Inclinometer Accuracy

The Specification

Slope Indicator states that the system accuracy of the inclinometer is ±0.3 inches per 100 ft, when casing is installed within 3 degrees of vertical and when proper reading techniques are used. This is a conservative, but practical specification of the accuracy that one can expect from ordinary inclinometer installations and ordinary reading practices. It includes random and systematic error for 50 reading increments taken with a 2-foot probe.

The specification was derived empirically from a large number of datasets and includes both random and systematic error for 50 reading increments and a 2-foot inclinometer probe. For a single reading increment, random errors were found to be 0.007 inches and systematic errors were found to be 0.005 inches. Random error accumulates with the square root of the number of reading increments, and systematic error accumulates directly with the number of reading increments. The total error for a 100-foot traverse (50 reading increments) can be calculated as:

Total Error = Random Error + Systematic Error

= 0.007 x sqrt(50) + 0.005 x 50

= 0.050 + 0.250

= 0.300 inches

Systematic errors can be corrected, but random error cannot. Thus the limit for precision for 50 reading increments is ±0.05 inches, and the limit of precision for a single interval (such as a shear zone) is about ±0.01 inch

Orders of Accuracy

Conventional land surveyors have long used a convention of "orders of accuracy", with each order consisting of prescribed methods to attain a certain accuracy. First-order surveys, for example, are much more involved and expensive than third-order surveys. Inclinometer surveys are analogous to open-ended traverses and could also be rated for orders of accuracy, with methods of care and corrections prescribed.

Although some exceptions probably exist, an ordinary inclinometer precision of ±0.3 inches per 100 feet is probably quite adequate for soft ground construction where some displacement can be tolerated. For critical structures and situations, hard ground and rock, where much less displacement can be tolerated, the extra effort and associated cost to get better precision may be justified. Precision of ±0.1 inches per 100 feet, is a higher order of accuracy, and can be achieved with careful survey practices and error correction during data reduction. The limit to accuracy, ±0.05 inches per 100 feet, is achievable, but requires careful selection from redundant datasets and an excellent installation of casing.

Sources of Error

Potential error sources for inclinometer surveys are outlined below. Some of these errors are random, others are systematic. Systematic errors can be corrected using mathematical procedures. Random errors cannot. .

Accelerometers	Probe and Wheels	Cable	Readout	Casing
Bias	Connectors	Markings	Calibration	Inclination
Mechanical Alignments	Mechanical Alignment	Dimensional Change	Change due to Temperature	Non-Parallel Grooves
		Control		Curvature
				Backfill
				Joints
				Debris
				Displacement
				Groove-Width
				Top Reference

Systematic Errors

Measurements from the deepest part of an inclinometer casing have the highest potential for systematic errors due to four factors: (1) instrument warm-up drift being most acute, (2) calibration hysteresis more probable, (3) tendency of the borehole to drift from vertical, and (4) greatest distance from the top reference point. Systematic errors are:

Bias Error: This error is related to a small change in the bias of the inclinometer probe. The bias is usually eliminated during data reduction, but causes error if there is a change in the bias between opposite traverses through the casing or if the opposite traverse is missing from the survey. If the error is systematic, the bias is a constant value added to each reading and appears as a linear component in the plot. Bias error is the most common systematic error and the easiest to correct.

Rotation Error: In this context, rotation is a small change in the alignment of the probe's measurement axis. Ideally, the mechanicals of the probe are aligned so that the A-axis accelerometer measures tilt only in the A-plane. However, if the mechanical components of the probe are rotated slightly towards the B-plane, the A-axis accelerometer will be come slightly sensitive to tilt in the B-plane. The B-component in the A-axis reading is rotation error. Rotation errors become important when there is significant inclination in the cross axis AND when the alignment change occurs after the initial dataset was obtained. It takes some experience to correct this error.

Depth Error: The combination of casing curvature and a change in the vertical placement of the probe is another source of error. Depth errors caused by a change in the cable reference, a change in cable length, or a change in casing length. Unless the vertical displacement errors are known precisely, this kind of error is difficult to correct. Even when the error is known, corrections are not perfect.

The Basis for Corrections

Redundant data: Each dataset contains two surveys, one with readings in the A0 & B0 directions and one with readings in the A180 & B180 directions. This permits comparison of readings at each depth for consistency (checksums) and error (zero shift).

Fixed Bottom: Inclinometers (installed properly) should extend 10 to 20 feet into ground or part of a structure that is considered to be stable. This approach to bottom fixity allows for the bottom 5 to 10 readings in the casing to provide calibration data for the measurements and also serves to detect and quantify errors.

Visible Errors: Any small displacement that resembles any or a composite of the three forms of systematic errors described above should be suspected as error. It would be unreasonable for actual displacements to be similar in shape (graphically congruent) to a potential systematic error signature.

Accuracy and Scales

Graphing programs automatically apply scales to match the minimum and maximum values in a data series. Unfortunately, when the data are very good and within the band of error, the graph shows 100% noise and error. Such graphs have an alarming appearance and make very little sense.

Exaggerated scales may be useful for analytical work and error correction, but for final presentation, it is more appropriate to use a scale that minimizes the band of error. For 100 foot boreholes, a scale of ±1 or 2 inches is appropriate (±25 or 50 mm).

About Checksums

A checksum is the sum of a "0" and a "180" reading at the same depth. Ideally, the sum would be zero since the two readings have opposite signs. In practice, checksums are not zero because of bias in the probe, variations in casing grooves, and the positioning of the probe.

Checksums provide a quick way to evaluate the quality of your data. An abnormally large checksum may indicate a bad reading. The standard deviation of checksums is a measure of the random error in the survey. In general, the standard deviation of checksums should not exceed 10 for the A axis and 20 for the B axis.

Checksums can also be used to confirm that a bias shift has occurred in the probe. A drifting mean checksum within a dataset indicates a bias-shift during one pass of the survey. Larger than normal checksums may indicate a bias-shift between the 0 and 180 pass.