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The Application and Use of In-Place Inclinometers

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THE APPLICATION AND USE OF IN-PLACE INCLINOMETERS

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ABSTRACT

Whilst the traversing Inclinometer has been in use since 1958, with improved electronics, dataloggers and computers the use of In-place Inclinometers has become more prevalent in the construction industry and similarly by other users of Geotechnical Instrumentation.

Inclinometers are used to monitor subsurface movements of earth in landslide areas and deep excavations. They are also used to monitor deformations in structures such as dams and embankments.

This paper will discuss the types of In Place Inclinometers, their performance and their application in the various forms of construction Geotechnical Engineers are concerned with.

Methods of data acquisition and applications of software will also be discussed.

1 INTRODUCTION

A rudimentary inclinometer system includes inclinometer casing, an inclinometer probe and control cable, and a inclinometer readout unit.

Inclinometer casing is typically installed in a near-vertical borehole that passes through a zone of suspected movement. The bottom of the casing is anchored in stable ground and serves as a reference.

The inclinometer probe is then used to survey the casing and establish its profile (or top is surveyed if the former is not feasible). Ground movement causes the casing to move from its initial position to a new position. The rate, depth, and magnitude of this displacement is calculated by comparing data from the initial survey to data from subsequent surveys.

1.1 PARTS OF THE PROBE

The inclinometer probe consists of a stainless steel body, a connector for control cable, and two pivoting wheel assemblies. The distance between the wheel pivots is the gauge length.

When properly connected to the control cable, the probe is waterproof and has been used deeper than 300 metres.

Each of the two wheel assembly consist of a yoke and two wheels. The upper wheel of each assembly is referred to as the “reference wheel”.

Figure 1 – Parts of the Probe

1.2 MEASUREMENT PLANES

The inclinometer probe employs two force-balanced servo-accelerometers to measure tilt. One accelerometer measures tilt in the plane of the inclinometer wheels. This is the "A"axis. The other accelerometer measures tilt in a plane perpendicular to the wheels. This is the "B" axis. Figure 2 shows the probe from the top. When the probe is tilted toward the A0 or B0 direction, readings are positive. When the probe is tilted in the A180 or B180 directions, readings are negative.

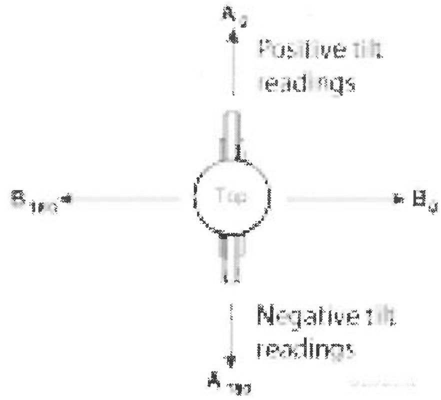


Figure 2 – Measurement Planes

1.2.1 A0 Casing Groove and Reference Wheels of Probe

Inclinometer casing is installed so that one set of grooves is aligned with the expected direction of movement. One groove, typically the "downhill" groove, should be marked A0. In a standard inclinometer survey, the probe is drawn from the bottom to the top of the casing two times. In the first pass, the reference (upper) wheels of the probe should be inserted into the A0 groove. This ensures that movements in the direction of the A0 groove are positive values.

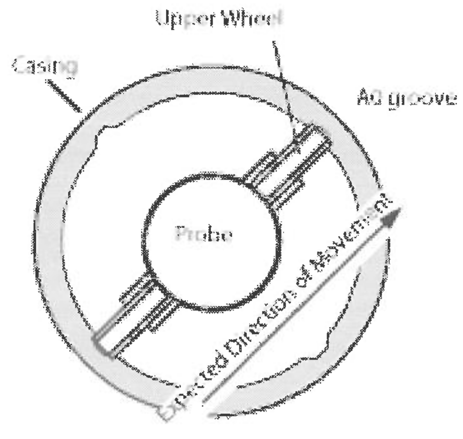


Figure 3 – A0 Casing groove and upper wheels of probe

1.3 CUMULATIVE DEVIATION

By summing and plotting the deviation values obtained at each measurement interval, we can see the profile of the casing.

The black squares at each measurement interval represent cumulative deviation values that would be plotted to show the profile of the casing.

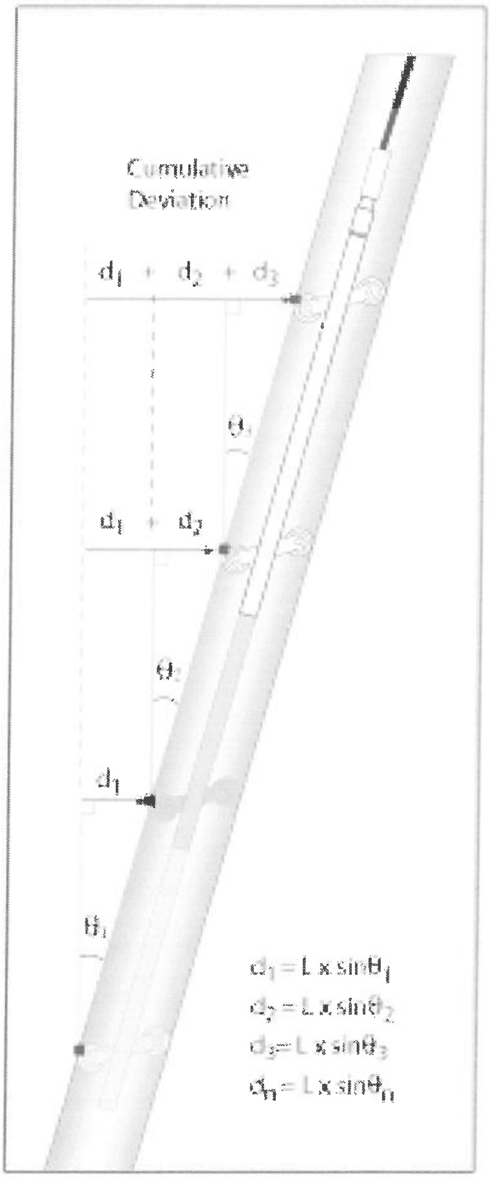
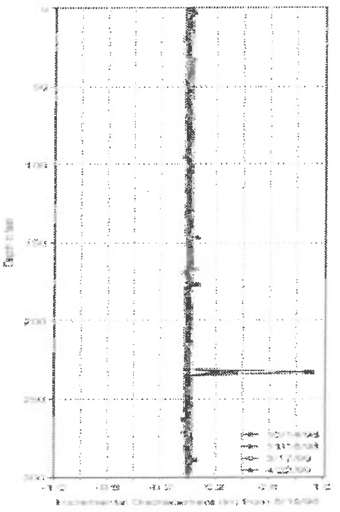


Figure 4 – Cumulative Deviation

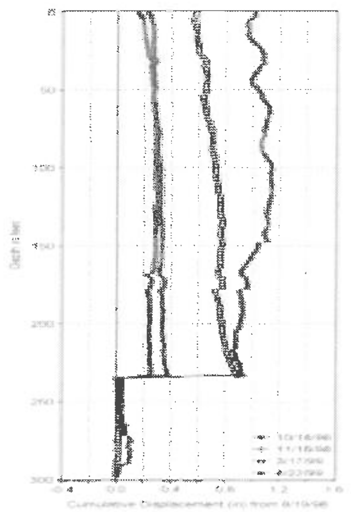
1.4 DISPLACEMENTS

Changes in deviation are called displacements, since the change indicates that the casing has moved away from its original position. When displacements are summed and plotted, the result is a high resolution representation of movement.

Displacement is a change in deviation and shows that the casing has moved away from its original position. The figures below show plots of a borehole with a shear zone at 230 feet.



Incremental displacement plot shows movement at each measurement interval



Cumulative displacement plot shows a displacement profile. Displacements are summed from bottom to top

Figure 5 – Displacements

1.5 MANUAL REDUCTION OF DATA

Normally, computer software is used to reduce inclinometer data. Prior to 1985, all calculations were performed manually. The method of manual reduction of data is in the Slope Indicator Digitilt Inclinometer Probe Manual.

INITIAL PROFILE OF BOREHOLE CASING

When using Inclinometers it is imperative that base line readings are taken prior to any commencement of construction or excavations. This will allow any changes in the initial profile to be easily identified.

1.6 THE ADVANTAGES AND DISADVANTAGES OF TRAVERSING INCLINOMETERS

The advantages of the traversing (portable) Inclinometer are that:

- one system can be used in many boreholes
- the direction of the movement and the magnitude of the movement can be calculated
- small O.D. of probe that allows it to be used effectively in casing that moves and is deformed
- Maximum performance, ie: accuracy and precision

The disadvantages are that it is:

- labour intensive, and
- requires processing of the data by manual intervention before a comparison can be made (not real time)

To address the disadvantages, in the past six years low cost In Place Inclinometers have been designed, built and used in various applications throughout the world.

Prior to this In Place Inclinometers with servo-accelerometers were used for automatic monitoring, however market pressure has made this approach cost prohibitive.

2 STANDARD IN-PLACE INCLINOMETERS

2.1 APPLICATIONS

The In-Place Inclinometer is ideal for data logging and near-real time monitoring. Typical applications include:

- Monitoring deformation of diaphragm walls supporting deep excavations.
- Monitoring ground movements induced by tunnel construction.
- Monitoring deformations of embankments and retaining walls.
- Monitoring landslide areas above dams, highways, and railroads to provide early warning of slope failure.

2.2 OPERATION

The In-Place Inclinometer system consists of inclinometer casing and a string of inclinometer sensors. The Inclinometer casing is installed in a vertical borehole that passes through a suspected zone of movement. This zone would normally be identified by surveys with the traversing probe. The sensors, each connected with pivoting joints, are positioned inside the casing to span the zone of movement. When ground movement occurs, casing is displaced, causing a change in the tilt of the sensors inside.

The sensors measure tilt, the angle of inclination from vertical. The tilt measurement is converted to lateral deviation using the formula L sine Ø, where L is the gauge length of the sensor and Ø is the tilt angle.

Gauge lengths can be any length up to 3m. They are typically 1, 2 or 3 metres.

2.3 ADVANTAGES

2.3.1 Real Time Monitoring

The In-Place Inclinometer is ideal for continuous, unattended monitoring and can deliver readings in near-real time.

2.3.2 Rigid Gauge Tubing

Accurate displacement calculations require straight-line sensor gauge lengths. Rigid gauge tubing satisfies this requirement. Rigid gauge tubing also provides reliable performance in soft ground, where abrupt changes in profile may occur at a shear zone.

2.3.3 Dataloggers

Data loggers and post-processing software can present profile plots and trend plots of inclinometer data just minutes after the readings are obtained.

2.3.4 Removable

Wheeled sensors can be easily removed to allow verification checks with a traversing probe.

2.4 DISADVANTAGES

- More sensors the greater the cost
- Diameter of sensor and cables passing the sensor
- Components in Data logger (expense of)

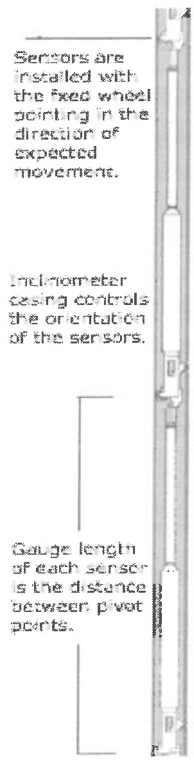


Figure 6 – In-Place Inclinometers (Fixed wheel is "reference" wheel, analogous to upper wheel)

3 MULTIPLEXED IN-PLACE INCLINOMETERS

3.1 DESCRIPTION

Standard In-Place Inclinometers have a cable running or attached to each sensor. As the number of sensors in the borehole increases, the internal diameter of the borehole can get "crowded".

To overcome this crowding there is a version of the IPI called the Multiplexed (Muxed) IPI. This enables the string of sensors to be connected by the same signal-cable segmented by means of internal multiplexing.

3.2 ADVANTAGES

- Reduces amount of cable required
- Reduces the components required at the Datalogger
- Allows more movement in the borehole before interference ("crowding")

3.3 DISADVANTAGES

- The sensor is more expensive
- Series connection affects reliability

4 SLED SENSORS

4.1 DESCRIPTION

Sled Sensors are intended for a low cost application not requiring maximum performance. Standard IPI & Muxed sensors use wheels that will push against the grooves of the inclinometer casing and can be easily retrieved allowing redeployment.

EL Sled Sensors use a sled that fits neatly into the groove of the casing. It is lower technology and uses a less accurate sensor.

4.2 ADVANTAGES

- Lower cost

4.3 DISADVANTAGES

- Intended for one time installation
- Only uniaxial
- Each sensor needs its own cable
- Uses less sensitive sensor (lower resolution)

4.4 DATALOGGING

Although In-Place Inclinometers can be read manually, their use with a multi-channel Datalogger makes them ideal for continuous, unattended monitoring and can deliver readings in near real time.

The datalogger can then be interrogated via modems and telephones for viewing data on the owners, contractors and/or consultants computer.

4.5 PRESENTATION SOFTWARE (POST PROCESSING)

Having collected the information from IPI's will generate a huge amount of data that will require processing. There are software packages available that will present this data in graphical form. This software also allows thresholds to be set and alarms triggered when limits are exceeded.

4.6 CURRENT INSTALLATIONS OF IN-PLACE INCLINOMETERS IN AUSTRALIA

- Hope Valley Reservoir, S.A.
- Prospect Dam, NSW
- Happy Valley Dam, S.A
- University of Wollongong, NSW
- Parramatta Rail Link NSW

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6 REFERENCES

- Mikkelsen, P. Erik (1986) *Design and Installation of Instrumentation*, 1st Edition, Slope Indicator Co. USA
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COMPARISON OF INCLINOMETERS AND IN-PLACE INCLINOMETERS

TABLE 1

INSTRUMENT	PORTABLE INCLINOMETER	EL IPI	MUXED EL IPI	EL SLED IPI
Part Number	50302510	56804121, 56804122	56804521, 56804522	56804410
Orientation	Biaxial	Uniaxial, Biaxial	Uniaxial, Biaxial	Uniaxial
Range from Vertical	+/- 53°	+/- 10°	+/- 10°	+/- 30°
Resolution	0.02mm / 500mm	0.04mm / m	0.04mm / m	0.05mm/m
Repeatability	± 0.003° .01% F.S. at 30°	± 22 arc seconds	± 22 arc seconds	± 72 arc seconds or ± 0.35mm/m
Temperature Rating	-20 to +50° C	-15 to 40°C *	-15 to 40°C *	-15 to 40°C *
Dimensions	25.4 x 653mm	38mm x 380mm	38mm x 380mm	38m x 380mm
Accuracy	± 0.25mm / reading	1mm/1m	1mm/1m	4mm/m
Gauge Length	500mm	1m, 2m, 3m	1m, 2m, 3m	1m, 2m, 3m
Casing O.D. (mm)	48, 70, 85	70, 85	70, 85	70, 85
Materials	Stainless Steel	Stainless Steel	Stainless Steel	Aluminum

*with optional, extended range calibration