Designation: ~~E4 – 15~~ E4 – 16

American Association State
Highway and Transportation Officials Standards
AASHTO No: T67

Standard Practices for Force Verification of Testing Machines[1]

This standard is issued under the fixed designation E4; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These practices cover procedures for the force verification, by means of standard calibration devices, of tension or compression, or both, static or quasi-static testing machines (which may, or may not, have force-indicating systems). These practices are not intended to be complete purchase specifications for testing machines. Testing machines may be verified by one of the three following methods or combination thereof:

1.1.1 Use of standard weights,

1.1.2 Use of equal-arm balances and standard weights, or

1.1.3 Use of elastic calibration devices.

NOTE 1—These practices do not cover the verification of all types of testing machines designed to measure forces, for example, the constant-rate-of-loading type which operates on the inclined-plane principle. This type of machine may be verified as directed in the applicable appendix of Specification D76/D76M.

1.2 The procedures of 1.1.1 – 1.1.3 apply to the verification of the force-indicating systems associated with the testing machine, such as a scale, dial, marked or unmarked recorder chart, digital display, etc. *In all cases the buyer/owner/user must designate the force-indicating system(s) to be verified and included in the report*.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values ~~given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered~~ stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3.1 ~~Since conversion factors are not required in this practice, either inch-pound units, SI units, or metric values can be used as the standard.~~Other customary force units may be used with this standard such as the kilogram-force (kgf) which is often used with hardness testing machines

1.4 Forces indicated on displays/printouts of testing machine data systems—be they instantaneous, delayed, stored, or retransmitted—which are verified with provisions of 1.1.1, 1.1.2, or 1.1.3, and are within the ±1 % accuracy requirement, comply with Practices E4.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D76/D76M Specification for Tensile Testing Machines for Textiles
E6 Terminology Relating to Methods of Mechanical Testing
E74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines
E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System

[1] 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.

Current edition approved ~~Dec. 1, 2015~~May 15, 2016. Published ~~January 2016~~June 2016. Originally approved in 1923. Last previous edition approved in ~~2014~~2015 as ~~E4 – 14.~~E4 – 15. DOI: ~~10.1520/E0004-15.~~10.1520/E0004-16.

[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 For definitions of terms used in this practice, refer to Terminology E6.

3.2 *Definitions:*

3.2.1 *elastic calibration device, n*—a device for use in verifying the force readings of a testing machine consisting of an elastic member(s) to which forces may be applied, combined with a mechanism or device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation under force.

3.2.2 *portable testing machine (force-measuring type), n*—a device specifically designed to be moved from place to place and for applying a force (load) to a specimen.

3.2.3 *testing machine (force-measuring type), n*—a mechanical device for applying a force to a specimen.

3.3 ~~*Definitions:*~~*Definitions of Terms Specific to This Standard:*

3.3.1 ~~*accuracy*—~~*accuracy, n*—the specified permissible variation from the reference value.

3.3.1.1 *Discussion*—

A testing machine is said to be accurate if the indicated force is within the specified permissible variation from the actual force. In these methods the word "accurate" applied to a testing machine is used without numerical values, for example, "An accurate testing machine was used for the investigation." The accuracy of a testing machine should not be confused with sensitivity. For example, a testing machine might be very sensitive; that is, it might indicate quickly and definitely small changes in force, but nevertheless, be very inaccurate. On the other hand, the accuracy of the results is in general limited by the sensitivity.

3.3.2 *calibration, n— in the case of force testing machines*, the process of comparing the force indication of the machine under test to that of a standard, making adjustments as needed to meet error requirements.

3.3.3 *capacity* ~~*range*—~~*range, n*—in the case of testing machines, the range of forces for which it is designed. ~~Some testing machines have more than one capacity range, that is, multiple ranges.~~

3.3.3.1 *Discussion*—

Some testing machines have more than one capacity range, that is, multiple ranges.

3.3.4 ~~*correction*—~~*correction, n*—in the case of a testing machine, the difference obtained by subtracting the indicated force from the correct value of the applied force.

~~3.1.5 *elastic calibration device*—a device for use in verifying the force readings of a testing machine consisting of an elastic member(s) to which forces may be applied, combined with a mechanism or device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation under force.~~

3.3.5 *error (or the deviation from the correct* ~~*value)*—~~*value), n*—in the case of a testing machine, the difference obtained by subtracting the force indicated by the calibration device from the force indicated by the testing machine.

3.3.5.1 *Discussion*—

The word "error" shall be used with numerical values, for example, "At a force of ~~30 000 lbf (133 kN),~~300 kN [60 000 lbf], the error of the testing machine ~~was + 15 lbf (+ 67 N)."~~was + 67 N [+ 15 lbf]."

3.3.6 ~~*force*—~~*force, n*—in the case of testing machines, a force measured in units such as pound-force, newton, or kilogram-force.

3.3.6.1 *Discussion*—

The newton is that force which acting on a 1-kg mass will give to it an acceleration of 1 m/s^2. The pound-force is that force which acting on a ~~1-lb~~[1-lb] mass will give to it an acceleration of ~~32.1740 ft/s~~9.80665 ^{2} ~~(9.80665~~ m/s^2~~).~~ [32.1740 ft/s^2]. The ~~newton~~kilogram-force is that force which acting on a 1-kg mass will give to it an acceleration of ~~1~~9.80665 m/s^2~~.~~[32.1740 ft/s^2].

3.3.7 *percent* ~~*error*—~~*error, n*—in the case of a testing machine, the ratio, expressed as a percent, of the error to the correct value of the applied force.

3.3.7.1 *Discussion*—

The test force, as indicated by the testing machine, and the applied force, as computed from the readings of the verification device, shall be recorded at each test point. The error, *E*, and the percent error, *E*p, shall be calculated from these data as follows:

$$E = A - B \tag{1}$$

$$E_p = [(A - B)/B] \times 100$$

where:

~~A = force indicated by machine being verified, lbf (or N), and~~
~~B = correct value of the applied force, lbf (or N), as determined by the calibration device.~~

A = force indicated by machine being verified, N [or lbf], and
B = correct value of the applied force, N [or lbf], as determined by the calibration device.

3.3.8 *permissible variation (or ~~tolerance)—~~tolerance), n—*in the case of testing machines, the maximum allowable error in the value of the quantity indicated.

3.3.8.1 *Discussion—*

It is convenient to express permissible variation in terms of percentage of error. The numerical value of the permissible variation for a testing machine is so stated hereafter in these practices.

3.3.9 *resolution of the force indicator, n—*smallest change of force that can be estimated or ascertained on the force indicating apparatus of the testing machine, at any applied force. Appendix X1 describes a method for determining resolution.

3.3.10 *resolution of ~~the force indicator—~~analog type force indicators (scales, dials, recorders, etc.), n—*the resolution is the smallest change ~~of force that can be estimated or ascertained on the force indicating apparatus of the testing machine, at any applied force.~~ in force indicated by a displacement of ~~Appendix X1 describes a method for determining resolution.~~a pointer, or pen line.

3.3.10.1 *Discussion—*

The resolution is calculated by multiplying the force corresponding to one graduation by the ratio of the width of the pointer or pen line to the center to center distance between two adjacent graduation marks. The typical ratios used are 1:1, 1:2, 1:5, or 1:10. A spacing of 2.5 mm [0.10 in.] or greater is recommended for the ratio of 1:10. A ratio less than 1:10 should not be used.

3.3.10.2 *Discussion—*

If a force indicating dial has graduations spaced every 2.0 mm [0.080 in.], the width of the pointer is approximately 1.0 mm (0.040 in.), and one graduation represent 25N [5 lbf]. The ratio used would be 1:2 and the resolution would be equal to 12-½ N [2-½ lbf].

~~3.1.10.1 *resolution of analog type force indicators (scales, dials, recorders, etc.)—*the resolution is the smallest change in force indicated by a displacement of a pointer, or pen line. The resolution is calculated by multiplying the force corresponding to one graduation by the ratio of the width of the pointer or pen line to the center to center distance between two adjacent graduation marks. The typical ratios used are 1:1, 1:2, 1:5, or 1:10. A spacing of 0.10 in. (2.5 mm) or greater is recommended for the ratio of 1:10. A ratio less than 1:10 should not be used.~~

~~3.1.10.1 *Discussion—*~~

~~If a force indicating dial has graduations spaced every 0.080 in. (2.0 mm), the width of the pointer is approximately 0.040 in. (1.0 mm), and one graduation represent 5 lbf (25N). The ratio used would be 1:2 and the resolution would be equal to 2-1/2 lbf (12-1/2 N).~~

~~3.1.10.2 *resolution of digital type force indicators (numeric, displays, printouts, etc.)—*the resolution is the smallest change in force that can be displayed on the force indicator, at any applied force.~~

~~3.1.10.1 *Discussion—*~~

~~A single digit or a combination of digits may be the smallest change in force that can be indicated.~~

~~3.1.10.2 *Discussion—*~~

~~If the force indication, for either type of force indicator, fluctuates by more than twice the resolution, as described in 3.1.10.1 or 3.1.10.2, the resolution, expressed as a force, shall be equal to one-half the range of the fluctuation.~~

3.3.11 ~~*testing machine (force-measuring type)—*~~*resolution of digital type force indicators (numeric, displays, printouts, etc.), n—*~~a mechanical device for applying a force to a specimen.~~the resolution is the smallest change in force that can be displayed on the force indicator, at any applied force.

3.3.11.1 *Discussion—*

A single digit or a combination of digits may be the smallest change in force that can be indicated.

3.3.11.2 *Discussion—*

If the force indication, for either type of force indicator, fluctuates by more than twice the resolution, as described in 3.3.10 or 3.3.11, the resolution, expressed as a force, shall be equal to one-half the range of the fluctuation.

~~3.1.11.1 *portable testing machine (force-measuring type)*—a device specifically designed to be moved from place to place and for applying a force (load) to a specimen.~~

3.3.12 *verification, n— in the case of force testing machines*, the process of comparing the force indication of the machine under test to that of a standard and reporting results, without making adjustments.

3.3.13 *verified range of* ~~*forces—*~~*forces, n—*in the case of testing machines, the range of indicated forces for which the testing machine gives results within the permissible variations specified.

4. Significance and Use

4.1 Testing machines that apply and indicate force are used in many industries, in many ways. They may be used in a research laboratory to measure material properties, and in a production line to qualify a product for shipment. No matter what the end use of the machine may be, it is necessary for users to know that the amount of force applied and indicated is traceable to the International System of Units (SI) through a National Metrology Institute (NMI). The procedures in Practices E4 may be used to verify these machines so that the indicated forces are traceable to the SI. A key element of traceability to the SI is that the devices used in the verification have known force characteristics, and have been calibrated in accordance with Practice E74.

4.2 The procedures in Practices E4 may be used by those using, manufacturing, and providing calibration service for testing machines and related instrumentation.

5. Calibration Devices

5.1 When verifying testing machines, use calibration devices only over their Class A force ranges as determined by Practice E74.

6. Advantages and Limitations of Methods

6.1 *Verification by Standard Weights*—Verification by the direct application of standard weights to the weighing mechanism of the testing machine, where practicable, is the most accurate method. Its limitations are: (*1*) the small range of forces that can be verified, (*2*) the nonportability of any large amount of standards weights, and (*3*) its nonapplicability to horizontal testing machines or vertical testing machines having weighing mechanisms that are not designed to be actuated by a downward force.

6.2 *Verification by Equal-Arm Balance and Standard Weights*—The second method of verification of testing machines involves measurement of the force by means of an equal-arm balance and standard weights. This method is limited to a still smaller range of forces than the foregoing method, and is generally applicable only to certain types of hardness testing machines in which the force is applied through an internal lever system.

6.3 *Verification by Elastic Calibration Devices*—The third method of verification of testing machines involves measurement of the elastic strain or deflection under force of a ring, loop, tension or compression bar, or other elastic device. The elastic calibration device is free from the limitations referred to in 6.1 and 6.2.

7. System Verification

7.1 A testing machine shall be verified as a system with the force sensing and indicating devices (see 1.2 and 1.4) in place and operating as in actual use.

7.1.1 If this is not technically possible, refer to Annex A1, Verifying the Force Measuring System out of the Test Machine. Out of the test machine verifications shall be in accordance with the main body of Practices E4 and its Annex A1

7.2 System verification is invalid if the devices are removed and checked independently of the testing machine unless verification is performed according to Annex A1.

7.3 Many testing machines utilize more than one force measuring device in order to obtain more accurate force indication at lower applied forces. These devices are routinely installed and uninstalled in the testing machine. For such devices, interchangeability shall be established during the original verification and shall be reestablished after an adjustment is performed. This is accomplished by performing a normal verification with the device in place as during normal use. It is advisable that orientation be kept consistent, such as by noting the direction of the cable connector so that when reinstalling the device, the orientation will be repeated. Remove and reinstall the device between the two verification runs to demonstrate interchangeability. Repeat the procedure for each interchangeable force measuring device used in the testing machine.

7.3.1 Introduction of the new force measuring devices shall require that interchangeability be established per 7.3.

7.4 A Practices E4 Verification consists of at least two verification runs of the forces contained in the force range(s) selected. See 10.1 and 10.3.

7.4.1 If the initial verification run produces values within the Practices E4 requirements of Section ~~17~~14, the data may be used "as found" for run one of the two required for the new verification report.

7.4.2 If the initial verification run produces any values which are outside of the Practices E4 requirements, the "as found" data may be reported and may be used in accordance with applicable quality control programs. Calibration adjustments shall be made to the force indicator system(s), after which the two required verification runs shall be conducted and reported in the new verification report and certificate.

7.4.3 Calibration adjustments may be made to improve the accuracy of the system. They shall be followed by the two required verification runs, and issuance of a new verification report and certificate.

8. Gravity and Air Buoyancy Corrections

8.1 In the verification of testing machines, where standard weights are used for applying forces directly or through lever or balance-arm systems, correct the force for the local value of gravity and for nominal air buoyancy.

8.1.1 The force exerted by a weight in air is determined by:

$$\text{Force} = Mg\left(1 - \frac{d}{D}\right) \tag{2}$$

where:

F = Force, N
M = true mass of the weight, kg
g = local acceleration due to gravity, m/s^2,
d = air density (1.2 kg/m^3), and
D = density of the weight in the same units as d.

8.1.2 For the purposes of this standard, g can be calculated with a sufficient uncertainty using the following formula.

$$g = 9.7803[1 + 0.0053\,(\sin\,\varnothing)^2] - 0.000001967h \tag{3}$$

where:

where:

$\varnothing$ = latitude
h = elevation above sea level in metres

NOTE 2—Eq 3 corrects for the shape of the earth and the elevation above sea level. The first term, which corrects for the shape of the earth, is a simplification of the World Geodetic System 84 Ellipsoidal Gravity Formula. The results obtained with the simplified formula differ from those in the full version by less than 0.0005%. The second term combines a correction for altitude, the increased distance from the center of the earth, and a correction for the counter-acting Bouguer effect of localized increased mass of the earth. The second term assumes a rock density of 2.67 g/cm^3. If the rock density changed by 0.5 g/cm^3, an error of 0.003 % would result.

8.2 The force in customary units exerted by a weight in air is calculated as follows:

$$F_c = \frac{Mg}{9.80665}\left(1 - \frac{d}{D}\right) \tag{4}$$

where:

where:

F_c = force expressed in customary units, that is, pound force or kilogram-force,
M = true mass of the weight,
g = local acceleration due to gravity, m/s^2,
d = air density (1.2 kg/m^3),
D = density of the weight in the same units as d, and
9.80665 = the factor converting SI units of force into customary units of force; this factor is equal to the value for standard gravity, 9.80665 m/s^2.

If M, the mass of the weight is in pounds, the force will be in pound-force units ~~(lbf).~~[lbf]. If M is in kilograms, the force will be in kilogram-force units (kgf). These customary force units are related to the newton (N), the SI unit of force, by the following relationships:

$$1\ \text{lbf} = 4.448222\text{N} \tag{5}$$

$$1\ \text{kgf} = 9.80665\ \text{N (exact)} \quad (6)$$

8.2.1 For use in verifying testing machines, corrections for local values of gravity and air buoyancy to weights calibrated in pounds can be made with sufficient accuracy using the multiplying factors from Table 1. Alternatively the following formula may be used to find the multiplying factor, *MF*. Multiply *MF* times the mass of the weight given in pounds to obtain the value of force in pounds-force, corrected for local gravity and air buoyancy.

$$MF = \frac{9.7803[1 + 0.0053\,(\sin\,\varnothing)^2] - 0.000001967h}{9.80665} \times 0.99985 \quad (7)$$

where:

$\varnothing$ = latitude
h = elevation above sea level in metres

NOTE 3—Eq 7 and Table 1 correct for the shape of the earth, elevation above sea level, and air bouyancy. The correction for the shape of the earth is a simplification of the World Geodetic System 84 Ellipsoidal Gravity Formula. The results obtained with the simplified formula differ by less than 0.0005%. The term that corrects for altitude, corrects for an increased distance from the center of the earth and the counter-acting Bouguer effect of localized increased mass of the earth. The formula assumes a rock density of 2.67 g/cc. If the rock density changed by 0.5 g/cc, an error of 0.003 % would result. The largest inaccuracy to be expected, due to extremes in air pressure, temperature, and humidity when using steel weights, is approximately 0.01%. If aluminum weigths are used, errors on the order of 0.03% can result.

8.3 Standard weights are typically denominated in a unit of mass. When a standard weight has been calibrated such that it exerts a specific force under prescribed conditions, the weight will exert that force only under those conditions. When used in locations where the acceleration of gravity differs from the one in the calibration location, it is necessary to correct the calibrated force value by multiplying the force value by the value for local gravity and dividing by the value of gravity for which the weight was calibrated. Any required air buoyancy corrections must also be taken into account.

9. Application of Force

9.1 In the verification of a testing machine, approach the force by increasing the force from a lower force.

NOTE 4—For any testing machine the errors observed at corresponding forces taken first by increasing the force to any given test force and then by decreasing the force to that test force, may not agree. Testing machines are usually used under increasing forces, but if a testing machine is to be used under decreasing forces, it should be calibrated under decreasing forces as well as under increasing forces.

9.2 Testing machines that contain a single test area and possess a bidirectional loading and weighing system must be verified separately in both modes of weighing.

9.3 High-speed machines used for static testing must be verified in accordance with Practices E4. **Warning—** Practices E4 verification values are not to be assumed valid for high-speed or dynamic testing applications (see Practice E467).

NOTE 5—The error of a testing machine of the hydraulic-ram type, in which the ram hydraulic pressure is measured, may vary significantly with ram position. To the extent possible such machines should be verified at the ram positions used.

10. Selection of Verification Forces

10.1 Determine the upper and lower limits of the verified force range of the testing machine to be verified. In no case shall the verified force range include forces below 200 times the resolution of the force indicator.

10.2 If the lower limit of the verified force range is greater than or equal to one-tenth of the upper limit, five or more different verification forces shall be selected such that the difference between two adjacent verification forces is greater than or equal to one

TABLE 1 Multiplying Factor, MF, in Air at Various Latitudes, see Eq 7

Latitude, Ø,°	Elevation Above Sea Level, h, m (ft)					
	0 (0)	500 (1640)	1000 (3280)	1500 (4920)	2000 (6560)	2500 (8200)
0	0.9972	0.9971	0.9970	0.9969	0.9968	0.9967
5	0.9972	0.9971	0.9970	0.9969	0.9968	0.9967
10	0.9973	0.9972	0.9971	0.9970	0.9969	0.9968
15	0.9975	0.9974	0.9973	0.9972	0.9971	0.9970
20	0.9978	0.9977	0.9976	0.9975	0.9974	0.9973
25	0.9981	0.9980	0.9979	0.9978	0.9977	0.9976
30	0.9985	0.9984	0.9983	0.9982	0.9981	0.9980
35	0.9989	0.9988	0.9987	0.9986	0.9985	0.9984
40	0.9993	0.9992	0.9991	0.9990	0.9989	0.9988
45	0.9998	0.9997	0.9996	0.9995	0.9994	0.9993
50	1.0003	1.0002	1.0001	1.0000	0.9999	0.9998
55	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002
60	1.0011	1.0010	1.0009	1.0008	1.0007	1.0006
65	1.0015	1.0014	1.0013	1.0012	1.0011	1.0010
70	1.0018	1.0017	1.0016	1.0015	1.0014	1.0013