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Instruction Manual

Model 6100

MEMS Inclinator Probe

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1. Introduction

Figure 1 shows 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 box are to be found in the GK-603 manual; and for installation of the inclinometer casing in the Model 6500 installation manual.

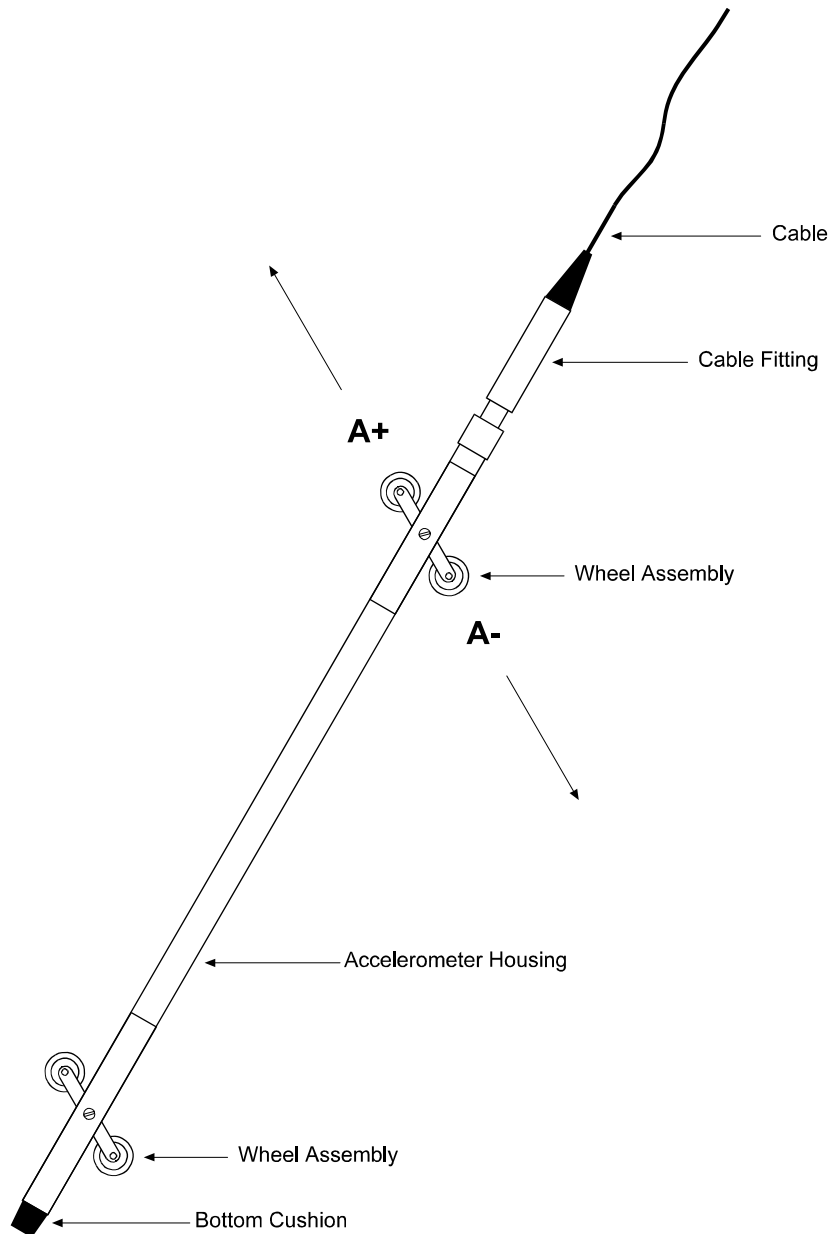


Figure 1 Inclinometer System

2. Incliner 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.

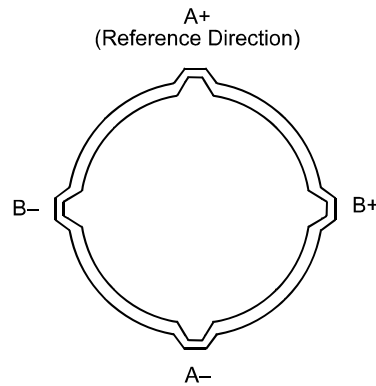


Figure 2. Incliner Casing

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 2) designed to fit the wheels of a portable inclinometer probe (Figure 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.

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 2 sets of wheels separated by a distance of 2 feet (English system) or .5 meter (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 2 foot (English system) or .5 meter (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 2 foot (English) or .5 meter (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.

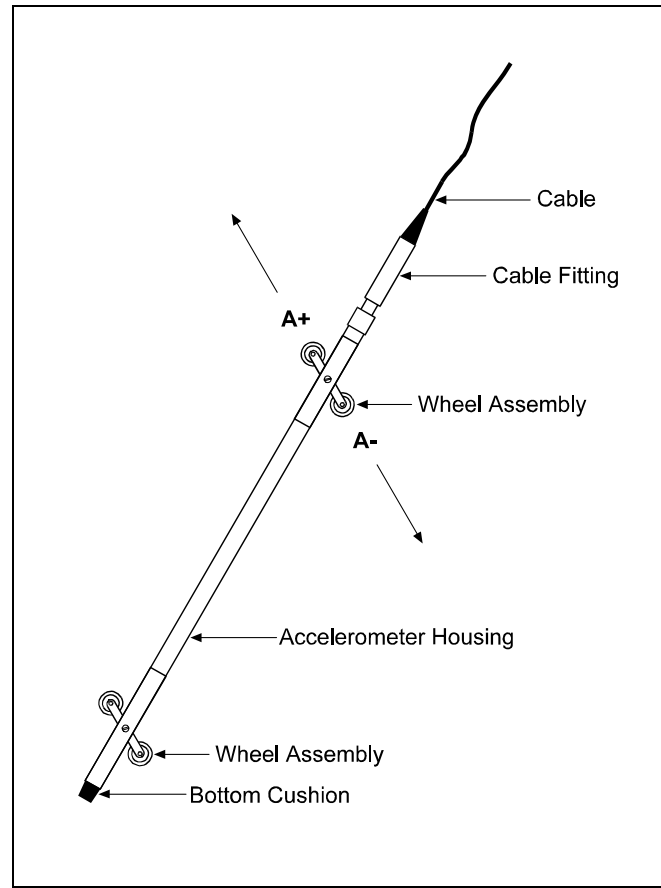


Figure 3 – Inclinometer Probe

Inclinometer probes usually contain two accelerometers with their axes oriented at 90° to each other. The A axis is in line with the wheels (Figure 3 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 of 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 ($L \sin \theta$) 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, 2 feet for English systems, .5 meter 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 $\sin \theta$. 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 4.

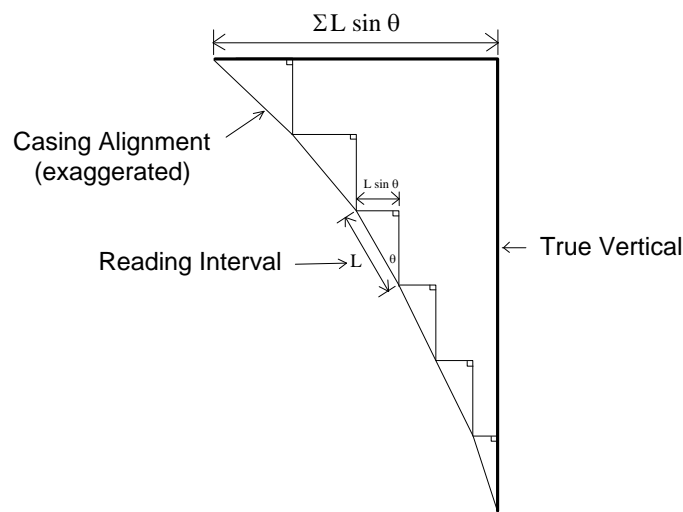


Figure 4. Inclinometer Survey Description

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 5. From such a deflection plot it is easy to see at which depth the movement is occurring and its magnitude.

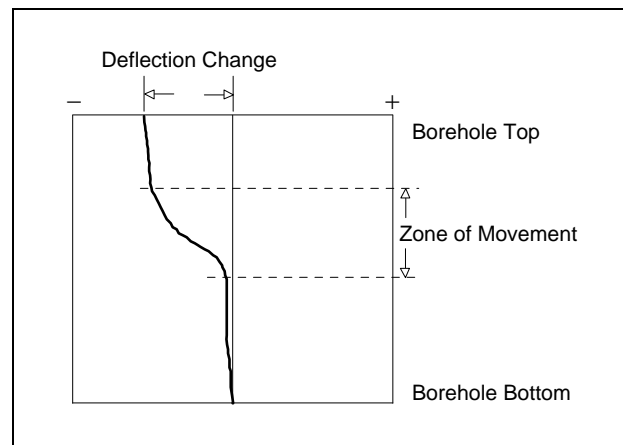


Figure 5 Plot of Borehole Deflection

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-603 Readout Box Manual for more information on the Check Sum analysis 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 3 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. Therefore it is important to handle the probe with care at all times. Further discussion of this topic is given in section 6.4.

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.

4. Inclinometer Cable ---

The inclinometer cable is designed to be strong. The cable has a central braided Kevlar strand, with a breaking strength of 350 kgm 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 can not pull out of the connector.

The cable is also designed to serve as a depth marker and has brass markers crimped to the polyurethane jacket at intervals equal to the wheelbase of the inclinometer probe. (0.5 meters or 2 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 GK-603 or GK-601 Readout Box.

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:

- a.) Check both connectors to see if they are free of dirt, moisture and damage.
- b.) 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.
- c.) 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 over-tighten, just a little beyond finger tight is all that is required. (Over tightening can twist the connector and damage the pins).

- d.) 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

Cables are supplied on wooden spools. Manual cable 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 see also the instruction manual for the GK-601 or GK-603 Readout Box)

5.3.1

Secure access to the top of the inclinometer casing and attach the pulley assembly (if used) 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.

5.3.2

If the cable is stored on a reel (non-slip ring type) pull off enough cable to allow the probe to reach the bottom of the casing. Connect the readout box to the cable and use the MENU to configure for the MEMS probe. (See GK603 instructions).

5.3.3

Orient the probe so that the upper-most 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.

5.3.4

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.]

5.3.5

Allow sufficient time for the probe to achieve temperature stability. (Observing the readout on the readout box will show when the readings have stabilized.)

5.3.6

Raise the probe until the nearest cable marker lies just past the jaws of the pulley assembly (or, if the pulley is not used, until the nearest cable marker rests on top of the top of the casing.) Secure the cable in the jaws and take a first reading following the directions of the readout box manual.

5.3.7

Raise the probe until the next cable marker lies just past the jaws. 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 a reading is taken.

5.3.8

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-603) to set 2 (see GK-603 instructions) and repeat procedures 6.6 and 6.7 to store the data (GK-603).

5.3.9

When the survey has been completed, clean and dry the probe. Replace the cap on the connector and return the probe to its carrying case. The cable should be cleaned and recoiled. Replace the cap on the connector.

6. Maintenance _____

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

6.1

Maintenance of the 'O' ring on the connector requires that it be kept clean and free of cuts and knicks. 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).

6.2

Make sure that the connectors are completely dry before replacing the protective caps. Otherwise corrosion could result.

6.3

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. Periodically spray the springs, pivots and axles with light oil.

6.4

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-603 readout box. The procedure is described in Appendix I of the GK-603 Instruction Manual.

6.5

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.

8. Specifications

Model No:	6100-1M (Metric Probe)	6100-1E (English Probe)
Wheel base:	0.5m or 1.0m	2 feet
Sensors:	2 MEMS accelerometers	2 MEMS accelerometers
Range (100% F.S.):	$\pm 15^\circ$	$\pm 15^\circ$
Full scale output:	± 4 VDC	± 4 VDC
Resolution:	.025 mm /500mm	.0001 ft/ 2 ft
Repeatability:	.02% F.S.	.02% F.S.
Total system accuracy:	± 7 mm/ 30 m	± 0.3 inch/ 100 ft
Temperature range:	$- 20^\circ$ to 50°C	$- 4^\circ$ to 122°F
Temperature coefficient:	$<.0002\%$ F.S./ $^\circ\text{C}$	$<.0002\%$ F.S./ $^\circ\text{F}$
Shock survival:	2000g	2000g
Dimensions:	700 \times 25 mm dia.	32 \times 1 in. dia.
Weight (with case):	7.5 kg	16 lb

Notes

1. Range/Full scale:

The probe outputs four volts at an inclination of 15° to the vertical. These parameters are referred to as full scale. Operation beyond this inclination is possible, but the resolution and accuracy is slightly reduced.

2. Resolution:

The resolution shown in the table above is only true in the range of $\pm 5^\circ$ 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 $10.3 \times 1/0.966 = 10.7$ arc seconds. The figures given assume that the readout box can detect a change of output of 0.0005 VDC.

3. Repeatability:

The figure shown applies only to the sensors. It includes hysteresis and non-linearity.

4. Total system accuracy:

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 in a proper manner and that the casing is within about 5 degrees off the vertical.

5. Dimensions:

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.

9. Appendix ---

Model 6015 Horizontal Inclinometer Probe Operating Instructions.

The Geokon Model 6015 Horizontal Inclinometer Probe is designed to make high resolution measurements of settlement or heave in tank foundations, dams, highway embankments, landfills, etc.

The system consists of the probe and cable, inclinometer casing, pull cable and the readout unit. The casing is installed in a horizontal trench or borehole below or through the fill material. When the casing cannot extend completely through the fill a return pulley and cable arrangement is required.

An initial, baseline survey is taken to which all subsequent surveys are compared. The instrument yields the sine of the angle of inclination of the probe in the casing. Knowing the gage length and this angle, the vertical deflection can be calculated for each gage increment read. By summing these segments a change profile can be constructed which is a direct measurement of the casing and soil settlement or heave. The readings are repeated in reverse probe orientation to eliminate probe offset errors.

1. Installation

Probe Orientation.

The Probe is always installed in the casing with the fixed wheels in the bottom groove. The probe is marked on one end with a white cross. When the probe is tilted down at this end the change in output will be negative.

1.1

In a standard survey the probe is pulled to the far end of the casing, either by pulling from an accessible far end or by a return cable and pulley arrangement. First connect the electrical cable to the end of the probe with the white cross. Connect the pull cable to the eyebolt connected to the other end of the probe. Align the wheels properly as the probe is pulled into the casing and pull the probe to the beginning point at the far end.

1.2

Using the GK-603 readout box take readings at the prescribed intervals (2ft. or 0.5m) while pulling the probe back to the beginning using the procedures described in the Model 6000 Inclinometer manual.

1.3

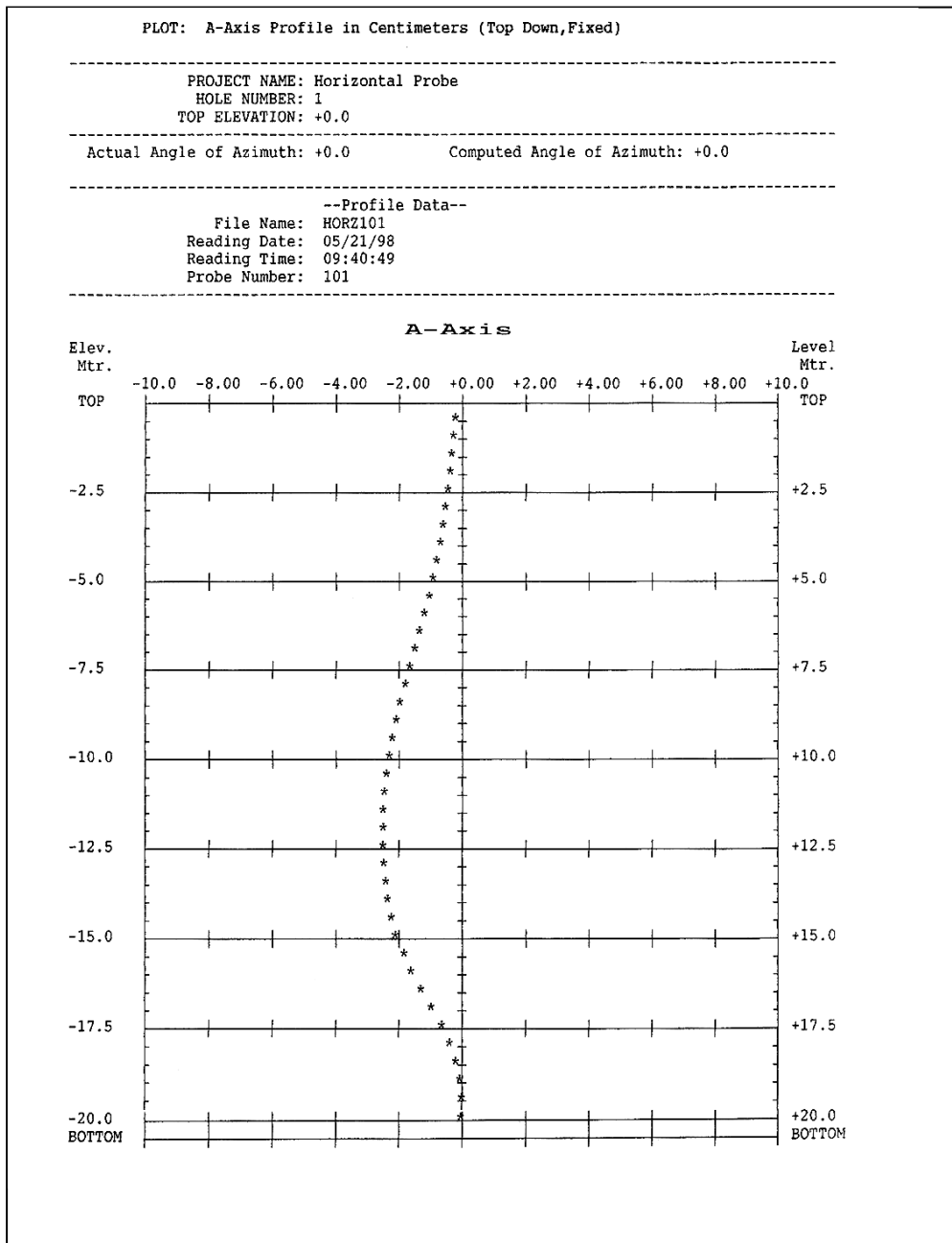
Now, reverse the connections to the probe by switching the pull cable with the electrical cable, then pull the probe back to the far end and repeat the survey.

2. GK-603 Setup

The default mode in the GK-603 is for a bottom up survey, i.e., the data is referred to the bottom or far end of the casing. For horizontal surveys the top down mode should be selected such that the data is referred to the accessible end of the casing that can be surveyed. (In 3.2.5.2, select Top Down).

2.1

Profiles created in this mode will show settlement on the negative side of the zero line with the zero position to the left (see sample plot below). "Top" will now be the readout end of the profile; "Bottom" will be the far end of the profile. Refer to the manual for all other GK-603 parameters.



Sample Plot