48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603·448·1562
Fax: 603·448·3216
Email: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Model 6100

MEMS Inclinometer Probe

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FIGURES

1. INTRODUCTION

Figure 1, Figure 2, and Figure 3 show the component parts of the inclinometer system. The probe is designed to be used in conjunction with a special cable connected to a readout box and with grooved inclinometer casing. This manual describes the use and maintenance of the inclinometer probe and cable. Further details of the operation of the readout system are to be found in the GK-604D manual; and for installation of the inclinometer casing in the Model 6500 installation manual.

Figure 1 - Inclinometer System

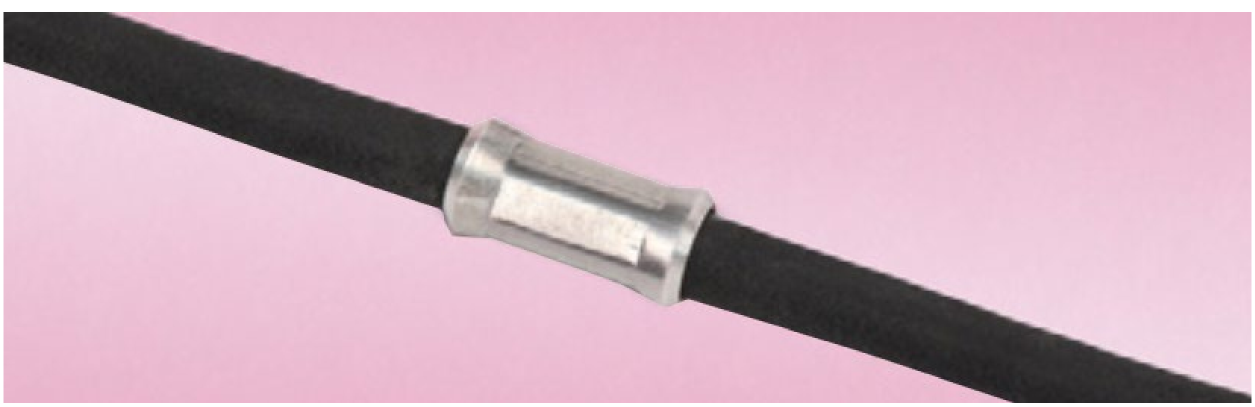

Figure 2 - Model 6000-2 Control Cable (showing cable marker)

Figure 3 - Pulley Style Cable Grip

2. INCLINOMETER THEORY

In the geotechnical field inclinometers are used primarily to measure ground movements such as might occur in unstable slopes (landslides) or in the lateral movement of ground around on going excavations. They are also used to monitor the stability of embankments, slurry walls, the disposition and deviation of driven piles or drilled boreholes and the settlement of ground in fills, embankments, and beneath storage tanks.

In all these situations it is normal to either install a casing in a borehole drilled in the ground, to cast it inside a concrete structure, to bury it beneath an embankment, or the like. The inclinometer casing has four orthogonal grooves (Figure 4) designed to fit the wheels of a portable inclinometer probe (Figure 7 in Section 3). This probe, suspended on the end of a cable connected to a readout device, is used to survey the inclination of the casing with respect to vertical (or horizontal) and in this way to detect any changes in inclination caused by ground movements.

The probe itself contains two MEMS, (Micro Electro Mechanical Sensor), accelerometers, which flex when acted on by the force of gravity. This changes their capacitance and their output voltage.

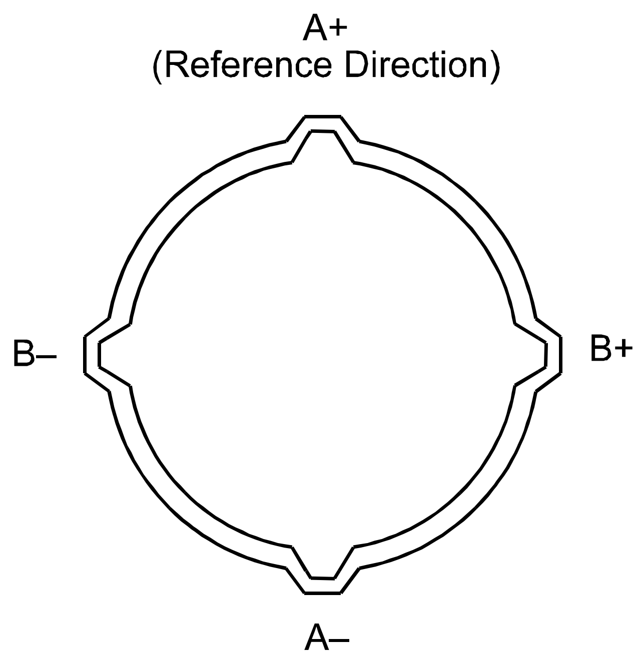

Figure 4 - Inclinometer Casing

Since the output voltage is proportional to the sine of the angle of inclination the output is also proportional to the horizontal deviation of the borehole (or the vertical deviation of a horizontal borehole).

In order to obtain a complete survey of the ground along the installed inclinometer casing it is necessary to take a series of tilt measurements along the casing. Typically an inclinometer probe has two sets of wheels separated by a distance of two feet (English system) or 0.5 meters (Metric system). A casing survey would begin by lowering the probe to the bottom of the casing and taking a reading. The probe would then be raised at two foot (English system) or 0.5 meters (Metric system) intervals and a reading taken at each interval until the top of the casing is reached. The set of readings thus generated is called the A+ readings. Marks on the cable at two foot (English) or 0.5 meters (Metric) spacing facilitate the process. The probe is then removed from the casing, rotated through 180°, replaced in the casing, lowered to the bottom of the borehole and a second set of readings (the A− set) obtained as the probe is raised at the reading interval.

Inclinometer probes usually contain two MEMS sensors with their axes oriented at 90° to each other. The A axis is in line with the wheels (Figure 7 illustrates) with the B axis orthogonal to it. Thus, during the survey, as the A+, A− readings are obtained, the B+, B− readings are also recorded.

During the data reduction these two sets or readings (A+, A− and B+, B−) are combined (by subtracting one set of readings from the other) in such a way that ***the effect of any zero offset*** of the force balance accelerometer ***is completely eliminated.*** [This zero offset is the reading obtained from the inclinometer probe when it hangs vertical. Ideally the offset (or bias) would be zero, but usually there is a zero offset and the zero offset may change during the life of the probe due to drift of the transducer, wear and damage of the wheels or most likely due to a sudden shock to the transducer caused by dropping or allowing it to hit too hard against the bottom of an installed inclinometer casing.]

Subsequent surveys of the inclinometer casing, when compared with the original survey, will reveal any changes of inclination of the casing and the locations at which these changes are taking place. Analysis of the change of inclination (L sin θ) is best performed by computing the horizontal offset of the upper wheels relative to the lower wheels over the reading interval (L) of the survey (usually the wheel base of the probe, two feet for English systems, 0.5 meters for Metric). At each position of the inclinometer the two readings taken on each axis (A+, A− and B+, B−) are subtracted from each other leaving a measure of sin θ. This value is then multiplied by the reading interval (L) and the appropriate factor to output horizontal deflection in engineering units (inches for English, centimeters or millimeters for Metric). These offsets are compared to the original survey offsets and then the differences accumulated to produce a deflection profile as shown in Figure 5.

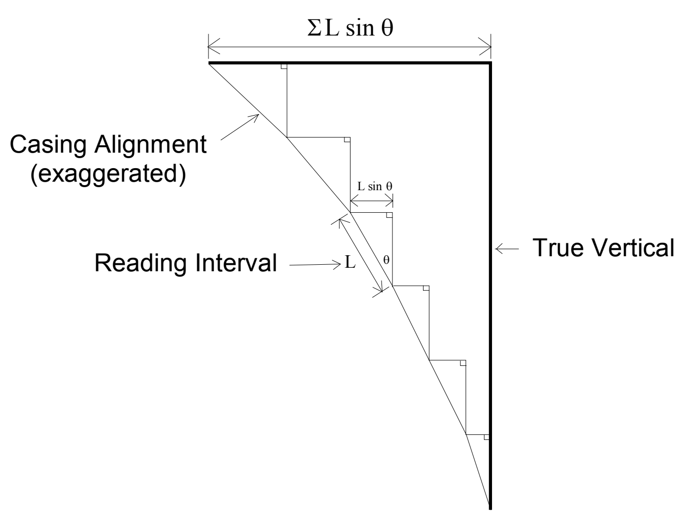

Figure 5 - Inclinometer Survey Description

When all these incremental horizontal deflections are accumulated and plotted beginning at the bottom of the borehole the net result is to produce a plot of the change in horizontal deflection between the time of the initial survey and the time of any subsequent survey. See Figure 6. From such a deflection plot it is easy to see at which depth the movement is occurring and its magnitude.

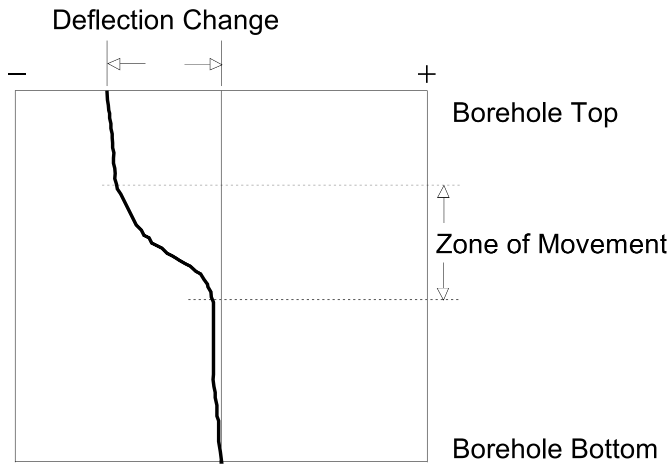

Figure 6 - Plot of Borehole Deflection

Other methods of analysis can be used but generally add little to the overall understanding of the situation. For example, using a single set of data, a profile of the borehole can be created. Also, a plot can be made of the actual change in reading (inclination) at each measurement depth increment. A plot of this nature reveals the depths at which movement is occurring. But this information can be obtained from the change in deflection curve with little difficulty.
One other analysis is the Check Sum (or Instrument Check) which can be used to measure the quality of the survey data.

The quality of the data can be impaired by any or all of the following:

- Skipping over or duplicating a reading.
- Not allowing the inclinometer sufficient time to come to rest before taking a reading.
- Malfunction of the probe, cable or readout device. This may be the result of shock, moisture, low battery conditions, opens or shorts in the cable or probe, etc.
- Carelessness in positioning the wheels so that the probe wheels do not rest on the same part of the casing from one survey to the next.
- Positioning the wheels so that they fall right on top of a casing joint so that the reading is unstable or simply erroneous.

The Check Sum analysis is performed by adding the A+, A- readings and the B+, B- readings. When this is done the part of the reading due to the tilt is eliminated leaving only a value that is equivalent to twice the zero offset of the inclinometer transducer. See the GK-604D Readout Manual for more information on the Check Sum analysis (Appendix A) and for a further description of the readout process as it pertains to the use of the readout box. For more details concerning the installation of the inclinometer casing, refer to the instruction manual for Model 6500 Inclinometer Casing.

3. INCLINOMETER PROBE

Figure 7 shows the component parts of the inclinometer probe: A cylindrical, stainless steel housing contains one (uniaxial probe) or two (biaxial probe) MEMS accelerometers. At each end of this housing is a wheel assembly containing pairs of spring loaded wheels, fitted with sealed roller bearings and designed to fit standard inclinometer casing grooves.

At the base of the probe there is a rubber cushion designed to reduce shock loading on the accelerometer should the probe be dropped on to a solid surface. This last point is very important. The accelerometers are capable of withstanding a certain amount of rough handling, (shocks < 2000g) but allowing the probe to fall against hard surfaces can permanently damage the accelerometer requiring expensive factory repairs. Therefor it is important to handle to probe with care at all times. Further discussion of this topic is given in Section 6.

At the top of the probe is a cable fitting containing the cable connector. On later models of the probe the cable fitting is detachable (at the factory only) to facilitate replacement of the connector should it become damaged. The connector is a 6-pin Bendix connector which on later models has a stainless steel shell and is hermetically sealed (glass insulation). A screw cap is provided to protect the connector when it is not connected to the cable. The cable fitting also carries an O-ring designed to seal against the connector on the cable and to make the cable connection waterproof.

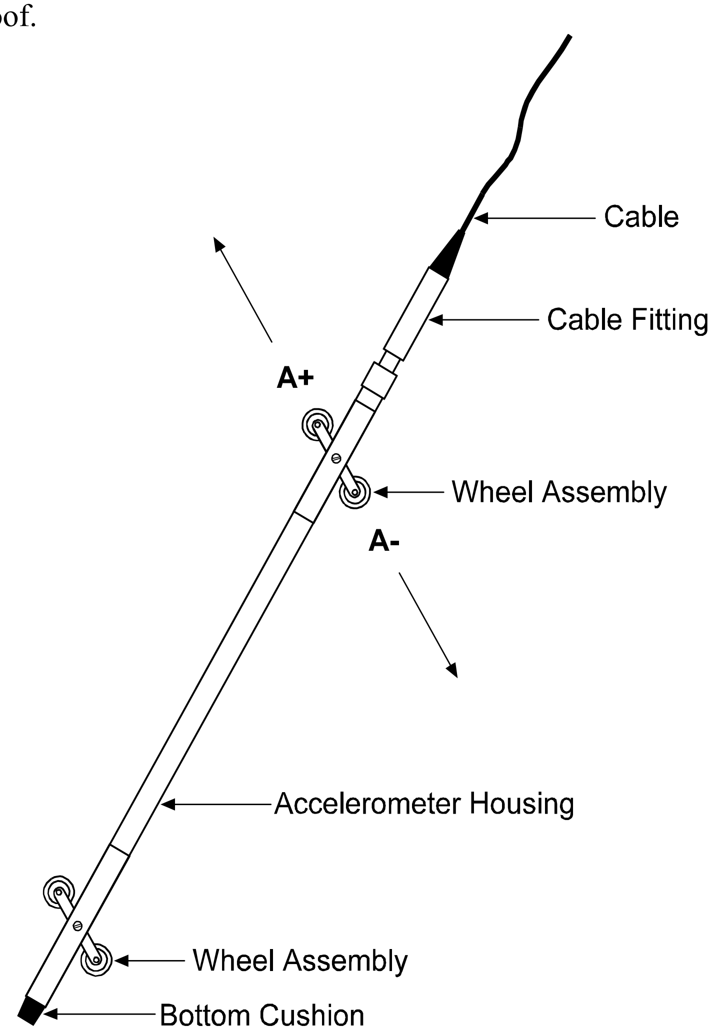

Figure 7 - Inclinometer Probe

4. INCLINOMETER CABLE

The inclinometer cable is designed to be strong. The cable has a central braided Kevlar strand with a breaking strength of 150 kg which effectively prevents the cable from stretching and allows for a heavy pull on the inclinometer should it become jammed in the casing. It should be noted that this Kevlar strand is firmly attached to the lower cable connector so that the cable cannot pull out of the connector.

The cable is also designed to serve as a depth marker and has aluminum markers crimped to the polyurethane jacket at intervals equal to the wheelbase of the inclinometer probe. (0.5 meters or two feet)

A screw cap is provided to protect the cable connector when not in use.
The upper cable connector is a Lemo connector which plugs into the Interface Unit, (standalone or reel-mounted), of the GK-604 readout system.

5. OPERATING INSTRUCTIONS

5.1 Connecting the cable to the probe

A common source of damage to the inclinometer system is careless mating of the cable to the probe. There are keys and keyways on the shells of the two mating halves designed to prevent the connector pins from being damaged. But with repeated use, the keys and keyways can become worn and allow misalignment of the pins and sockets. Then forcing the two halves of the connector together will bend or break the pins. Therefore great care should always be exercised in making sure that the pins align with the sockets before pushing the two halves together. Some operators avoid possible wear and tear on the connector from repeated connection and disconnection, by leaving the cable permanently connected to the probe. This procedure is recommended where the probe is subject to continuous use.

As mentioned previously, the connector on the probe has an O-ring located on the upper face. This O-ring keeps water out of the connector, a very important consideration where the probe is operating under water. It is vital that this O-ring be kept clean and free of cuts, nicks or scuffs. Always check this O-ring before making the connection. A periodic light application of O-lube will prolong the life of the O-ring. Five spare O-rings are provided with a new probe.

It is important also to make sure that the flat surface on the face of the cable connector, the surface that comes into contact with the O-ring, is clean and free of scratches.

The cable connection procedure is as follows:

1) Check both connectors to see if they are free of dirt, moisture and damage.

2) Align the pins with the sockets and gently mate the two halves. Avoid at all costs twisting and grinding the two halves of the connectors.

3) Tighten the knurled clamp nut on the cable half of the connectors. Tighten until finger tight and then, using a wrench on the wrench flats on the knurled clamp nuts, and while holding on to the cable clamp, gently tighten enough to compress the O-ring and bring the two metal surfaces into contact with one another. **Note:** It is best to let the probe hang free while tightening the connector, thus avoiding any twisting of the connector halves. *Do not overtighten,* just a little beyond finger tight is all that is required. (Overtightening can twist the connector and damage the pins).

4) Keep the two protective caps in a safe place and always replace them on the connectors when the cable is disconnected from the probe.

5.2 Cable reels

Spare or replacement cables are supplied on wooden spools. For the analog probes used with the analog readout two options are available: a) for those users who do not wish to use a cable reel the cable is connected directly to the Model GK 604-4 Interface Unit. b) For those preferring a reel the cable is connected to the Interface unit mounted inside a Model GK-604-3 cable reel integral to the GK-604-1 Inclinometer Readout. Digital probes always operate with a Gk-604D system which includes the reel, GK-604D-5 or GK-604D-6.

Cable storage reels with hand cranks are also available at additional cost. The reels are useful in storing the cable neatly when not in use. Where reels are used it is normal to pull off sufficient cable from the reel before commencing a survey.

For deeper boreholes and casings, where the weight of the cable becomes too heavy to manage manually, special motorized reels with slip ring contacts are used.

Where no reels are used the operator frequently uses an open top box or carton in which to loosely coil the cable so that it dispenses easily without tangling during a survey.

5.3 Running the survey

(For additional details on how to configure the probe see also the instruction manual for the GK 604D Inclinometer System)

1) Attach the pulley assembly to the top of the casing so that it is pointing in the A+ direction. (The A+ direction is normally chosen to be in the direction of the anticipated movement.) The A+ direction should be marked on the casing. (Older inclinometer systems use cable holds which are now obsolete).

2) If the cable is connected to the Interface Unit mounted inside the Model GK 604-3 cable reel, pull off enough cable to allow the probe to reach the bottom of the casing. If no reel is being used connect the cable to the stand alone Interface unit (Mode GK-604-4) and use the MENU to configure for the MEMS probe. (See GK-604D Manual instructions).

3) Orient the probe so that the uppermost wheel on the probe is in the A+ groove. This should ensure that the A+ direction corresponds to a positive voltage output with increasing tilt.

4) Carefully lower the probe to the bottom of the casing. Do not allow the probe to fall freely by allowing the cable to slip through the hands. It is tempting to do this in the interest of speeding things up but it runs the very grave risk of allowing the probe to strike hard against the bottom of the casing and to damage the accelerometer inside the probe. [It is good practice to place soft wadding in the bottom of the casing so as to remove all possibility of shock damage to the probe.

5) Place the pulley and cable grip assembly inside the top of the inclinometer casing and raise the probe until the first cable marker is just past the grips. (If a cable hold is in use rest the cable marker inside the cable hold)

6) Allow sufficient time for the probe to achieve temperature stability. (Observing the readout on the readout box will show when the readings have stabilized.) Take a first reading following the directions of the GK 604D manual.

7) Raise the probe until the next cable marker shows just above the cable grips. Wait two seconds and take a reading. Repeat this process until the probe reaches the top of the casing. It is vital that the probe is stationary at each reading and that sufficient time (two seconds) be allowed to elapse for the probe to settle down before the second reading is taken.
8) Remove the probe from the casing, twist through 180° until the upper wheel is in the A− direction then lower the probe once again to the bottom of the casing. Advance the readout box (GK-604) to data set two (see GK-604 instructions). Repeat as per step seven above.

9) When the survey has been completed, save the data to a file.

10) Clean and dry the probe using the DEOXIT #DN5 spray supplied. Replace the cap on the probe connector and return the probe to its carrying case. The cable should be cleaned and recoiled. Replace the cap on the cable connector.

6. MAINTENANCE

The inclinometer probe is a totally sealed unit and, as such, field adjustments are not required.

Maintenance of the O-ring on the connector requires that it be kept clean and free of cuts and nicks. Periodic greasing with ‘O’ lube is recommended. A worn or damaged ‘O’ ring should be replaced with a new one (five ‘O’ rings are supplied with each new probe).

Wheel assemblies should be kept dry when in storage. They should be kept free of dirt by using a compressed air gun to blow away grit. **After every survey spray the springs, pivots and axles with light oil**. This is very important and should not be neglected. Geokon **recommends lubricating the wheel bearings after each use** as noted below in Figure 8. This practice forces out any water or contaminates that may be present thus extending the service life.

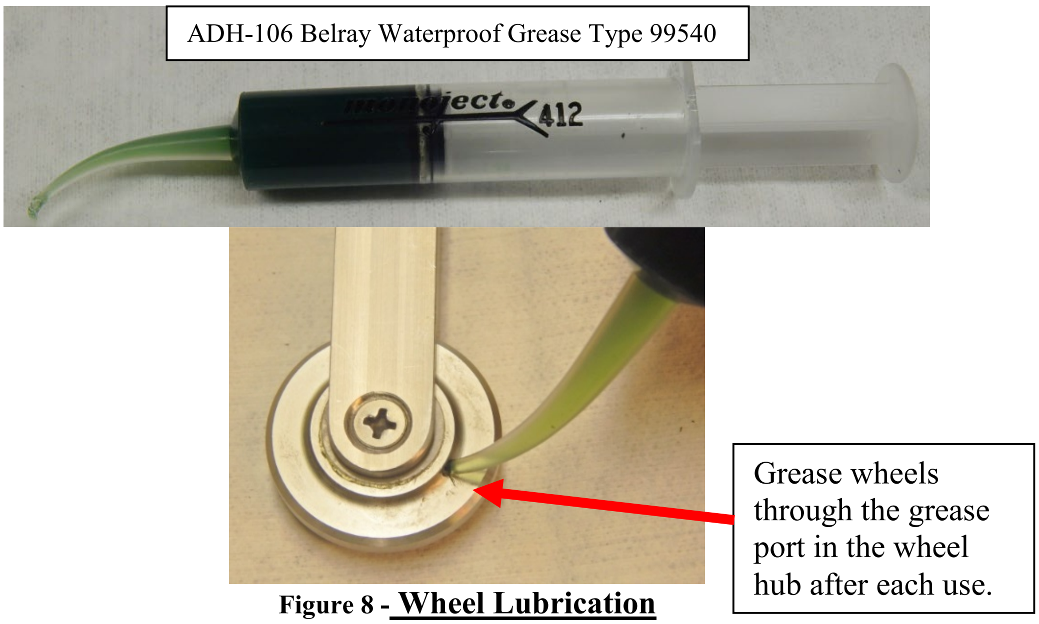

Figure 8 - Wheel Lubrication

One of the main problems encountered is failure to keep the connectors dry. Often this is caused by failure to fully tighten the cable connector to the probe connector. This connection must be made up tight in order to compress the O-ring in the end of the probe connector. Periodically the pins of the probe connector **must** be sprayed with DEOXIT #DN5 spray contact cleaner and rejuvenator. A small spray can of this is supplied with each inclinometer probe. After each daily use always make sure that the connectors are completely dry before replacing the protective caps. Otherwise corrosion could result.

If the zero offset changes due to aging or rough handling this will not affect the quality or accuracy of the readings because the offset is removed by taking two sets of readings in the A+ and A– directions. However, if the zero offset changes by more than 5000 digits then the probe should be returned to the factory for repairs. Zero offset can be set to zero at any time using the software inside the GK-604 readout instrument (See Section the GK-604D Manual).
It is good practice to have a piece of inclinometer casing permanently fastened to a fixed immovable structure in the laboratory. This casing is used as a periodic check on the calibration of the probe. Placing the probe in the casing should give a reading that does not change with time.

7. CONCLUSION

The inclinometer probe is a highly sensitive precision instrument and should be handled with care at all times. If the probe is dropped or is allowed to strike hard against the bottom of the casing it can sustain serious damage to the accelerometer requiring expensive repairs. With careful handling and maintenance the probe will have a long life and will give excellent service.

APPENDIX A. SPECIFICATIONS

Model No:	**6100-1M (Metric Probe)**	**6100-1E (English Probe)**
Wheel base:	0.5m or 1.0m	2 ft.
Sensors:	Two MEMS accelerometers	Two MEMS accelerometers
Range (100% F.S.)[1]:	± 30°	± 30°
Full scale output:	± 4 VDC	± 4 VDC
Resolution[2]:	.025 mm /500mm	.0001 ft/ 2 ft
Repeatability[3]:	± 1mm/30m	. ± 0.05in/100ft
Total system accuracy[4]:	± 4 mm/ 30 m	± 0.17 inch/ 100 ft
Temperature range:	– 30° to 85°C	– 22° to 185°F
Temperature coefficient:	<.0002% F.S./ °C	<.0002% F.S./ °F
Shock survival:	2000g	2000g
Dimensions:	700 × 25 mm dia.	32 × 1 in. dia.
Weight (with case):	7.5 kg	16 lb
Power Requirements:	12 VDC (9V min./15V max.)	12 VDC (9Vmin./15V max.)

Notes:

[1] The probe outputs +/-4 volts at an inclination of +/-30° to the vertical. These parameters are referred to as full scale. Operation beyond this inclination is not possible.

[2] The resolution shown in the table above is only true in the range of ± 5° from the vertical. Beyond this the resolution is reduced by a factor equal to 1/cosine of the angle from the vertical. For instance, the resolution at 0 degrees from vertical is 10.3 arc seconds and the resolution at 15 degrees from the vertical is 10.3 x 1/0.966 = 10.7 arc seconds. The figures given assume that the readout box can detect a change of output of 0.0005 VDC.

[3] The figure shown applies to the use of a single probe used repeatedly over a short space of time in a single borehole.

[4] In practice, system accuracy is controlled mainly by the precision with which the inclinometer can be positioned at exactly the same depth, in the casing, from survey to survey. Factors such as debris in the casing or casing damage also have their effect. The stated accuracy assumes that the surveys are conducted over a period of time in a proper manner and that the casing is within about five degrees off the vertical. Accuracy is improved by allowing the probe to reach equilibrium at each depth level before taking a reading.

[5] The probe is designed for use in all casing sizes up to 85mm ID (3.34in.). The wheel diameter is 30mm. The cable connector adds 150mm to the length of the probe.