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Instruction Manual

Model 6000

Inclinometer Probe

(Doc Rev H, 1/16)

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1. Introduction

Figure 1 to 1C 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 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 1A - Model 6000-2 Control Cable (top showing cable marker)

Figure 1B pulley style cable grip

Figure 1C Cable holds (obsolete)

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.

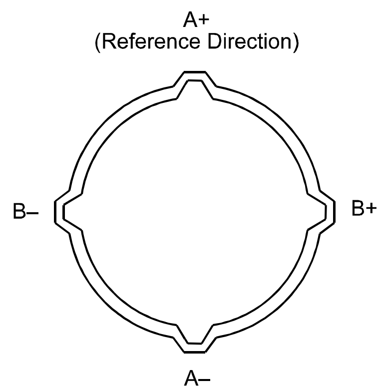

Figure 2. Inclinometer Casing

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 a pendulous mass that is acted on by the force of gravity. Most inclinometers use a force balance accelerometer in which a position sensor detects the position of the mass and provides a restoring force sufficient to return the mass to its vertical null position. The greater the inclination from the vertical null,

the greater the restoring force so that, in effect, the mass is prevented from moving. The magnitude of the restoring force, transduced into an electrical output and displayed on the readout, becomes a measure of inclination. Since the restoring force 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.

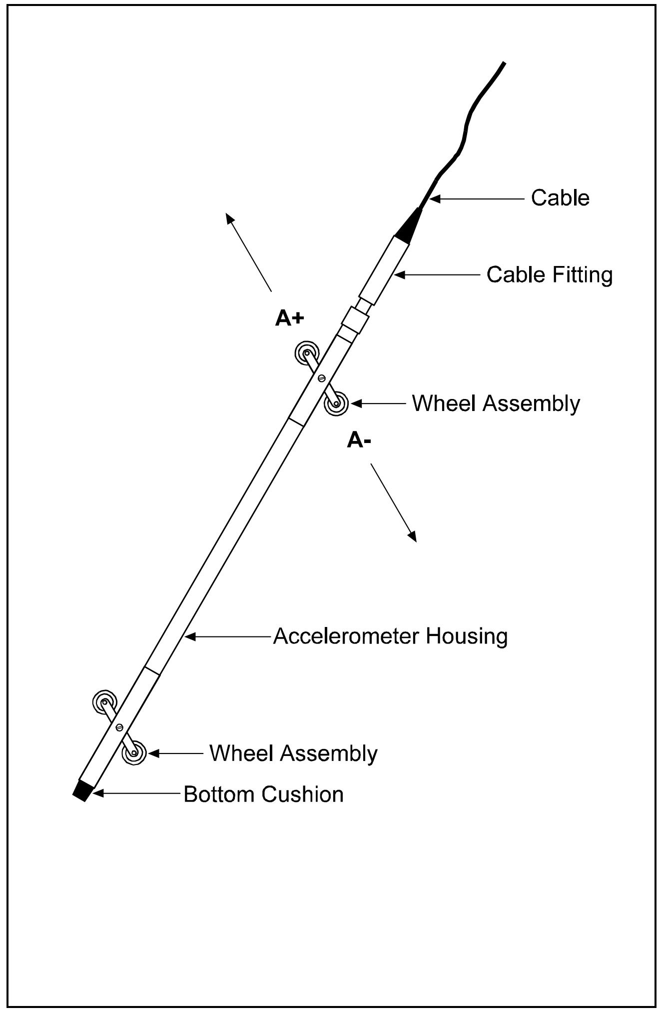

Figure 3. Inclinometer Probe

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 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, 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 sineθ. 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.

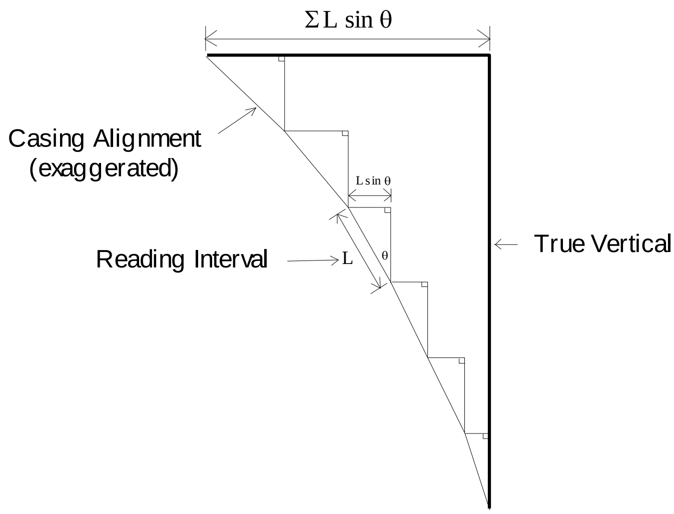

Figure 4. Inclinometer Survey Description

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.

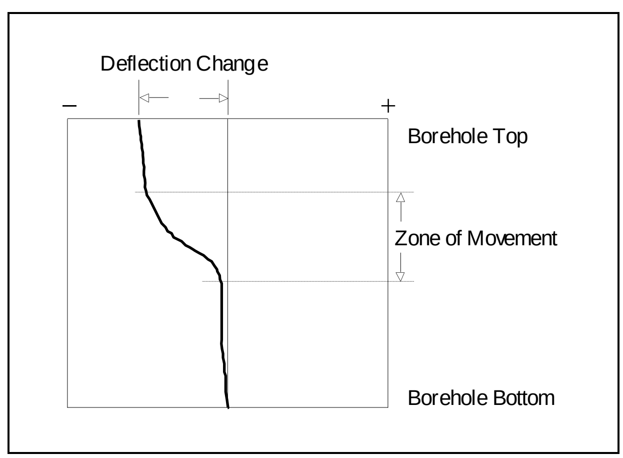

Figure 5. Borehole Deflection

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) force balance servo 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 < 1000g) but allowing the probe to fall against hard surfaces can permanently damage the accelerometer requiring expensive factory repairs. Therefore it is important to handle to 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 150kgm 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 aluminum 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

Spare or replacement cables are supplied on wooden spools. For use with the GK-604 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-604-1Inclinometer Readout.

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 604 Readout Instrument)

- Attach the pulley assembly to the top of the inclinometer casing and 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.
- 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-604 instructions).
- 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.
- 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.]
- 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)

- 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 603 or GK 604 readout box manual.

- 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.

- 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 or GK-604) to data set 2 (see GK-604 instructions). Repeat as per section 5.3.7.

- When the survey has been completed, save the data to a file. Clean and dry the probe. 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).

- 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.

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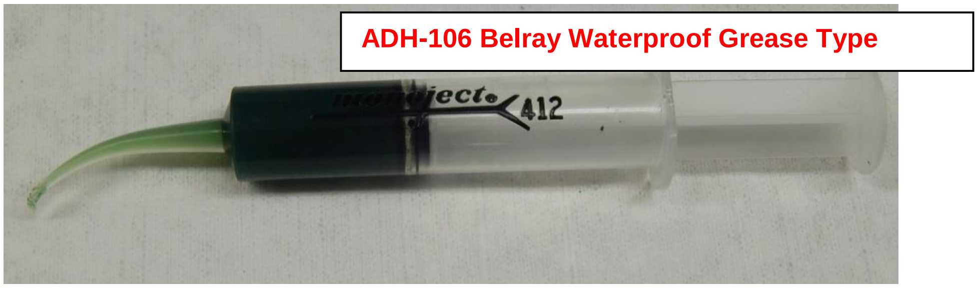
- Wheel assemblies should be kept dry when in storage. They should be kept free of dirt by using a compressed air gun to blow away grit. **Periodically spray the springs, pivots and axles with light oil**. This is very important and should not be neglected.

Wheel Bearing Maintenance:

Geokon recommends lubricating the wheel bearings after each use as noted below in Figure 6. This practice forces out any water or contaminates that may be present thus extending the service life.



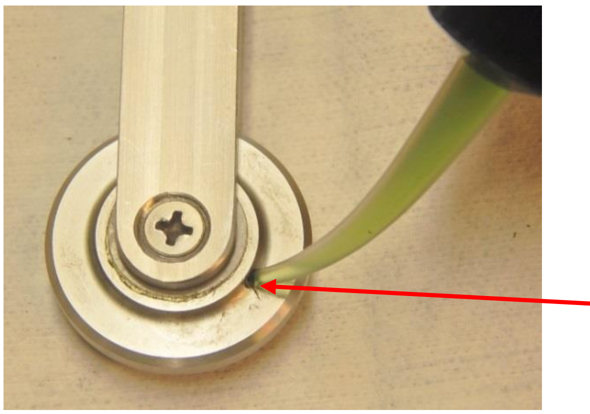


Figure 6. Wheel Lubrication

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

8. Specifications

Model No:	**6000M** (Metric Probe)	**6000E** (English Probe)
Wheel base:	0.5m or 1.0m	2 feet
Sensors:	2 force-balanced	2 force-balanced
Range [1]:	± 53°	± 53°
Full scale output:	± 5 VDC	± 5 VDC
Resolution:	.025 mm /500mm	.0001 ft/ 2 ft
Repeatability:	.02% F.S.	.02% F.S.
Total system accuracy:	± 6 mm/ 30 m	± 0.25 inch/ 100 ft
Temperature range:	– 20° to 50°C	– 4° to 122°F
Temperature coefficient:	.002% F.S./ °C	.001% F.S./ °F
Shock survival:	1000g	1000g
Dimensions:	700 × 25 mm dia.	32 × 1 in. dia.
Weight (with case)**:**	7.5 kg	16 lb

Notes

1. Range/Full scale:
The probe outputs five volts at an inclination of 30° to the vertical. The calibrated range of the probe is 30 degrees: this range is referred to as full scale (F.S.). Beyond this angle to the vertical the resolution is reduced by a factor equal to 1/cosine of the angle from the vertical, as explained below.

2. Resolution:

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 30 degrees from the vertical is 10.3 x 1/0.866 = 11.9 arc seconds = 0.029mm/500mm, and at 45° inclination the resolution is 0.035 mm per 500 mm. The resolution also depends on the capabilities of the readout box. 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. At 30 degrees from the vertical the total system accuracy is +/- 8mm per 30meters or +/- 0.35 inches per 100 ft.

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.

Appendix A

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.

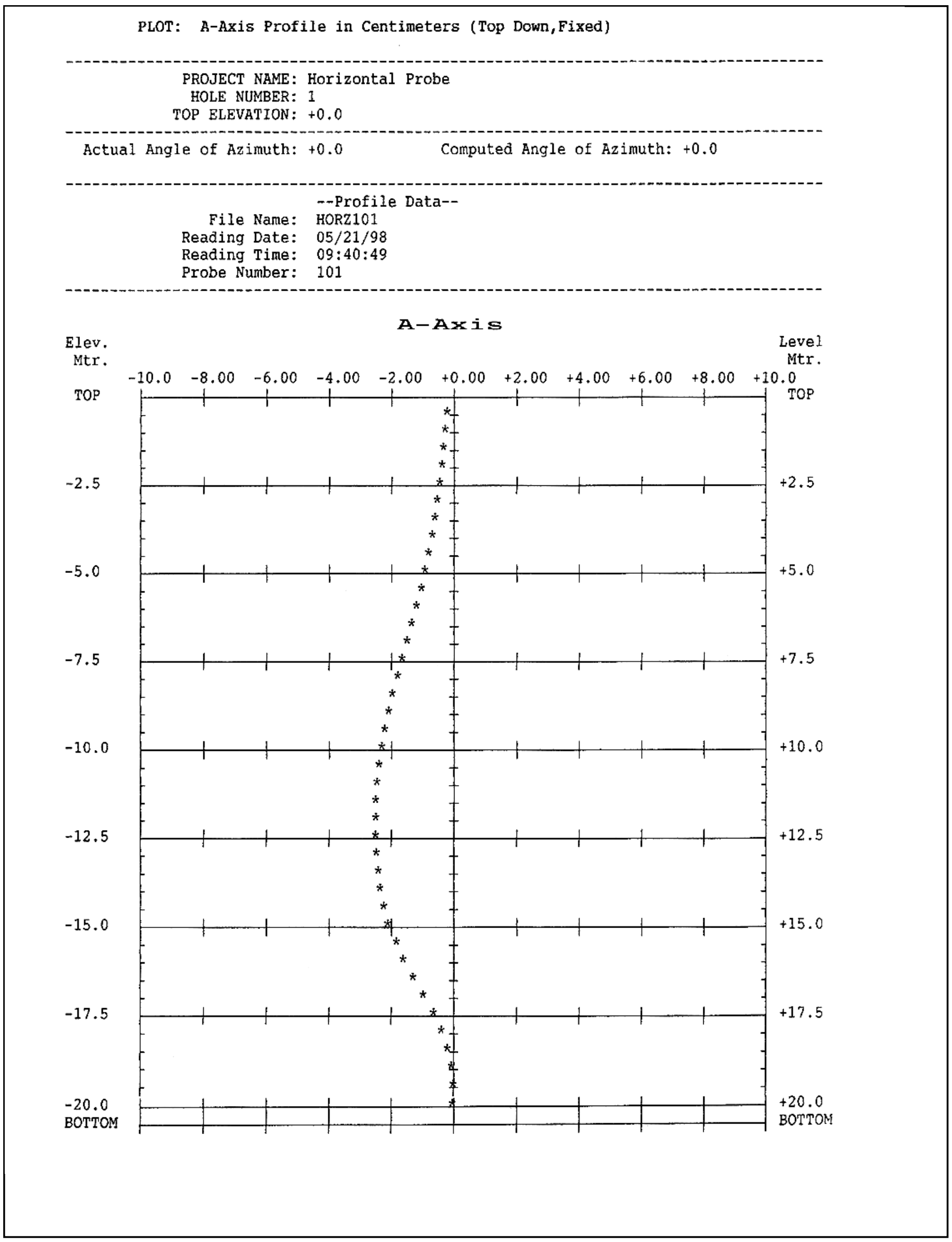
The Probe is always installed in the casing with the fixed wheels in the bottom groove. The probe is marked on one end with a white cross. When the probe is tilted down at this end the change in output will be negative.

- 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.
- 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.
- 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).

- 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

Appendix B Model 6000-11 Inclinometer Calibration Frame

B.1 Introduction

The Model 6000-11 Inclinometer Probe Calibration Frame is designed to permit the periodic checking of the calibration and zero stability of an inclinometer probe. In order for this to take place the Frame should be mounted on the vertical surface of a stable structure – one that is not subject to tilting caused by subsidence of the ground or by the effect of heavy traffic etc.

B.2 Initial Set Up

The Frame Mounting Plate has three mounting holes – one at the top and two slotted holes at the base. The plate should be used as a template to mark the position of three locations on a stable vertical surface. These locations are where holes most be drilled. If the Rawl Drop-in Anchors supplied with the Frame are to be used then the holes required are preferably 3/8 inch diameter or, if only metric is available,10mm.

Begin by positioning the Mounting Plate in its desired location and drill the top-most hole. Drill the hole 1 ¼ inches, (32mm), deep. Insert the expansion anchors into the holes, with the slotted end down and tap until it is flush with the surface. Then insert the setting tool provided, small end first, into the anchor and expand the anchor by hitting the large end of the setting tool with several sharp hammer blows.

With the anchor in place, fasten the Frame Mounting Plate to the Rawl Anchor using the ¼ -20 Flat Head Screw provided. The head of this screw will fit the countersink in the plate. Do not tighten this screw beyond finger-tight.

To position the two lower holes, two methods can be used. In the first method the Beam is pinned into the central, vertical location and a spirit level is held against the side of the beam and the two lower holes marked when the beam is vertical. the other method is to use the Inclinometer probe, installed inside the inclinometer casing on the beam, as an indicator of the vertical.

When the two lower hole locations have been marked swing the Mounting Frame to one side and carefully drill the two holes for the Rawl Anchors and install the Rawl Anchors as described previously.

Now swing the Mounting Plate back into position and use the two ¼ - 20 Socket Head Cap Screws provided to bolt the Plate to the Rawl Anchors. Use the two ¼ inch Flat Washers provided, between the Plate and the head of the Cap Screws. If the wall surface is not vertical additional washers can be used between the plate and the Rawl Anchors. (Note that the Inclinometer Readings will not be significantly altered by slight deviations from the vertical in a direction perpendicular to the wall). Leave the lower bolts slack until the final adjustment is made.

Place the Inclinometer Probe in the casing with the A Axis parallel to the plate. Connect the Probe to a Readout Box and then swing the Mounting Plate until the Probe Reading is at the previously determined reading corresponding to the reading when the Probe is vertical after taking due account of any zero offset the Probe might have. Now tighten the upper and lower bolts.

B.3 Operation of the Calibration Frame

The calibration frame has five Drill Bushing locations into which the Locating Pin will fit. The pin has a bayonet feature which allows the Locating Pin to be pulled out of the Drill Bushings and twisted through 90 degrees to hold the Pin in its retracted position. The central Bushing marks the position when the Inclinometer Probe is vertical, the other 2 pair of holes mark the +/- 5 degree and +/- 10 degree tilt positions. Readings should be taken in all five positions, first with the A+ direction facing left and then again with the A+ direction facing right. The procedure should then be repeated for the B Axis. Readings taken at regular intervals will show any tendency for the calibration or the zero reading to drift with time.

Note. Any changes in the calibration can be compensated for, by plugging the new Calibration Factor into the software used to calculate deflections. This is true also for any observed zero offset. However, it should be noted that small changes in the zero offset reading (< 2000), are automatically compensated for by the process of running two surveys at 180 degrees apart. Therefore it is not usually necessary to make any correction to the zero offset. It should be used as an indication of whether the Probe has suffered undue shock loading. It may suggest that more care needs to be taken when handling the Probe.

B.4 Maintenance of the Calibration Frame

The Calibration Frame requires no maintenance. The upper pivot uses an oil-impregnated bronze bushing. Periodic checks with a spirit level might be undertaken to check on the verticality of the Frame. The mounting bolts can be checked to make sure that they are tight.