each conductor and between each conductor and the drain wire or screen.

There should be a VERY high, or infinite electrical resistance between the conductors and the drain or screen (a value in MΩ's is acceptable).

None of the individual conductors should be shorted to the screen or drain wire (showing Zero resistance) and none should be shorted together (showing Zero resistance).

As a terminal resistor is fitted to a string of IPI sensors, the resistance between the Yellow and the Green conductors and should be in the order of 100 - 140Ω.

The electrical resistance between the Brown and White, the power conductors will vary significantly depending on the number of sensors in the string. The resistance should never be Zero and should not exceed 2000Ω.

13. SPARE PARTS

Under normal use spare parts are not generally required for In-Place Inclinometers but replacement components are available as follows:

Part number	**Description**
B15-001	IPI wheel set assembly
Various	IPI connector o-ring seals

14. RETURN OF GOODS

14.1. Returns Procedure

If goods are to be returned for either service/repair or warranty, the customer should contact **Geosense®** for a **Returns Authorisation Number,** request a **Returned Equipment Report Form QF034** and, where applicable, a **Returned Goods Health and Safety Clearance Form QF038,** PRIOR TO SHIPMENT. Numbers must be clearly marked on the outside of the shipment.

Complete the **Returned Equipment Report Form QF034**, including as much detail as possible, and enclose it with the returned goods.

All returned goods are also to be accompanied by a completed **Returned Goods Health and Safety Clearance Form QF038** attached to the outside of the package (to be accessible without opening the package) and a copy of both forms should be emailed to support@geosense.co.uk, in advance.

14.1.1. *Chargeable Service or Repairs*

Inspection & Estimate

It is the policy of **Geosense®** that an estimate is provided to the customer prior to any repair being carried out. A set fee for inspecting the equipment and providing an estimate is also chargeable.

A valid purchase order (credit customer) or advance payment for the inspection fee(s) is required before inspection can take place. In the event of a warrantable claim being accepted, the value will be credited back to the customer's account (credit customer) or refunded (pre-payment customer).

14.1.2. *Warranty Claim*

(See Limited Warranty Conditions)

This covers defects which arise as a result of a failure in design or manufacturing. It is a condition of the warranty that the **IPI** must be handled and used in accordance with the manufacturer's instructions and has not been subjected to misuse.

To make a warranty claim, contact **Geosense®** and request a **Returned Equipment Report Form QF034.** Tick the warranty claim box and return the form with the goods as detailed above. You will then be contacted and informed whether your warranty claim has been validated.

14.2. Packaging and Carriage

All used goods shipped to the factory **must** be sealed inside a clean plastic bag and packed in a suitable carton. If the original packaging is not available, **Geosense®** should be contacted for advice. **Geosense®** will not be responsible for damage resulting from inadequate returns packaging or contamination, under any circumstances.

14.3. Transport & Storage

All goods should be adequately packaged to prevent damage in transit or intermediate storage.

15. LIMITED WARRANTY

The manufacturer, (**Geosense Ltd)**, warrants the **IPI** manufactured by it, under normal use and service, to be free from defects in material and workmanship under the following terms and conditions:

Sufficient site data has been provided to **Geosense®** by the purchaser as regards the nature of the installation to allow **Geosense®** to select the correct type and range of **IPI** and other component parts.

The **IPI** equipment shall be installed in accordance with the manufacturer's recommendations.

The equipment is warranted for **2 years** from the date of shipment from the manufacturer to the purchaser.

The warranty is limited to replacement of part or parts which are determined to be defective upon inspection at the factory. Shipment of defective part or parts to the factory shall be at the expense of the Purchaser. Return shipment of repaired/replaced part or parts covered by this warranty shall be at the expense of the Manufacturer.

Unauthorised alteration and/or repair by anyone which, causes failure of the unit or associated components, will void this **LIMITED WARRANTY** in its entirety.

The Purchaser warrants through the purchase of the **IPI** equipment that he is familiar with the equipment and its proper use. In no event shall the manufacturer be liable for any injury, loss or damage, direct or consequential, special, incidental, indirect or punitive, arising out of the use of or inability to use the equipment sold to the Purchaser by the Manufacturer.

The Purchaser assumes all risks and liability whatsoever in connection with the **IPI** equipment from the time of delivery to Purchaser

Nova House, Rougham Industrial Estate, Rougham, Bury St Edmunds, Suffolk, IP30 9ND, England.

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