GEOKON
The World Leader in Vibrating Wire Technology

48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603•448•1562
Fax: 603•448•3216
E-mail: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Model 6015

Horizontal Inclinometer Probe

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1. Introduction

1.1 The Geokon Model 6015 Horizontal Inclinometer Probe

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

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

Figure 1 Horizontal Inclinometer Probe

Figure 2 – The FPC-1 Handheld Readout Box

The probe itself contains two force balance accelerometers in which a pendulous mass that is acted on by the force of gravity and a position sensor which detects the position of the mass and provides a restoring force sufficient to return the mass to its null position. The greater the inclination from the horizontal null position the greater the required restoring force so that, in effect, the mass is prevented from moving. The magnitude of the restoring force, converted into an electrical output and displayed on the readout, becomes a measure of inclination from the horizontal. Since the restoring force is proportional to the sine of the angle of inclination from the horizontal the A+ and A- outputs are also proportional to the differential vertical displacement of one end of the probe with respect to the other. These successive vertical displacements can be accumulated, as the probe is pulled from one end of the casing to the other to provide a settlement (or heave) profile of the entire casing.

The probe is constructed so that the electrical cable can be connected to either end. Also there is an eyebolt that can be threaded onto the either end of the cable using the same connector threads. This enables the probe to be flipped end to end so that two surveys can be run with the probe in reverse positions to generate A+ and A- readings analogous to the two halves of a vertical inclinometer survey, where the probe is turned through 180 degrees to generate A+ and A- readings which, when subtracted from each other, remove any instrument bias.

The probe is a precision instrument and is susceptible to shock damage so that it needs to be handled with care at all times.

1.2 The 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 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 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 readout cable connector is a Lemo connector which plugs into the reel of the GK-604 Readout Box.

1.3 Cable Connectors

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.

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. In order for this O-ring to do its job the connector must always be tightened all the way down during a survey. It is vital, also, 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 Eyebolt connector has the same threads as the cable connector, it too should be tightened all the way to make sure that water cannot enter the inside of the probe

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

1.4 Cable reels

Reels are useful in storing the cable neatly when not in use. For longer 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.

2. Horizontal Inclinometer Theory

In all most applications it is normal to install a horizontal casing buried beneath an embankment, or under a tank foundation or along the ground surface, or the like. The inclinometer casing has four orthogonal grooves (Figure 3) designed to fit the wheels of a horizontal inclinometer probe (Figure 1). The purpose of the grooved casing is to keep the wheels of the probe upright so that the A axis is always vertical.

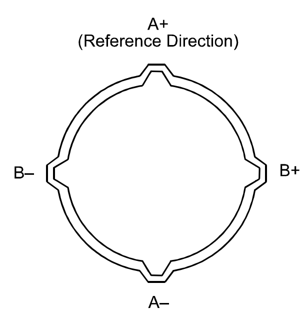


Figure 3 Inclinometer Casing

An initial, baseline survey is taken to which all subsequent surveys are compared. The instrument A+ and A- readings yield the sine of the angle of inclination of the probe in the casing. Knowing the gage length and this angle, the vertical deflection of one end of the gage relative to the other 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 A+, B+ survey is repeated with the probe turned end for end to generate a second set of readings designated the A- and B- readings. When the A+ and A- readings are subtracted from each other any instrument bias is removed leaving only the absolute value of the sine of the angle from the horizontal.

The difference in elevation between one end of the probe and the other end is given by Lsin θ where L is the length of the probe between the fixed wheels (either 2ft or 0.5 meters) and θ is the tilt angle of the probe away from the horizontal. Settlements are calculated by comparing the initial values of Lsin θ with subsequent values of Lsin θ so that the settlement of any station, n, along the casing is given by the equation.

$$\text{Settlement or heave at the nth station} = \sum_{1}^{n} (L \sin \theta_n)_{initial} - (L \sin \theta_n)_{subsequent}$$

3. Installation

3.1 Installing the casing.

The casing can be 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 pull-in cable arrangement is required. Care should be taken to keep the A grooves as perpendicular as possible throughout the length of the casing.

3.2 Running the survey

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 the A+ output will be negative.**

In a standard survey the probe is pulled by a cable to the far end of the casing, either by pulling from an accessible far end or, if the casing is dead-ended, by a return cable and pulley arrangement. The survey readings are taken while the probe is being pulled towards the near end. 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 away from the readout location.

3.3 Taking the readings

Before taking any readings wait until the probe has reached temperature equilibrium. This is signified by the readings on the readout box becoming steady.

Using the FPC-1 handheld readout box (and following the GK 604D instructions), take readings at the prescribed intervals, (2ft. or 0.5m), while pulling the probe back to the readout location**. Pause long enough, (a second or two), at each reading interval to allow the sensor to stabilize before taking the reading**. The intervals are marked on the electrical cable. Store these set of readings which are designated as the A+ and B+ readings. The B+ readings can be construed as a measure of any casing twist and the probe uses these readings automatically to adjust the A readings and compensate for any twist. Only the A axis readings are used to calculate settlements or heave.

Now, reverse the connections to the probe by switching the pull cable eyebolt with the electrical cable connector, then pull the probe back to the far end. Using the Gk-604D instruction advance the data set to 2 on the FPC-1 handheld readout screen and repeat the survey. The readings from this survey are designated the A- and B- readings. Store these readings. When the survey has been completed, disconnect the cables from the ends; clean and dry the probe. Replace the caps on the connectors and return the probe to its carrying case. The cable should be cleaned and recoiled on the reel.

4. Data Reduction

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 or bias*** of the force balance accelerometer ***is completely eliminated.*** [This zero offset or bias is the reading obtained from the inclinometer probe when it sits perfectly horizontal. 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 it]. The actual value of the offset is unimportant (if less than 5000) as long as the value does not change during the two halves of the survey.

Subsequent surveys of the inclinometer casing, when compared with the original survey, will reveal any changes of settlement or heave of the casing and the locations at which these changes are taking place. Analysis of the settlement ($L \sin \theta$) is performed by computing the vertical offset of one pair of wheels relative to the other pair wheels over the reading interval (L) of the survey (usually the wheel base of the probe, 2 feet for English systems, 0.5 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 vertical deflection in engineering units (inches for English, centimeters or millimeters for Metric).

These vertical offsets are then compared to the original survey offsets and then these differences at each station are accumulated to produce a settlement or heave profile.

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

Other analyses can be used but generally add little to the overall understanding of the situation. For example, using a single set of data and comparing it to a level straight line, ($\sin\theta = 0$) a level survey of the casing can be created. Also, a plot can be made of the actual change in reading (inclination) at each measurement casing increment. A plot of this nature reveals the location 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. Good quality data is obtained when the check sums at each measured interval are roughly equal. 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 Appendix 1 for more information on the Check Sum analysis. For more details concerning the installation of the inclinometer casing, refer to the instruction manual for Model 6500 Inclinometer Casing.

5. Maintenance

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

5.1

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).

5.2

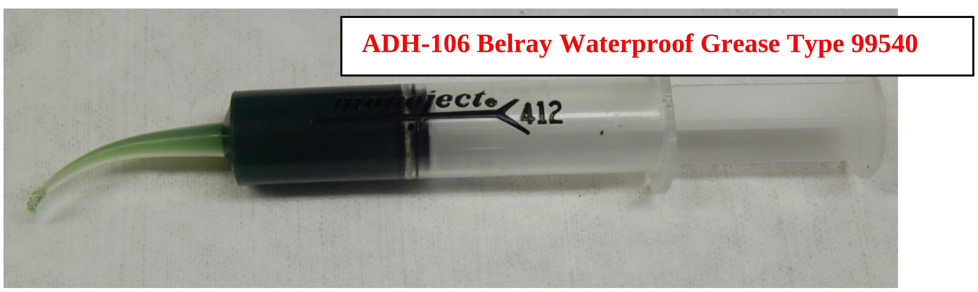
Make sure that the connectors are completely dry before replacing the protective caps. Otherwise corrosion could result.

5.3

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.

<u>Wheel Bearing Maintenance:</u>

Geokon recommends lubricating the wheel bearings after each use as noted below in Figure 4. This practice forces out any water or contaminates that may be present thus extending the service life.



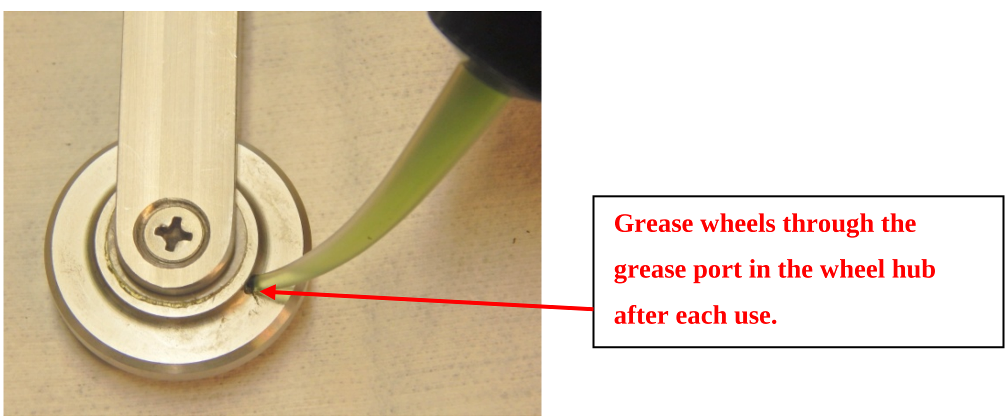


Figure 4. Wheel Lubrication

5.4

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 FPC-1 Handheld readout box.

5.5

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.

6. Specifications

Model No:	**6015M** (Metric Probe)	**6015E** (English Probe)
Wheel base:	0.5m or 1.0m	2 feet
Sensors:	2 force-balanced accelerometers	2 force-balanced accelerometers
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 horizontal. The calibrated range of the probe is 30 degrees: this range is referred to as full scale (F.S.). Beyond this angle to the horizontal the resolution is reduced by a factor equal to 1/cosine of the angle from the horizontal, as explained below.

2. Resolution:
The resolution shown in the table above is only true in the range of ± 5° from the horizontal. Beyond this the resolution is reduced by a factor equal to 1/cosine of the angle from the horizontal. For instance the resolution at 0 degrees from horizontal is 10.3 arc seconds and the resolution at 30 degrees from the horizontal 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 position 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 horizontal. At 30 degrees from the horizontal the total system accuracy is +/- 8mm per 30meters or +/- 0.35 inches per 100 ft.

APPENDIX I- CHECK-SUMS and "FACE ERRORS" ON INCLINOMETER PROBES

I-1 Introduction

Many users have expressed concern about **check-sums or "face errors"** on inclinometer probes. They are concerned with the affect of the "face error" on the accuracy of the readings. The purpose of this appendix is to show that under normal circumstances the affect of the "face error" or checksum is negligible even with check-sums as large as 2000. **The only time a problem would arise is if the face error or check-sum was to change between the two halves of a survey**. **This is why it is extremely important to not bang the probe on the bottom of the borehole between survey halves, and to not handle the probe roughly while out of the hole.**

The term "face error" comes from surveying terminology. It is normal for all theodolites to have a "face error" which is caused by imperfections of alignment of the collimation axis and other misalignments. These "face errors" are removed routinely by taking two readings of the theodolite: one angle is measured with the face of the vertical scale on the left of the theodolite and another with the face of the vertical scale on the right of the theodolite. The average of the two readings "face right" and "face left" gives the true angle since the "face error" cancels out.

Similarly with the inclinometer probe: the "face error" arises from the fact that the axis of the inclinometer probe is not parallel with the electrical axis of the internal, force-balance, servo-accelerometer transducer. Once again the "face error" is eliminated by taking two surveys of inclinometer readings one with the wheels of the inclinometer probe pointing in one direction and another with the wheels of the probe at 180° to the first direction. If the first set of readings are all too large by the amount of the "face error" then the second set of readings will be too small by the amount of the "face error" and the average or sum of the two readings will be a measure of the true inclination since the affect of the face error will be totally eliminated.

I-2 The Effect of the "Face Error" on the accuracy of the readings

The "face error" or check-sum can only affect the accuracy of the readings if it affects the calibration of the probe. This is possible because the output of the probe transducer is proportional to the sine of the inclination from the vertical and the sine function is non-linear.

Imagine, for a moment, that the electrical axis of the transducer is five degrees away from being parallel with the axis of the inclinometer. This would give rise to a "face error" of 01743. (The inclinometer reader displays 20,000 sin ∅). So, one set of readings would be all too large by this amount and the other set of readings from a normal inclinometer survey would be too small by this amount, but the sum of the two readings would be accurate, the "face errors" having canceled out. However, if we assume that the hole is almost vertical then the transducer will be tilted at an angle of 5 °. The difference in the slope of the sine function at any point is equal to the cosine of the angle at that point. The cosine of 0 ° is 1.0000 the cosine of 5 ° is 0.996 so that the effect of this "face error" on the calibration of the probe is to increase it by a factor of 1/0.996 = 1.004.

The practical implication of this would mean that if the apparent deflection of a borehole was 100 mm, the true deflection would be 100.4 mm. For practically all applications, in the real world, the difference is insignificant and is a lot less than the differences which normally occur from survey to survey i.e. a lot less than the precision of the inclinometer probe survey. (Lack of precision is caused by a failure to position the wheels of the probe in exactly the same place from survey to survey; failure to wait sufficiently long to allow the probe transducer to come to rest before reading; and random dirt in the inclinometer casing).

Note that the normal system accuracy of an inclinometer probe is ± 8 mm in 30 meters. By comparison it can be seen that the normal system accuracy or precision is very much larger than the calibration error caused by the "face error" and that for all practical purposes the "face error" is of no consequence and can be completely discounted if it is less than 2000 digits.

(As another example , supposing the check-sum was as large as 5000 digits. This is equivalent to a gross angular error of misalignment of almost 15 degrees. The effect on the calibration would be a little over 3 % so that the apparent deflection of 100 mm would be out by 3 mm which again is smaller than the normal data spread due to imprecision).

I-3 Measurement of the "Face Error"

The "face error" is the reading shown by the inclinometer probe when it is perfectly vertical. In practice , the easiest way to obtain the "face error" is to run a normal inclinometer survey, with the two sets of readings at 180 °, and then to run a "check sum" report. (see section 3.2.2.1) Examination of the data will reveal **the average check sum which is equal to twice the "face error."**

I-4 Setting of the "Face Error" to zero

There are three ways of setting the "face error" to zero. None of them are necessary from the point of view of improving accuracy.

I-4.1 Mechanically

At the time of manufacture the electrical axis of the transducer is adjusted by means of shims etc., until it points parallel to the axis of the inclinometer probe. This method suffers from the disadvantage that if the "face error" changes due to wear and tear on the probe and rough handling, shock loading of the transducer then the probe needs to be returned to the factory for dismantling and re-adjustment.

I-4.2 Electrically

Electronic circuitry can be included in the probe so that the output of the transducer can be adjusted to zero when the probe is vertical. The disadvantage of this method is that it introduces electronic components into the inside of the probe which may alter with time, temperature and humidity and which, if the "face error" changes due to wear and tear or rough handling, will require the probe to be dismantled and the electronic circuitry readjusted. Also, this form of correction only masks the "face error". It does not really remove it and if the "face error" is very large the calibration will be affected as described in Section I-2.

I-4-3 By software

The best way for setting the "face error" to zero is by applying an automatic correction to the measured readings using the software capabilities of the inclinometer readout box. The advantage of this method lies in its simplicity and the ability to set the "face error" to zero at any time without dismantling the probe. This is the method chosen by Geokon. Another advantage of this method is that it is possible by judicious choice of the "face error" entered into the software program to make one probe give exactly the same digits output as another probe. This is sometimes thought to be desirable where probes are switched and unbroken continuity of the raw data is desired. It is not necessary for reason of accuracy as has already been explained.

The disadvantage of this method is that, if the probe is changed, the operator must remember to change the zero shift offset in the program to accommodate the "face error" of the new probe.

I-5 Conclusion

It has been shown that for most practical purposes check-sums of less than 2000 digits are of no consequence and can be completely ignored providing the inclinometer survey is conducted in the normal way. (i.e., 2 sets of readings at 180°) It has further been shown that the best method by far, for setting the "face error" to zero, is by means of the software capabilities in the inclinometer reader. This is the method chosen by Geokon.