INTERNATIONAL

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Standard ~~Test Method~~ Practices for Monitoring ~~Ground~~ Earth or Structural Movement Using ~~Probe-Type~~ 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.

~~1. Scope*~~

~~1.1 This test method covers the use of inclinometers to monitor the internal movement of ground. The test method covers types of instruments, installation procedures, operating procedures, and maintenance requirements. It 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values shall conform to the guidelines for significant digits and rounding established in Practice D6026 unless superseded by this test method.~~

~~1.2.1 The procedures used to specify how data are collected, recorded or calculated in this test method 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 test method to consider significant digits used in analytical methods for engineering design.~~

~~1.3 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.~~

~~1.4 *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 health and safety practices and determine the applicability of regulatory limitations prior to use.*~~

~~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~~
~~D6026 Practice for Using Significant Digits in Geotechnical Data~~
~~D7299 Practice for Verifying Performance of a Vertical Inclinometer Probe~~

[1] This ~~test method~~ 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. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms, see Terminology D653.

3.1.2 Definitions of terms specific to this test method are included in Section 5.

4. Significance and Use

4.1 An inclinometer is a device for measuring deformation normal to the axis of a pipe by passing a probe along the pipe and measuring the inclination of the probe with respect to the line of gravity. Measurements are converted to distances using trigonometric functions. Distances are summed to find the position of the pipe. Successive measurements give differences in position of the pipe and indicate deformation normal to the axis of the pipe. In most cases the pipe is installed in a near-vertical hole. Measurements indicate subsurface horizontal deformation. In some cases the pipe 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 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—Notwithstanding the statements on precision and bias contained in this test method, the precision of this test method 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 these test methods 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 The probe type inclinometer uses sensors inside a probe to indicate the orientation of the probe relative to the pull of gravity. The complete system consists of:

5.1.1 A permanently installed pipe, called casing, with test method grooves. The casing is made of plastic, aluminum alloy, or fiberglass.

5.1.2 *The Probe*—Most probes use force balance accelerometers which give a voltage output that is proportional to inclination of the probe. Biaxial probes contain two sensors oriented 90° apart to permit readings in orthogonal directions at the same time.

5.1.3 A portable readout unit with power supply for the sensors and display to indicate probe inclination. The readout unit may have internal memory to record data.

5.1.4 An electrical cable connecting the probe and readout unit with distance markings. Fig. 1 shows a typical set of components.

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. Note that a special probe may be required for non-vertical boreholes.

6.1.2 Assemble all components required for the casing, including casing, joints, connectors, 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 the casing grooves free of obstructions. When assembling couplings, use procedures to prevent spiraling of the casing

FIG. 1 Typical Components of Method A Inclinometer System

~~grooves. 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 range of the readout equipment. Extend the borehole at least 5 m (16 ft) beyond the zone of expected movement. It may be necessary to use casing, hollow-stem augers, 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 align one set of groves with this reference. This orientation is commonly referred to as the A direction. It should align with the direction of greatest anticipated movement (see Note 2). Add clean water to the casing if necessary to help overcome 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. Care should be exercised 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.~~

~~NOTE 2—This recommendation has legacy to the past where the sensor in the B axis was not as precise as the sensor aligned with the main axis. For probes produced in the past two decades, both sensors give good quality readings if the carriage wheels are in good condition. If the A 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 filling material. 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. Options include cement grout, sand (see Note 3), and pea gravel. 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 large 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 off 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.~~

~~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. Sand placed by tremie often results in open voids as the sand bridges between the casing and borehole walls. In addition, the sand may settle resulting in drag on the casing that may deform or damage the casing.~~

~~6.2 *Installation on The Ground Surface of Horizontal Casing:*~~

~~NOTE 4—A practical limit for installing horizontal casing is about 100 m. Beyond 100 m cable friction makes it difficult to pull the inclinometer probe through the casing. Special TFE-fluorocarbon inserts on the cable alleviate the problem to some degree.~~

6.2.1 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. Note that a special probe is required for horizontal casing. If one end of the casing is to be buried then the end cap contains a pulley to carry a wire that is used to pull the probe into the inclinometer casing. Special care must be taken to insure that the pulley is correctly assembled, free to turn and has the wire in place. Take precautions at all times during installation to keep the wire clean.

6.2.2 Create a near-level surface over the length where the casing is to be installed. Cover with a bed of at least 50-mm (2-in.) deep and 300-mm (12-in.) wide of clean sand, pea gravel or a lean grout.

6.2.3 Assemble all components required for the casing, including casing joints, connectors, 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 borehole. Exercise care to keep the casing grooves free of obstructions. When assembling couplings, use procedures to prevent spiraling of the casing grooves. Twist adjacent couplings in alternate directions before fixing to minimize spiraling. Examine the casing during assembly to confirm that spiraling is not occurring.

6.2.4 Place the casing onto the bed and adjust its position until it is within the tolerances required by the readout device. Establish the reference orientation for the casing and align one set of groves with this reference. This orientation is commonly referred to as the A direction. It aligns with the direction of greatest anticipated movement. Visually check for and remove any spiraling. Determine that the pull cable is in position and moves freely through the inclinometer casing.

6.2.5 Use hand tools or light construction equipment to place clean sand, pea gravel or lean grout evenly, at least 150-mm (6-in.) wide, on both sides of the casing. Cover the inclinometer casing with at least 50 mm (2 in.) of clean sand, pea gravel or lean grout. Place fill over casing in 150-mm (6-in.) lifts. Fill for the first lift should not contain any particles larger than 25 mm (1 in.). If compaction is required, use hand compactors for the first two lifts.

6.3 *Equipment Verification:*

6.3.1 Inclinometers are factory calibrated and supplied with a calibration factor, K, that is specific to the probe and the readout unit. Some manufacturers provide standardized readout units that can be used with multiple probes. However it should be noted that electronic variations in the readout equipment may cause conditions where different probes will give different readings. It is recommended that a verification check be performed any time a probe and readout unit combination is changed. For applications involving small but important changes over several years, recalibrate the instrument to the precision of the device at least once per year.

6.3.2 Perform a verification check before each set of inclinometer readings. in accordance with manufactur's recommendations or Practice D7299. Verification checks on vertical casing can indicate malfunctioning equipment but cannot provide an accurate calibration.

6.3.3 Perform a verification check by assembling the probe, cable and readout equipment and allowing it to equilibrate to ambient temperature for at least 10 min. The probe is positioned in the test stand or casing and readings taken. The probe is removed, rotated 90°, reinserted and read. This operation is repeated to obtain readings at 180 and 270°. Consult the manufacturer's instructions to determine if your readings are within the recommended ranges for the equipment. Any obvious malfunctioning of the equipment, such as drift in the reading with time, inability to reproduce a reading, should be corrected before using the instrument.

6.4 *Measurement Method:*

6.4.1 The probe is inserted into the casing oriented in the reference direction (that is, the 'A' direction) to the bottom of a vertical or inclined casing or to the far end of a horizontal casing. A measurement traverse is made by holding the probe stationary at each depth interval and recording depth and reading. Recommended practice is to use a reading interval equal to the wheel spacing on the probe. After each reading, raise the probe by the reading interval and take the next set of readings. Repeat the procedure to the top of the casing to complete the traverse. Remove the probe from the casing, rotate it 180°, and lower it to the bottom of the casing. Start readings for this traverse from exactly the same depth as the first traverse and make each reading at exactly the same depth as the first traverse. For biaxial probes, two traverses complete the set of readings. For uniaxial probes, two more traverses must be made for the B direction the same way as for the A direction.

6.4.2 Check the set of readings by summing the readings for the A and A' directions at each depth and the readings for the B and B' direction. These sums are called check-sums and should equal a constant value that is a characteristic of the probe. Refer to the manufacturer's literature for information on allowable variation in the check-sum. A single deviation in a check-sum probably indicates a bad reading. Erratic behavior of the check-sums generally indicates a poor electrical connection or a malfunctioning probe or readout.

6.5 *Initial Readings:*

6.5.1 Make initial observations after allowing sufficient time for the grout around the casing to set or for the backfill to stabilize. Since computation of all displacements is based on the initial readings, it is important to have a valid set. Verify the initial set of readings with at least two sets of readings, taken on the same day. Check these readings for stability of the check-sums and for displacement within the accuracy of the equipment. Repeat observations until satisfactory agreement is obtained. From all initial readings taken, one set should be selected for use as the reference set for all subsequent readings. Take readings on any spiral with a spiral sensor if corrections for twist are desired, or if there is potential for twist in the casing of sufficient magnitude to affect the computed displacements of the casing.

6.5.2 The top position (x, y, and z) of the inclinometer casing must be located by survey at the same time initial readings are made by survey to the accuracy of the inclinometer readings. Later changes in the top position of the casing can be used to check the inclinometer readings or to correct for movement of the bottom of the inclinometer casing.

6.6 *Observations:*

6.6.1 The frequency of observations depends upon the rate of movement and the allowable movements. Some installations may require several readings per day. Others may require a few readings per year. In uncertain conditions, inclinometer casings should be read frequently just after installation and the results used to adjust the interval of subsequent observations. Observations should coincide with the observations of other instrumentation, such as extensometers, piezometers, settlement devices, movement surveys, and the like.

6.6.2 The same procedure outlined for taking initial readings is used to take observations. It is essential that readings be taken at the same depths as used for the initial readings. It is generally desirable to use the same equipment, people and procedures for the same inclinometers to reduce systematic error. The check-sum should be examined after completing the readings for each inclinometer and repeat readings taken if any data are in question. Other data to be recorded with the initial readings include: ground surface elevation, date of installation, date of initial reading and elevation of bottom of casing.

6.7 *Maintenance:*

6.7.1 Check the wheel fixtures, bearings and springs frequently. Tighten and replace as necessary. Clean and lubricate guide wheels as recommended by manufacturer. For horizontal inclinometers using a pull wire, use a cloth to keep the pull wire clean at all times. Check the water seals on the electrical connections and replace as they become worn. Keep all electrical connections clean and dry. On probes using batteries, check the connections and charge as necessary. Consult the manufacturer's literature for instructions for maintenance operations and precautions, especially for removal of the battery if the device is not to be used for the next month. It is important to minimize dirt entering the casing. It may accumulate in the casing grooves. It may become necessary to flush the inclinometer casing with cleaning water and use a large bottle brush to clean the grooves.

7. Calculation

7.1 *General*—The numerical readings (R_1, R_2, R_3, R_4) are proportional to the deflection of the casing from the instrument's reference direction (that is, vertical or horizontal). The casing deflection, *d*, equals:

$$d = \frac{L}{K} * R \quad (1)$$

where: *L* is the reading interval and *K* is the instrument constant. *K* is supplied by the manufacturer and determined by factory calibration.

NOTE 5—Often the gage length of the sensor's wheels is taken as the reading interval.

7.1.1 Average the readings in opposite directions (180° apart) to compute the incremental casing deflection at each depth:

$$d_{1-3} = \frac{L}{K}\frac{(R_1 - R_3)}{2} \qquad d_{2-4} = \frac{L}{K}\frac{(R_2 - R_4)}{2} \tag{2}$$

d_{1-3} is the computed incremental casing deflection at one depth in direction 1–3, d_{2-4} is the computed incremental casing deflection at one depth in direction 2–4.

7.1.2 Compute the position of the casing at any depth, D_n, as the sum of the incremental casing deflections from the end of the casing to that depth, or:

$$D_{n_{1-1}} = \sum_{i=1}^{i=n} d_{t_{1-1}} \qquad D_{n_{2-4}} = \sum_{i=1}^{i=n} d_{t_{2-4}} \tag{3}$$

Eq 3 assumes that the reference point is at the bottom of the casing.

7.1.3 Use Eq 3 with the initial set of readings to find the initial position of the inclinometer casing. Two or more sets of initial readings taken on the same day can be averaged to obtain a more precise set of initial readings, unless significant movements are occurring over the time interval required to take the two sets of readings. If significant movements occur during the time that initial readings are taken, the sequential data sets will show a consistent trend indicating movement and averaging of the initial data sets is not required.

7.1.4 Use Eq 3 with any subsequent set of readings to find the new position of the inclinometer casing at the time of the readings.

7.1.5 Use Eq 4 to compute the displacement of the casing, ΔD_n, between two times as the difference in position of the casing for those two times. It is usual practice for the readings at $t=t_0$ to be the initial set of readings.

$$\Delta D_{n_{1-3}} = \sum_{i=1}^{i=n} d_{t_{1-3\,@\,t-t}} - \sum_{i=1}^{i=n} d_{t_{1-3\,@\,t-t_0}} \tag{4}$$

$$\Delta D_{n_{2-4}} = \sum_{i=1}^{i=n} d_{t_{2-4\,@\,t-t}} - \sum_{i=1}^{i=n} d_{t_{2-4\,@\,t-t_0}}$$

7.1.6 If L and K are constant and the same for all sets of readings, Eq 4 can be simplified to Eq 5.

$$\Delta D_{n_{1-3}} = \frac{L}{2K}*\left[\sum_{i=1}^{i=n}(R_{1t} - R_{3t})_{@\,t=t} - \sum_{i=1}^{i=n}(R_{1t} - R_{3t})_{@\,t-t_0}\right] \tag{5}$$

$$\Delta D_{n_{2-4}} = \frac{L}{2K}*\left[\sum_{i=1}^{i=n}(R_{2t} - R_{4t})_{@\,t-t} - \sum_{i=1}^{i=n}(R_{2t} - R_{4t})_{@\,t-t_0}\right]$$

7.2 *Corrections for Twist (Spiraling)*—Computations of displacement must be corrected for twist where the inclinometer casing grooves do not align with the desired directions of movement. These corrections require readings of twist at each depth that inclinometer readings are taken. Usually, a separate probe is required to read twist. Readings are normally taken at the same time as initial readings.

Assuming twist is measured at each depth of deflection readings as the angle, θ_i, the readings in the A-A' and B-B' directions are:

$$\Delta D_{i_R} = \sqrt{(\Delta D_{i_{1-3}})^2 + (\Delta D_{i_{2-4}})^2} \tag{6}$$

$$\varphi_i = \tan^{-1}\left(\frac{\Delta D_{i_{2-4}}}{\Delta D_{i_{1-3}}}\right)$$

$$\Delta D_{i_{A-A'}} = \Delta D_{i_R}\cot(\varphi_i + \theta_i)$$

$$\Delta D_{i_{B-B'}} = \Delta D_{i_R}\tan(\varphi_i + \theta_i)$$

where: θ_i is positive in clockwise direction.

7.3 *Adjustments for Surveyed Displacement*—In some cases the inclinometer casing cannot be practically installed into a fixed

~~stratum. If the absolute displacements are required, then the position of one point on the casing must be determined by survey each time inclinometer readings are taken. This section assumes that the position of the top of the casing is determined by survey. From the survey determine the displacement in direction A-A' ($\Delta D_{s_{A-A'}}$) and B-B' ($\Delta D_{s_{B-B'}}$) since the initial readings. These values are added to the displacements determined in Eq 6 to find the total displacements of the inclinometer casing.~~

~~8. Report~~

~~8.1 Report the results as a tabulation of displacement versus depth (see Fig. 2) and a plot of displacement versus depth (see Fig. 3) for both directions. If movement exists, a report of displacement at specific depth versus time is recommended (see Fig. 4 and Fig. 5). Even in situations where movement in the B-B' direction may be small or considered to be of no interest, these data are useful to indicate a malfunctioning instrument or defective casing or the occurrence of unexpected movements. Include the inclinometer number, project name, orientation of reading directions, date of reading and date of initial reading on the report.~~

~~9. Precision and Bias~~

~~9.1 *Precision*—Due to the nature of the soil or rock materials tested by this test method it is either not feasible or too costly at~~

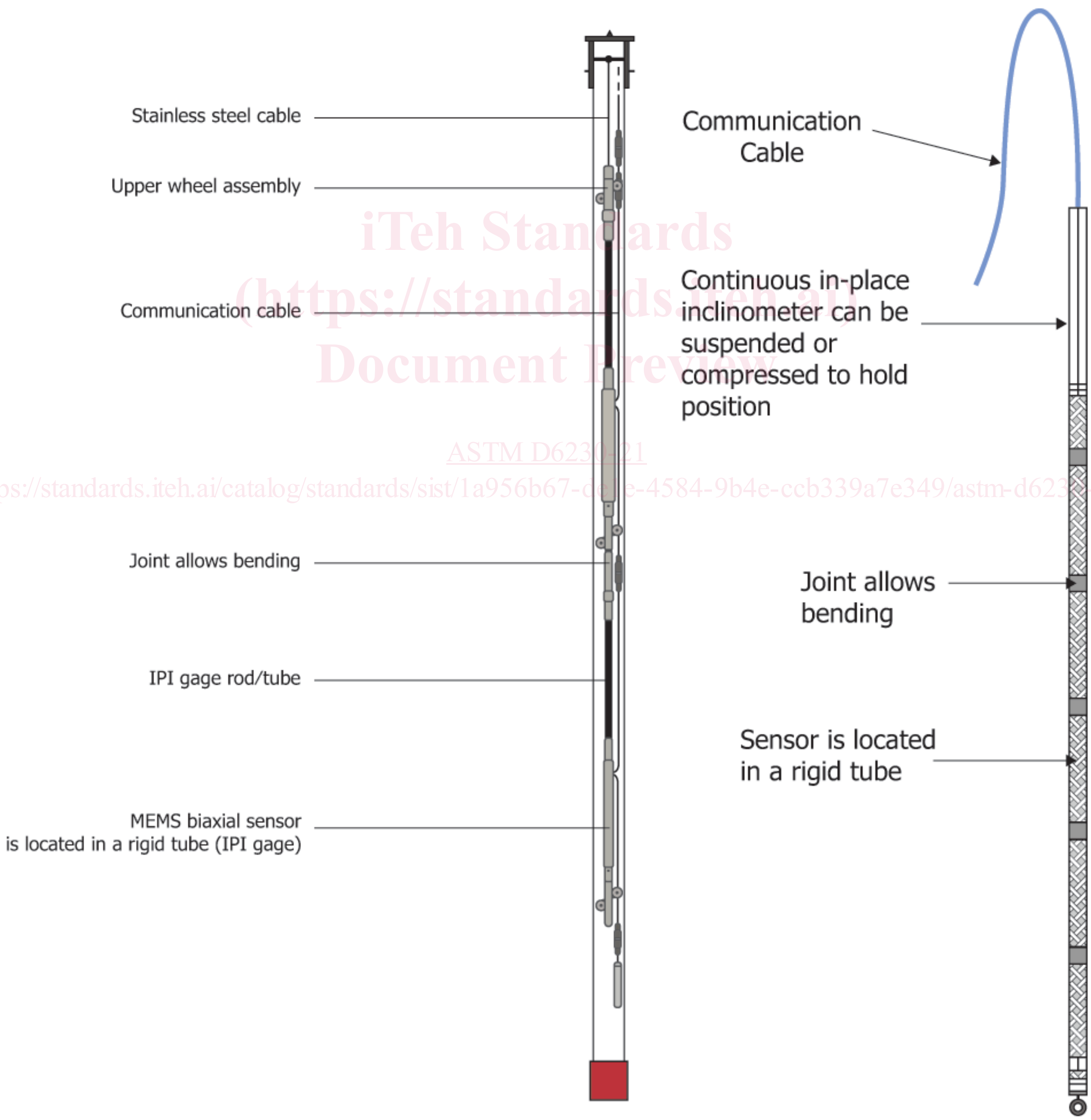

FIG. 2 ~~Inclinometer Data and Calculations~~Typical Components of Method B Inclinometer Systems