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Standard Practices for Monitoring Earth or Structural Movement Using Inclinometers[1]

This standard is issued under the fixed designation D6230; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Minor corrections were editorially made throughout in July 2021.

1. Scope*

1.1 This standard covers the use of inclinometers to monitor the internal movement of ground, or lateral movement of subsurface structures. The standard covers types of instruments, installation procedures, operating procedures, and maintenance requirements. The standard also provides formulae for data reduction.

1.2 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026 unless superseded by this standard.

1.2.1 The procedures used to specify how data are collected, recorded or calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analytical methods for engineering design.

1.3 *Units*—The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only. Reporting of test results in units other than SI shall not be regarded as nonconformance with this standard.

1.4 This standard offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this standard may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D3966/D3966M Test Methods for Deep Foundations Under Lateral Load

D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data

D7299 Practice for Verifying Performance of a Vertical Inclinometer Probe

3. Terminology

3.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.23 on Field Instrumentation.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *inclinometer casing, n*—a (typically segmented) pipe or casing with grooves specific for the type of inclinometer being used.

3.2.1.1 *Discussion*—Casing is typically made of plastic, aluminum alloy, or fiberglass.

3.2.2 *inclinometer probe, n*—an instrument comprised of a downhole probe which uses internal sensors to detect its own orientation relative to the force of gravity, with a wheel assembly for lowering into the inclinometer casing along the alignment grooves, connected by a cable to a readout or datalogger at the surface.

3.2.3 *in-place inclinometer gauge (IPI gauge), n*—an inclinometer probe which is designed to be installed at a fixed depth in an inclinometer casing, typically in an array of multiple units with known spacing and kept in place for the duration of the monitoring period.

3.2.4 *spiral probe, n*—a wheeled probe that tracks alignment differences between its top and bottom wheels. whose readings measure the spiraling twist of an inclinometer casing installation.

4. Significance and Use

4.1 An inclinometer is a deformation monitoring system, which uses a grooved pipe or casing with internal longitudinal grooves aligned with the anticipated direction of movement, installed in either a soil/rock mass or a geotechnical structural element. The inclinometer casing can be surveyed with a single traversing probe or with an array of in-place inclinometer (IPI) gauges connected to a data logger. The measurement and calculation of deformation normal to the axis of the inclinometer casing is done by passing a probe along the length of this pipe or placement of a sensor array, guided by the internal grooves. The probe or sensor array measures the inclination of the pipe, usually in two orthogonal directions 90° apart (X- and Y-direction) with respect to the axis of the casing (Z-direction, usually the line of gravity). Measurements are converted to distances using trigonometric functions. Successive surveys compared with an initial survey give differences in position and indicate deformation normal to the axis of the inclinometer casing. In most cases the inclinometer casing is installed in a near-vertical hole, and the measurements indicate subsurface horizontal deformation. In some cases, the inclinometer casing is installed horizontally, and the measurements indicate vertical deformation.

4.2 Inclinometers are also called slope inclinometers or slope indicators. Typical applications include measuring the rate and direction of landslide movement and locating the zone of shearing, monitoring the magnitude and rate of horizontal movements for embankments and excavations, monitoring the settlement and lateral spread beneath tanks and embankments, and monitoring the deflection of bulkheads, piles or structural walls.

NOTE 1—The precision of this standard is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable testing depends on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Method A*—The traveling-probe-type inclinometer system consists of an inclinometer probe, typically utilizing microelectromechanical systems (MEMS) technology sensors, which give the inclination of the probe digitally. Biaxial probes contain two sensors oriented 90° apart to permit readings in orthogonal directions at the same time. Other sensor types, such as ones based on force balance accelerometers, which give a voltage output that is proportional to inclination of the probe, may also be used. The probe(s) can have an analog or digital output. Use of a single uniaxial or biaxial probe pulled through the casing while being sampled is designated as Method "A." A portable readout unit, connected via cable or wirelessly, is used to display probe inclination and record the inclination data.

5.1.1 An electrical cable with distance markings connects the probe and power supply (which may also include the readout). Fig. 1 illustrates a typical set of components. The cable should include a clamp to prevent the probe from falling down the borehole. For deep holes a hoist or winch may be required.

5.2 *Method B*—The in-place inclinometer (IPI) array is a set of gauges which are installed in the casing at fixed distances apart, using spacer rods or pipes. These gauges may be individual units with connecting and spacing elements between them, or may consist of a continuous assembly. Some models of in-place inclinometers may be held in plane using guide wheels in grooved casings. Fig. 2 illustrates two types of common in-place inclinometer assemblies. The left schematic in Fig. 2 is an example of multiple probes assembled together to form a single in-place inclinometer installation, with wheels to align in a grooved casing. Gauge length for this assembly is measured wheel to wheel. The right schematic in Fig. 2 is an example of a continuous in-place inclinometer with no wheels. Gauge length in this case is measured joint center to joint center. Use of an in-place inclinometer array which is sampled while stationary in the casing is designated as Method "B." Other sensor types, including ones mentioned in Method "A" above and also ones based on vibrating wire technology, may be used. The use of an array may be more applicable in a scenario where observations need to be taken relatively rapidly, such as during a lateral pile load test (see Standard D3966/D3966M), or where observations need to be taken continually over long periods of time, such as monitoring shoring for excess deformation during excavation. Individual instruments in the array may be uniaxial or biaxial.

6. Procedure

6.1 *Installation of Casing in a Borehole:*

6.1.1 Select casing materials that are compatible with the environmental conditions at the installation. Select casing size consistent with the specific measurement requirements and conditions for the job. Store casing materials in a safe, secure place to prevent damage. Sunlight may damage plastic casing. High and low pH may damage metal casing.

FIG. 1 Typical Components of Method A Inclinometer System

6.1.2 Assemble all components required for the casing, including casing, segments, couplings, and end cap. Examine each component for defects. Do not use defective components since they may later cause problems with readings that are difficult to diagnose and impossible to correct. Keep all components clean and free of foreign matter during assembly. Follow the manufacturer's instructions for assembly of the casing. If required, use sealing mastic and tape to seal all couplings to prevent later flow of soil particles into the casing. This is especially important when using grout to seal the casing in the hole. Exercise care to keep any casing grooves free of obstructions. When assembling couplings, use procedures to prevent spiraling of the casing grooves. For grooved casings, twist adjacent couplings in alternate directions before fixing to minimize spiraling. Examine the casing during assembly to confirm that spiraling is not occurring. Place a cap on the bottom end and seal it to prevent inflow.

6.1.3 Create the borehole using procedures to keep it aligned within the required tolerances for plumb, level, or horizontal location. Extend the borehole at least 5 m (16 ft) beyond the zone of expected movement if in soil, or 1.5 m (5 ft) into rock if bedrock is stable. It may be necessary to use drilling casing, a hollow-stem auger, or drilling mud to keep the hole open and stable. Flush the hole until clear of drilling cuttings.

6.1.4 Insert the casing into the borehole. Establish the reference orientation for the casing and, for grooved casing, align one set of grooves with this reference. This orientation is commonly referred to as the X direction. It should align with the direction of greatest anticipated movement (see Note 2). If the absolute direction of displacement is required, measure the angle between site plan north and the reference grooves in the casing using a magnetic compass or other survey methods. Add clean water to the inclinometer casing if necessary to help prevent buoyancy. Use of water alone will not overcome buoyancy created by fresh cement grout. See following section for guidance. Use care to minimize any twist of the casing during installation. Exercise care to maintain orientation without twisting from the first piece of casing to the last. Twisting the top of the casing may cause spiraling of casing at depth. For casings greater than 50 m (165 ft) in length, the twist of the grooves along the casing shall be checked by independent measurements. Measurement of casing twist is commonly carried out by means of spiral probes.

NOTE 2—If the X grooves are not aligned with the actual maximum movement, both sensors detect the movement corroborating what the other is reading. Most commercially available software for reducing inclinometer readings will report the maximum movement and the direction.

6.1.5 Backfill the annular space between the borehole wall and the inclinometer casing with a suitable fill material. Options include non-shrink cement grout or cement-bentonite grout, sand (see Note 3) and pea gravel. The fill material shall not be stiffer than the surrounding material. The borehole can be pre-grouted or post-grouted. If post-grouted, grouting can be through a tremie placed in the annulus of the inclinometer casing and the borehole's walls or via an internal tremie connected to a one-way bottom grout valve. A lean cement grout backfill is preferable unless the surrounding ground is too pervious to hold the grout. Place grout with a tremie. Buoyancy must be overcome with grout backfills. Add a weight or earth anchor to the bottom of the inclinometer casing, temporarily place clean drill pipe inside the casing, or place the first 3 m (10 ft) of grout around the bottom of the casing and let it set, then complete the grouting. Place sand and gravel backfills slowly and with techniques to prevent leaving voids in the backfill. Such voids can later lead to erratic readings. Place backfill and withdraw drill casing or augers in sequence to prevent any squeezing of the borehole. Withdraw drill casing and hollow-stem augers without rotation to prevent damage to the inclinometer casing. Use measures to prevent backfill from spilling into the inclinometer casing. Many manufacturers include a recommended grout mix based on soil consistency in their product literature which may be used as a guideline.

NOTE 3—Many practitioners contend that sand should never be used as backfill especially for installations in excess of 30 m (100 ft) in depth.