



Designation: D6027/D6027M – 24

Standard Practice for Calibration/Verification of Linear Displacement Transducers for Geotechnical Purposes¹

This standard is issued under the fixed designation D6027/D6027M; 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 practice outlines the procedure for calibration/verification of displacement transducers and their readout systems for geotechnical purposes. It covers any transducer used to measure displacement, which gives an electrical output that is linearly proportional to displacement. This includes linear variable displacement transducers (LVDTs), linear displacement transducers (LDTs) and linear strain transducers (LSTs).

1.2 This calibration/verification procedure is used to determine the relationship between output of the transducer and its readout system and change in length. This relationship is used to convert readings from the transducer readout system into engineering units.

1.3 This calibration/verification procedure also is used to determine the accuracy of the transducer and its readout system over the range of its use to compare with the manufacturer's specifications for the instrument and the suitability of the instrument for a specific application.

1.4 *Units*—The values stated in either SI units or inch-pound units given in brackets are to be regarded separately as the standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combination values from the two systems may result in non-conformance with standard.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice [D6026](#) unless superseded by this standard.

1.5.1 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 consider-

¹ This practice is under the jurisdiction of ASTM Committee [D18](#) on Soil and Rock and is the direct responsibility of Subcommittee [D18.95](#) on Information Retrieval and Data Automation.

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ation 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.

1.6 This practice offers a set of instructions for performing one or more specific operations. This standard cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice 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.

1.7 *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.*

1.8 *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](#)

[D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data](#)

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

E2309/E2309M Practices for Verification of Displacement Measuring Systems and Devices Used in Material Testing Machines³

3. Terminology

3.1 Definitions:

3.1.1 Definitions of common technical terms used in this practice refer to Terminology **D653**. For definitions of common metrology terms used in this standard, refer to the International Vocabulary of Metrology.⁴

3.1.2 *calibrated range, n*—distance over which the linear displacement sensor system is calibrated.

3.1.3 *calibration, n*—operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

3.1.4 *displacement measurement standard, n*—system consisting of micrometer or Precision Gauge Blocks combined with an appropriate device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation of the member under an applied displacement

3.1.5 *displacement transducer, n*—an electrical transducer which converts linear displacement to electrical output.

3.1.6 *metrological traceability, n*—property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

3.1.7 *power supply, n*—a voltage source with output equal to that required by the sensor.

3.1.8 *readout system, n*—electronic equipment that accepts output from the signal conditioner for the transducer and provides a visual display or digital record of the transducer output.

3.1.9 *signal conditioner, n*—electronic equipment that makes the output of the transducer compatible with the readout system. The signal conditioner may also filter the transducer output to remove noise.

3.1.10 *total linear range (TLR), n*—total distance that the core may move from the position of maximum voltage output to the position of minimum voltage output with a linear relationship between displacement and voltage.

3.1.11 *transducer, n*—device, used in measurement, that provides an output quantity having a specified relation to the input quantity.

3.1.12 *verification, n*—provision of objective evidence that a given item fulfils specified requirements.

³ These practices are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.01 on Calibration of Mechanical Testing Machines and Apparatus.

⁴ *International vocabulary of metrology—Basic and general concepts and associated terms (VIM)*, 3rd Edition. Joint Committee for Guides in Metrology, 2012. https://www.bipm.org/utis/common/documents/jcgm/JCGM_200_2012.pdf

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *core, n*—central rod that moves in and out of the transducer body.

3.2.2 *null position, n*—the core position within the sensor body at which the transducer voltage output is zero (some transducers may not have a null position).

3.2.3 *percent error of displacement, E_p, n*—the ratio of the displacement measurement error to the applied displacement as measured by the displacement measurement standard, expressed as a percent.

4. Summary of Practice

4.1 A displacement transducer is mounted in such manner to permit it to be subjected to a precise, known displacement.

4.2 Displacement is applied in steps over the full range of the transducer and readings taken from the readout device.

4.3 The slope of the best-fit straight line relating sensor readout data to displacement is determined by linear regression.

4.4 The percent error of the transducer readout system is calculated and compared with the requirements for the specific use of the sensor.

4.5 See **Appendix X1** for a flowchart of the calibration/verification process.

4.6 See **Appendix X2** for identifying and determination measurement uncertainty component during a displacement transducer system calibration/verification.

5. Significance and Use

5.1 The displacement transducer plays an important role in geotechnical applications to measure change in dimensions of specimens.

5.2 The displacement transducer must be calibrated/verified for use in the laboratory to ensure reliable conversions of the sensor's electrical output to engineering units.

5.3 The displacement transducer should be calibrated/verified before initial use, at least annually thereafter, after any change in the electronic configuration that employs the sensor, after any significant change in test conditions using the transducer that differ from conditions during the last calibration/verification, and after any physical action on the transducer that might affect its response.

5.4 Displacement transducer generally has a working range within which voltage output is linearly proportional to displacement of the transducer. This procedure is applicable to the linear range of the transducer. Recommended practice is to use the displacement transducer only within its linear working range.

NOTE 1—Verification as in Practices **E2309/E2309M** should not be confused with calibration

6. Apparatus

6.1 *Linear Displacement Transducer*, to be calibrated.

6.2 *Power Supply with Output*, equal to that required by the sensor.

NOTE 2—Some LVDTs use ac voltage while others use dc. The LVDTs and displacement transducer may be damaged if connected to the incorrect power supply.

6.3 *Signal Conditioning, Readout Equipment, and Related Cables and Fittings.*

6.4 *Test Method A—Precision Gauge Block Calibration/Verification:*

6.4.1 *Precision Gauge Blocks*, a set of precision reference blocks traceable to the National Institute for Standards and Technology or another recognized standard agency. A gauge block set shall contain sizes necessary to perform satisfactorily the calibration procedures as outlined in Section 9 over the total linear range of the transducer (otherwise the test cannot be performed).

6.4.2 *Comparator Stand*, consisting of a base of warp-free stability and ground to a guaranteed flatness, a support column, and an adjustable arm onto which the sensor mounting block can be securely attached. Alternatively, mount the sensor in the configuration will be used in such a way that gauge blocks can be inserted to displace the core for calibration/verification purposes. As shown in Fig. 1.

6.4.3 *Sensor Mounting Block*, a device used to attach the sensor to the comparator stand. Alternatively, mount the sensor to the test equipment in which the transducer is to be used. The mounting holder shall be antiferromagnetic.

6.5 *Test Method B—Micrometer Fixture Calibration/Verification:*

6.5.1 *Micrometer Fixture*, a precision instrument for linear measurement capable of obtaining readings over the total linear range of the displacement transducer. The spindle must be nonrotating. The micrometer fixture is to be calibrated annually by the manufacturer or other qualified personnel. As shown in Fig. 2.

7. Hazards

7.1 Safety Hazards:



FIG. 1 Comparator Stand Fixture



FIG. 2 Micrometer Fixture

7.1.1 This practice involves electrical equipment. Verify that all electrical wiring is connected properly and that the power supply and signal conditioner are grounded properly to prevent electrical shock to the operator. Take necessary precautions to avoid exposure to power signals.

7.2 Safety Precautions:

7.2.1 Examine the sensor body for burrs or sharp edges, or both. Remove any protrusions that might cause harm.

7.2.2 The transducer can be permanently damaged if incorrectly connected to the power supply or if connected to a power supply with the wrong excitation level.

7.2.3 Follow the manufacturer’s recommendations with regard to safety.

7.3 Technical Precautions:

7.3.1 The core and body of the displacement transducer are a matched set. For best performance, do not interchange cores with other displacement transducer bodies.

7.3.2 Replace the core and body if either shows any signs of dents, bending, or other defects that may affect performance of the device.

7.3.3 Store the body and core in a protective case when not in use.

7.3.4 Do not exceed the allowable input voltage of the sensor as specified by the manufacturer.

7.3.5 Do not connect a voltage source to the output leads of the sensor.

7.3.6 Do not over tighten the sensor within the mounting block.

7.3.7 The behavior of some transducers may be affected by metallic holders. If possible, the working holder should be used during calibration/verification.

8. Calibration/Verification and Standardization

8.1 Calibration of Linear Displacement Transducers for Geotechnical Purposes shall be performed in accordance with D6027/D6027M.

8.1.1 If using Test Method A, verify that the gauge blocks are of sufficient precision and bias and in a clean, unscratched condition.

8.1.2 If using Test Method B, verify that the micrometer fixture is in good working order and of sufficient precision and bias.

8.2 Verification of Linear Displacement Transducers for Geotechnical Purposes shall be performed in accordance with Practices E2309/E2309M.

9. Procedure

9.1 Perform this calibration/verification in an environment as close to that in which the sensor will be used as possible. The displacement transducer, calibration/verification gauge blocks, micrometer fixture, and comparator stand shall be in the environment in which they are to be calibrated/verified for a sufficient length of time or for at least 1 hour prior to calibration/verification to stabilize temperature effects.

9.2 Verify that the power supply is adjusted to supply the recommended voltage to the sensor.

9.3 With equipment turned off, connect all power supply, signal conditioning, and recording equipment exactly as it will be used in service. Allow all electronics to warm up for a sufficient length of time, or for at least 30 min before beginning any readings.

9.4 Record type and serial number of the sensor to be calibrated/verified. If it has no serial number, record the model number and other identifying markings.

9.5 Record the maximum allowable input voltage specified by the manufacturer and the input voltage used for this calibration/verification.

9.6 Record the total linear range of the sensor and the range over which the transducer will be calibrated.

9.7 Record the type and serial number of the reference standard used.

9.8 *Test Method A—Precision Gauge Block Calibration/Verification:*

9.8.1 Attach the sensor mounting block to the adjustable arm of the comparator stand as shown in Fig. 1 or mount into test equipment as it will be used in service.

9.8.2 Slide the displacement transducer core and core extension rod assembly into the displacement transducer body.

NOTE 3—Some displacement transducers require the core to be in place before powering the displacement transducer.

NOTE 4—Displacement transducer should be checked use for freedom of movement particularly if the core rod and body of the transducer are manufactured as a single unit with a spring loaded core as part of the calibration/verification procedure.

9.8.3 Place the sensor body into the sensor mounting block and tighten the appropriate screw on the mounting block. Do not over tighten the screw on the mounting block. This can damage the sensor body.

9.8.4 Place a gauge block (or series of blocks) that has a height equal to the total linear range of the sensor under the core.

9.8.5 Adjust the sensor body up or down on the comparator stand support column as necessary to obtain a reading on the readout equipment that is approximately equal to the reading for the transducer with the core pushed into the transducer body to the end of the linear operating range as indicated by the manufacturer's calibration data.

9.8.6 Secure the adjustable arm on the support column of the comparator stand in this position by tightening the screw of the adjustable arm.

9.8.7 Remove the gauge block (or series of blocks) from beneath the core rod and allow the core rod to rest on the comparator base. Note the transducer reading with the core now extended from the transducer body. Logically, it shall equal approximately the voltage reading for the transducer with the core pulled from the transducer body to the end of the linear operating range as indicated by the manufacturer's calibration data (for if it is not, something is wrong).

9.8.8 Record the value of sensor output as sensor reading for zero displacement.

9.8.9 Select appropriate gauge blocks to displace the core through its total linear range in steps. It is recommended that a minimum of five readings equally spaced throughout the sensor total linear range be used.

9.8.10 Raise the core rod and place the appropriate gauge block(s) on the comparator stand base beneath the core rod in a manner to raise incrementally the core step-by-step into the transducer body.

9.8.11 Record the gauge block height in Column 1 and the corresponding output of the sensor readout equipment in Column 2 as shown in Table 1.

9.8.12 Continue to add gauge blocks at the selected displacement increments and record readings in Table 1 until the core has been displaced through its total linear range.

9.8.13 Remove the gauge blocks in reverse order and record readings in Table 1 until the core again rests on the comparator base.

9.8.14 Repeat these steps for a minimum of two times to obtain data on repeatability.

9.8.15 Calculate the calibration factor, linearity, computed displacement, and maximum percent error for each reading and as described in Section 10.

9.9 *Test Method B—Micrometer Fixture Calibration/Verification:*

9.9.1 Secure the sensor body into the chuck of the micrometer fixture. Do not over tighten the chuck around the sensor body.

9.9.2 Slide the core into the body.

9.9.3 Attach the core to the spindle of the micrometer head carrier using an appropriate attachment assembly.

9.9.4 Rotate the micrometer head until it is near its starting position of travel.

9.9.5 Move the micrometer head carrier along the bed of the micrometer fixture until the output of the sensor is approximately the lowest value indicated by the manufacturer for the working range of the transducer. Tighten the micrometer head carrier to the bed of the micrometer fixture.

9.9.6 Record the sensor readout as Sensor Reading 1 for zero displacement.

9.9.7 Rotate the micrometer head to displace the core through a fraction of its total linear range. It is recommended that a minimum of five readings equally spaced throughout the sensor total linear range be used.



TABLE 1 Example Displacement Transducer Calibration and/or Verification

Transducer Serial Number: <u>AB 0778</u>			Date: <u>10/23/2023</u>					
Model Number: <u>TT 1439</u>			Calibrated by: <u>dt</u>					
Manufacturer: <u>LVDTs, Ltd</u>			Checked by: <u>mta</u>					
Total Linear Range: <u>25mm</u>								
Allowable Excitation: <u>≤ 12 volts</u>								
Power Supply: <u>XXX</u> internal <u> </u> external			Sensor Readout Device: <u>Displacement System</u>					
Power Supply Serial Number if external: <u> </u>			Units for readout: <u>mm</u>					
Voltage Output Setting for power Supply if external: <u> </u>			Temperature: <u>22°C</u>					
Units of Displacement: <u>mm</u>								
Calibration or Verification Reference: <u>XXX</u> Gauge blocks <u> </u> Micrometer Fixture								
Run 1			Run 2					
Displacement Measurement Standard Reading (mm)	Displacement System Reading (mm)	% Error of Displacement	Displacement Measurement Standard Reading (mm)	Displacement System Reading (mm)	% Error of Displacement	Mean	% Repeatability	The repeatability @ 10 mm and the four closest displacements
2.500	2.496	-0.160	2.500	2.508	0.320	2.5020	0.480	0.012
5.000	4.990	-0.200	5.000	5.012	0.240	5.0010	0.440	0.022
10.000	9.967	-0.330	10.000	10.009	0.090	9.9880	0.420	0.042
17.500	17.456	-0.251	17.500	17.494	-0.034	17.4750	0.217	0.038
25.000	24.959	-0.164	25.000	24.996	-0.016	24.9775	0.148	0.037
Slope of best fit Line = <u>0.9987</u>						Accept <u>XXX</u> Reject <u> </u>		
Allowable Error ± 1% (Fixed Error ± 0.075 mm [0.003 in.])								

9.9.8 Record the micrometer displacement in Column 1 and the corresponding output of the sensor readout equipment in Column 2 as shown in [Table 1](#).

9.9.9 Continue to rotate the micrometer head to the selected displacement increments and record readings on [Table 1](#) until the core has been displaced through its total linear range.

9.9.10 Rotate the micrometer head in reverse order and record readings in [Table 1](#) until the core again rests on the comparator base.

9.9.11 Repeat these steps for a minimum of two times to obtain repeatability data.

9.9.12 Calculate the calibration factor, linearity, computed displacement, and maximum, percent error for each reading and as described in [Section 10](#).

10. Calculation

10.1 The calibration factor is determined using linear regression techniques. With the following definitions for readings in one direction:

R_i = reading of displacement transducer at i displacement,

D_i = measured i displacement of displacement transducer, mm [in.],

n = number of readings, and

K = calibration factor of transducer and readout system.

$$K = \frac{n \times \sum R_i D_i - \sum R_i \times \sum D_i}{n \times \sum R_i^2 - \sum R_i \times \sum R_i} \quad (1)$$

It is recommended that the data together with the best-fit line from regression be plotted as shown in [Fig. 3](#) to determine that all measurements lie close to the best-fitted line.

10.2 Determine the transducer error for each displacement reading using the following expressions:

$$E_r = R_i - R_0 \quad (2)$$

where:

R_0 = Displacement Measurement Standard Reading

10.3 Determine the transducer percent error for each displacement reading using the following expressions:

$$\%E_r = \frac{R_i - R_0}{R_0} 100 \quad (3)$$

where:

E_r = Error

11. Interpretation of Results

11.1 Each transducer is supplied with a specified maximum error. Compare the measured maximum percent error from calibration with that given by the manufacturer. If the measured error exceeds that specified by the manufacturer, either the readout system is inadequate or the transducer is defective. The transducer shall not be used until the source of the discrepancy is identified and resolved. Some applications may permit use of a transducer with a measured error larger than given by the manufacturer.

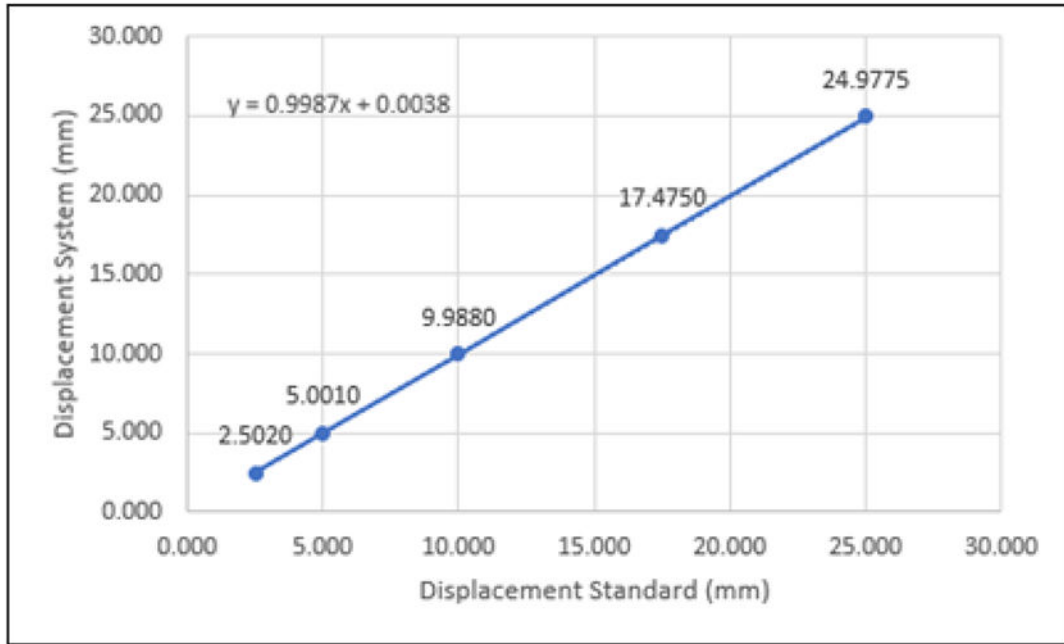


FIG. 3 Displacement Transducer Calibration

11.2 Each application for a displacement transducer has its own requirement for allowable error. Compare the percent error determined for each step during calibration with the maximum allowable percent error for the application. If the measured percent error exceeds the allowable percent error, this transducer cannot be used for the intended application.

11.3 Some geotechnical tests require displacements resolution to be read to 0.025 mm [0.001 in.]. A consolidation test requires displacements resolution to be read to 0.0025 mm [0.0001 in.]. The test method should specify the required accuracy, which is typically given as a percentage of its full scale or multiple of its resolution. If not specified by the test method, typical full accuracy for LVDTs is between 0.5 and 1.0 %, while for LDTs and LSTs, the typical full scale accuracy is between 0.1 and 0.25 %.

11.4 The steps described in 11.1 – 11.3 may be performed on each increasing and decreasing deformation step of the calibration, or they may be performed on the entire set of calibration data.

11.5 Several factors besides the transducer can cause the calibration to produce errors in excess of the maximum allowable error. These include:

- 11.5.1 Fluctuations in the output of the power supply,
- 11.5.2 Insufficient precision or accuracy of readout system,
- 11.5.3 Flexibility in the transducer mounting system,
- 11.5.4 Electrical noise in the transducer or readout system, and
- 11.5.5 Temperature changes during calibration.
- 11.5.6 If the transducer calibration gives too much error, a systematic procedure must be followed to isolate and correct the cause.

11.6 The calibration factor determined by this practice is specific to the electronic settings used during calibration. Altering any of these settings, such as changing the input power supply, will change the calibration factor and necessitate a new calibration.

11.7 The resulting calibration factor, K , is used to calculate displacement as:

$$\text{Change in Displacement} = (\text{change in Reading}) \cdot K \quad (4)$$

12. Report: Test Data Sheet(s)/Form(s)

12.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.5 and in Practice D6026.

12.2 Method of calibration/verification used.

12.3 Serial numbers and names of the manufacturers of all apparatus used in verifying the displacement system.

12.4 Serial number and name of the manufacturer of the displacement system if the system composed of separable components, the serial number and manufacturer of each component of the systems verified.

12.5 Displacement Transducer linear range.

12.6 Temperature during verification.

12.7 Complete record of the readings as shown in Table 1.

12.8 Calibration factor, if applicable.

12.9 Error in displacement for each measurement of displacement.

12.10 If the calibration/verification applies to bidirectional testing, it shall be so stated. Otherwise, the calibration/