Designation: D8232 – 18

Standard Test Procedures for Measuring the Inclination of Deep Foundations[1]

This standard is issued under the fixed designation D8232; 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 The test procedures described in this standard measure the inclination of deep foundation elements, including elements in the excavation stage. These Procedures apply to all deep foundations, referred to herein as "piles," regardless of their method of installation.

1.2 This standard provides minimum requirements for measuring the inclination of deep foundations. Plans, specifications, and/or provisions prepared by a qualified engineer may provide additional requirements and procedures as needed to satisfy the objectives of a particular test program.

1.3 This standard provides the following test Procedures:

Procedure A (Inclinometer Testing)—for testing both open boreholes and constructed piles	9.1
Procedure B (Pendulum Testing)—for testing open boreholes	9.2

1.4 Apparati and procedures herein designated "optional" may produce different test results and may be used only when approved by a qualified engineer (hereafter "the Engineer"). The word "shall" indicates a mandatory provision, and the word "should" indicates a recommended or advisory provision. Imperative sentences indicate mandatory provisions.

1.5 The Engineer shall design and approve the test configuration and test procedures.

1.6 The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard. This standard also includes illustrations and appendices intended only for explanatory or advisory use.

1.7 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this standard.

1.8 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.9 The procedures used to specify how data are collected, recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally 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; and 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 analysis methods for engineering design.

1.10 *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.*

1.11 *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:*

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

D6760 Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing

3. Terminology

3.1 *Definitions:*

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *battered pile or raked pile, n*—a pile purposely constructed at an inclination.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.11 on Deep Foundations.

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3.2.2 *depth interval, n*—the spacing between measurements along the pile axis.

3.2.3 *deviation, n*—the distance and azimuth, measured on the horizontal plane, from the planned pile axis to the as-built axis at any given depth.

3.2.4 *inclination, n*—the angle, in either degrees or percent, between the vertical and the as-built excavation axis at any given depth, either measured directly or calculated.

3.2.5 *pile axis, n*—the line connecting the centroids of all horizontal cross sections of the pile.

3.2.6 *reference depth, n*—the vertical location that is determined to be (by survey) or assumed to be on location with the planned excavation axis. Typically the ground surface.

4. Summary of Test Method

4.1 *Procedure A*—In this Procedure, a probe equipped with a biaxial inclinometer (tiltmeter) is attached to a suitable centralizer. In open boreholes, the drilling bucket may serve as such a centralizer. The probe is gradually lowered to the bottom of the hole, and the inclination is measured at predetermined depth intervals. A portable digital device, connected to the probe via data cable or wireless connection, calculates the deviation of the pile axis by integrating the inclination over depth and then plots the results. An optional gyrocompass compensates for any rotation of the probe. When inclination is measured in access ducts, the probe shall be connected to a suitable centralizer that will assure the centricity of the probe while minimizing its rotation. The centralizer may be omitted if the access ducts are equipped with suitable means (for example, grooves) to keep the probe centered and prevent its rotation.

NOTE 1—When the drilling bucket is used as centralizer, the accuracy of the measurement depends on how closely it fits the open hole.

4.2 *Procedure B*—In this procedure a probe, suspended from a suitable conductor cable or attached to the drill rig Kelly bar, is first placed over the borehole axis at the reference depth. The probe, which is equipped with ultrasonic, laser, mechanical or other distance meters and a bi-axial inclinometer is then lowered down to the bottom of the hole. At predetermined depths or time intervals, the distances from the instrument to the sidewall are recorded in at least two perpendicular directions (for a minimum of four data points). The probe is connected to a portable digital device that plots the pile profile and calculates the deviation and/or the inclination of the pile.

5. Significance and Use

5.1 Piling specifications often prescribe the maximum allowable pile deviation from the planned inclination. Such a deviation can be the result of variable soil profile, a drilling rig that is inadequate for the job and/or faulty workmanship. There is evidence to show that loading a pile that exceeds the specified inclination can introduce excessive bending moments and shear forces if the pile was designed strictly for axial loads. In excavation support consisting of a contiguous piled wall or diaphragm wall, an excessive deviation may eventually decrease the available basement space or create undesired gaps in adjacent piles and permit seepage or ground loss. Efficient control of pile inclination is therefore of utmost importance.

NOTE 2—Measuring the excavation profile to infer the pile inclination has the additional benefit of enabling the contractor to estimate the actual volume of concrete that will be needed. In addition, knowledge of the finished pile profile may assist in the analysis of pile integrity tests and load tests.

6. Hazards

6.1 The test is carried out over open deep excavations that are often full with slurry and under mechanical equipment such as drilling rigs and/or cranes. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7. Apparatus

7.1 *Signal transmission cable (optional)*—the cable shall be sufficiently robust to carry the probe and abrasion resistant to allow repeated field use and maintain flexibility in the range of expected temperatures. The cable itself, as well as all connectors, shall be waterproof to at least 150 % of the maximum testing depth. Alternatively, a wireless connection between the probe and the data recording and display unit may be established.

7.2 *Depth measuring device*—The cable shall be marked at regular intervals to assess depth of probe. Alternatively, a pulley over which the probe is deployed may be instrumented with a depth-encoding device to monitor the depth to the location of the probe throughout the test. The design of the pulley and cable reel shall be such that cable slippage shall not occur. Depth data may also be obtained from a rig-mounted depth meter or from a depth-sensing device incorporated in the probe.

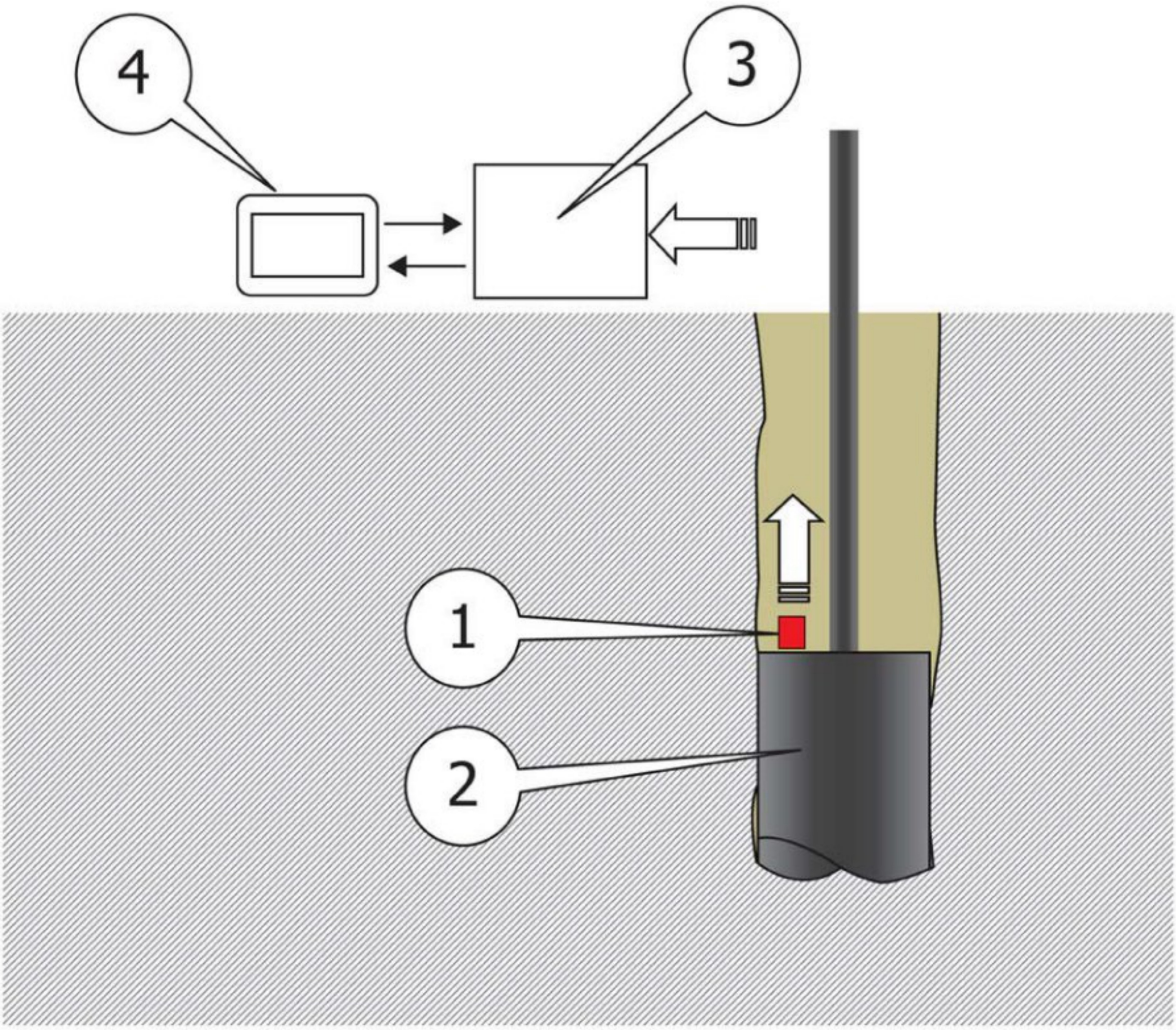
7.3 *Apparatus for recording, processing and displaying data*—The signals from the probe and the depth-measuring device shall be transmitted to a control box for handling the data and transmitting the results to a digital device for viewing and storing the results. Alternately, the data may be transmitted offsite from the probe to any location where the signals can be viewed and recorded remotely. The digital device may either be embedded in the control box or separate and may be equipped with a portable printer to produce hard copy of the results on site.

7.4 *Procedure A:*

7.4.1 *Probe*—The probe shall be designed to allow rigid attachment and quick detachment from the top of the centralizer. The probe housing shall be waterproof to at least 150 % of the maximum testing depth. A direction-indicating arrow shall be engraved on the probe to facilitate orientation. The probe shall be equipped with the following:

7.4.1.1 A bi-axial digital inclinometer, thermally-compensated and able to measure inclinations in two mutually-perpendicular directions.

7.4.1.2 A digital gyrocompass (optional), thermally-compensated and able to measure angles of rotation. A typical schematic arrangement of the testing apparatus is illustrated in Fig. 1.



(1 - Probe, 2 - Centralizer, 3 - Control Box, 4 - Digital Device)

FIG. 1 Testing Appratus—Procedure A—Schematic Arrangement

7.5 *Procedure B:*

7.5.1 *Probe*—If suspended by cable, the probe shall be sufficiently heavy to hang vertically even in thick drilling mud. The probe housing shall be waterproof to at least 150 % of the maximum testing depth. The probe shall be equipped with the following:

7.5.1.1 *A rotating sensor,* able to measure the distance to the sidewall at discrete angular steps. Alternatively, a minimum of four fixed ultrasonic or laser transceivers, able to measure the distance to the sidewall and oriented at equal angular spacings, may be used.

7.5.1.2 If probe is suspended on a single cable, a suitable means (gyrocompass, digital magnetic compass, set of orthogonal accelerometers or similar, henceforth referred to as "gyrocompass" in this document) to measure probe rotation around the vertical ("Z") axis.

7.5.1.3 Inclination sensors for verifying alignment and stability of the probe in the two horizontal axes.

7.5.2 *Winch or crane,* with sufficient capacity to carry the probe and cable from the center of the open hole, or an adapter for rigid attachment to the tip of the Kelly bar.

7.5.3 If suspended by cable, optionally a set of additional guide cables, sufficiently weighted at the bottom to maintain tension, may be deployed. The probe shall then include brackets to enable it to slide up and down the guide cables and prevent twisting and large-amplitude swinging of the probe. A typical schematic arrangement of the testing apparatus is illustrated in Fig. 2.

8. Calibration and Standardization

8.1 The inclinometer component of the probe shall be calibrated to an accuracy of 0.1 % throughout its full operational scale and temperature range, according to the manufacturer's instructions.

8.2 The depth-measuring device shall be field-calibrated at least once every six months to an accuracy of 2 % of the

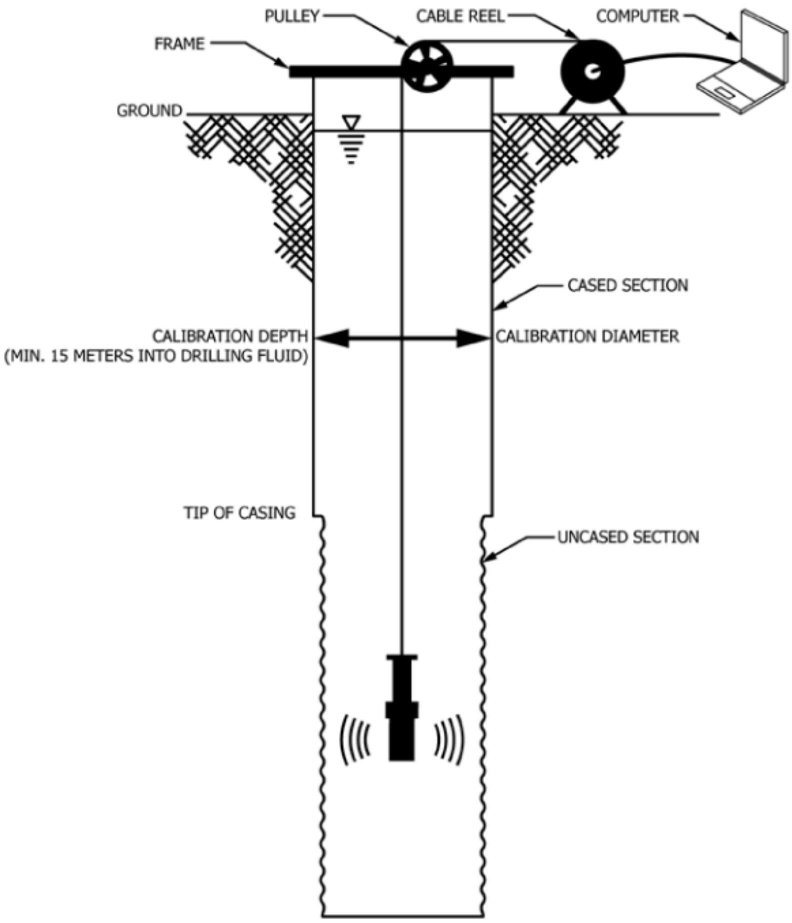


FIG. 2 Testing Apparatus—Procedure B

maximum testing depth or 0.5m, whichever is larger, according to the manufacturer's instructions.

8.3 The gyrocompass shall be field-calibrated daily to an accuracy of 1 degree/minute.

8.4 Ultrasonic wave speed in drilling fluid, as used in Procedure B, shall be determined prior to measuring each pile excavation. This shall be done in a portion of the excavation of known diameter (typically the casing, near the surface). Alternatively, wave speed can be independently measured by separate probe (either embedded in the probe or using a separate device).

NOTE 3—When Procedure B is used only for measuring inclination, wave speed calibration may be skipped since the absolute wave speed value has no effect on the location of the axis.

9. Procedure

9.1 *Procedure A:*

9.1.1 Place the centralizer at the ground surface.

9.1.2 Firmly attach the probe to the centralizer so the axes of the centralizer and the probe are parallel.

9.1.3 When the drilling bucket is used as a centralizer, attach (preferably by spot-welding) the base plate to a suitable horizontal surface on top of the drilling bucket, then attach the probe to the base plate. Make sure that the axis of the probe is parallel to the axis of the bucket.

9.1.4 Securely hang the optional depth measuring device from a suitable point on the drilling rig above the hole and pass the optional signal transmission cable around the wheel.

9.1.5 Turn the probe so that the arrow points to the project North, wait for signal stabilization and take a biaxial inclinometer reading. If the excavation has an enlarged upper section (casing), perform the above stage at the reference depth.

9.1.6 Without turning the centralizer, bring it to ground level and zero the depth measuring device.

9.1.7 Without turning the centralizer, lower it one depth interval, wait for the signal to stabilize and take depth, biaxial inclination and gyrocompass readings. Depth interval shall not exceed 20 % of the excavation depth.

9.1.8 Repeat the above procedure, one depth interval at a time, until the centralizer reaches the bottom.

9.1.9 Repeat the above procedure while raising the probe, one depth interval at a time, until the probe reaches the surface.

9.1.10 At the surface rotate the probe back to its original bearing (project North) and take a final depth and bearing reading.

9.1.11 Before disassembling the equipment, process the data and inspect the results, in case the test must be repeated for any reason.

9.1.12 Throughout the procedure of lowering and raising the probe keep the optional signal transmission cable under sufficient tension to assure depth reading accuracy.

9.2 *Procedure B:*

9.2.1 Completely assemble probe components.

9.2.2 If using a cable-suspended probe, position data cable wheel assembly approximately over the center of the excavation. Rigidly attach the frame to casing or ensure it does not move during the test. If using a Kelly bar mounted probe, ensure the probe is centered above the axis of the borehole and the Kelly bar is vertical.

9.2.3 When using in slurry, lower probe head until it is at least one diameter below top of drilling fluid, to eliminate reflected signals from the fluid surface.

9.2.4 Adjust any relevant sonar/laser parameters (such as signal frequency, gain, or attenuation) in data collection program window until a distinct return signal is obtained. Once a set of parameters is chosen, they shall not be changed for the duration of the profiling.

9.2.5 If the probe utilizes a single rotating transceiver, position the probe at a prescribed depth, then (if cable-suspended) ensure the probe has stabilized (stopped swinging and twisting). Once the probe is stable, record a complete 360° sweep of the excavation wall at the given depth.

9.2.6 If the probe utilizes a single rotating transceiver, repeat the previous step at each depth interval, at any intermediate depths when a change in excavation shape is observed or presumed (due to casing tip, drilling log indicating a cave-in, etc.) or any other depths of specific interest.

9.2.7 Alternatively, if using equipment with an array of fixed probes, the probe may be lowered to the bottom of the borehole then pulled up back up with steady speed, while each probe continually samples the distance to the sidewall on the downward and/or upward traverse.

9.2.8 Before disassembling the equipment, process the data and inspect the results, in case the test must be repeated for any reason.

10. Calculation or Interpretation of Results

10.1 *Procedure A:*

10.1.1 Using the calibration factors, convert all measurements to inclination values in two mutually-perpendicular direction.

10.1.2 Using the azimuth values obtained from the gyrocompass convert the inclination values thus obtained to inclinations in the North-South and East-West directions, respectively. One possible calculation method is given by Amir and Amir (2012).

10.1.3 Starting at the surface, the change of deviations in both directions for each depth interval is obtained by multiplying the respective depth interval and the mean inclination.

10.1.4 Calculate resultant deviation for each stop logged.

10.1.5 Calculate the closure error at the reference depth.

10.2 *Procedure B:*

10.2.1 As needed, all data points collected are corrected for twist of the probe using the gyrocompass data.

10.2.2 All data points are scaled using the calibrated wave speed factor obtained using the procedures in 8.4.

10.2.3 For a biaxial probe, the pile axis is located at the centroid of the four data points measured at each depth, respectively. Alternatively, 10.2.4 can be used to fit a circle to the data (since a minimum of three data points is required).

10.2.4 When a bored pile excavation is profiled, a circle is fitted to the data points recorded at each depth to approximate the cross-sectional profile of the pile. One possible method of curve-fitting using a least-squares technique is outlined in Gander et. al. 1994.

10.2.5 The center deviation for each depth interval relative to the reference is calculated by comparing the location of circle center points.

10.2.6 The value and the azimuth of the maximum resultant deviation is calculated.

11. Report: Records

11.1 Record as a minimum the following test information as required by the Engineer and as appropriate to the test apparatus and the test procedure.

11.2 *General:*

11.2.1 Project identification and location

11.2.2 Identification of testing firm/agency and testing person(s)

11.2.3 Identification and location of test pile

11.2.4 Pile construction method

11.2.5 Pile diameter and length

11.2.6 In raked piles: planned inclination angle and azimuth

11.2.7 Elevations of the pile top, pile bottom, and ground surface referenced to a datum

11.2.8 Material and diameter of access duct or casing (if applicable)

11.2.9 Allowable inclination from vertical

11.2.10 Project North: Magnetic, geodetic or site-specific

11.2.11 Description, calibration data and last date of calibration of all components of the apparatus for obtaining measurements and apparatus for conditioning, recording, and displaying data.

11.3 *Test results:*

11.3.1 Testing date

11.3.2 A numerical presentation of the deviation (amount and azimuth) versus depth for every station and the test closure error

11.3.3 Graphical representation of deviation versus depth (top and side view)

11.3.4 Optionally the excavation profile, when measured in a two- or three-dimensional representation

11.3.5 Temperature and weather conditions during test

11.3.6 Summary and description of the analysis procedure used including assumptions, limitations, and applied reduction factors, if appropriate.

11.3.7 Any changes, deletions, or additions to the requirements of this standard.

General information

Borehole:	1-S1
Diameter:	0.8
Depth:	42.2 m
Date:	3/1/2013

Test results summary

Max offset 0.37 m (0.88%) at 42.24 m towards 206 (SSW)

Test Error: 0.13 m

Test result graphs

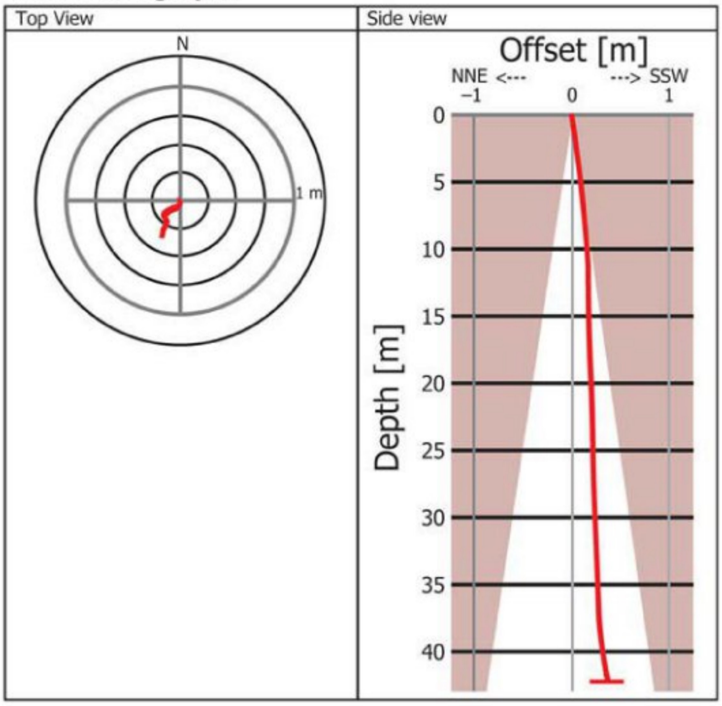


FIG. 3 Test Results—Procedure A

12. Precision and Bias

12.1 *Precision*—Test data on precision is not presented due to the nature of these test Procedures. It is either not feasible or too costly at this time to have ten or more agencies participate in an in situ testing program at a given site.

12.1.1 The Subcommittee D18.11 is seeking any data from the users of these test procedures that might be used to make a limited statement on precision.

12.2 *Bias*—There is no accepted reference value for this test procedure, therefore, bias cannot be determined.

13. Keywords

13.1 barrette; bored pile; crosshole testing; deviation; drilled shaft; gyro; inclination; inclinometer; integrity test; load bearing element; ultrasonic testing

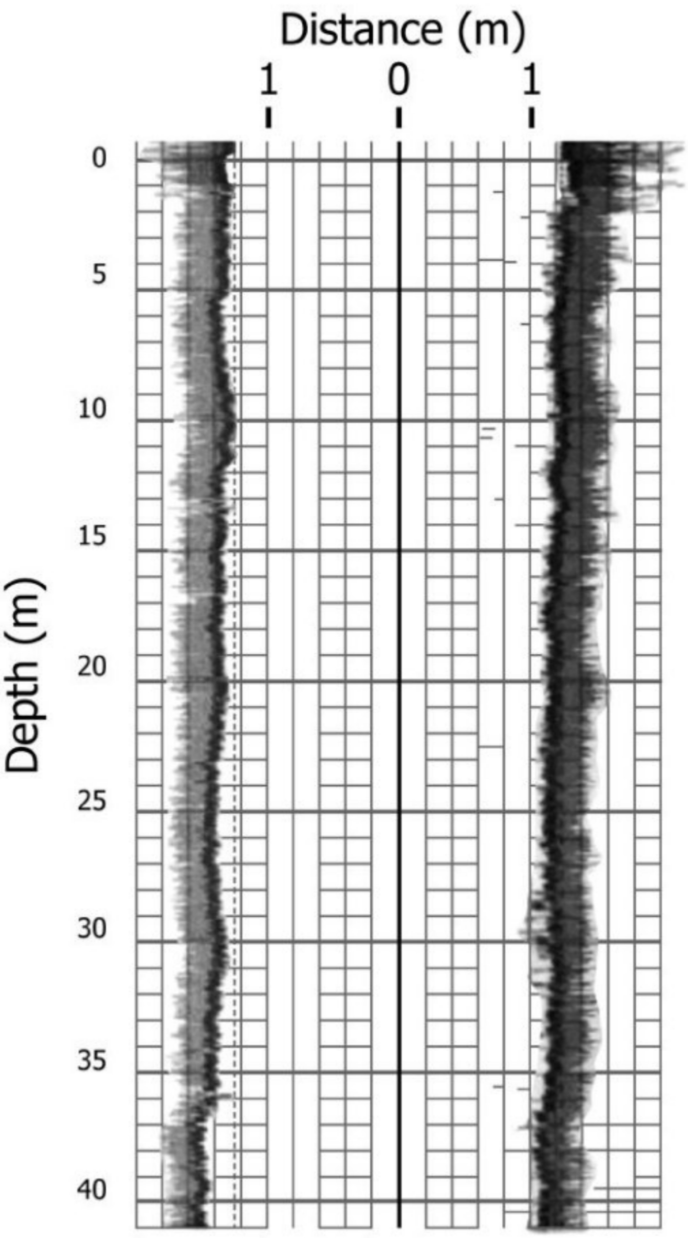


FIG. 4 Test Resultsin Two Dimensions—Procedure B

APPENDIX

(Nonmandatory Information)

X1. REFERENCES

(1) Amir, J.M. and Amir, E.I. (2012): Testing of Bored Pile Inclination, Proc. 9th Intl. Conf. Testing and Design Methods for Deep Foundations, Kanazawa

(2) Gander, W., Golub, G. H. & Strebel, R. (1994) "Least-squares Fitting of Circles and Ellipses," BIT Numerical Mathematics, Vol. 34, No. 4, pp. 558-578.