Designation: D 2412 – 02

Standard Test Method for
Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading[1]

This standard is issued under the fixed designation D 2412; 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 Department of Defense.

1. Scope

1.1 This test method covers the determination of load-deflection characteristics of plastic pipe under parallel-plate loading.

1.2 This test method covers thermoplastic resin pipe, reinforced thermosetting resin pipe (RTRP), and reinforced polymer mortar pipe (RPMP).

1.3 The characteristics determined by this test method are pipe stiffness, stiffness factor, and load at specific deflections.

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

NOTE 1—While this test method can be used in measuring the pipe stiffness of corrugated plastic pipe or tubing, special conditions and procedures are used. These details are included in the product standards, for example, Specification F 405.

1.5 The text of this test method 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 test method.

1.6 *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:*
D 695 Test Method for Compressive Properties of Rigid Plastics[2]
D 1600 Terminology for Abbreviated Terms Relating to Plastics[2]
D 2122 Test Method for Determining Dimensions of Ther-

moplastic Pipe and Fittings[3]
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[4]
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[4]
F 405 Specification for Corrugated Polyethylene (PE) Pipe and Fittings[3]
F 412 Terminology Relating to Plastic Piping Systems[3]

3. Terminology

3.1 *Definitions:* Definitions are in accordance with Terminology F 412, and abbreviations are in accordance with Terminology D 1600, unless otherwise specified.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 Δy—measured change of the inside diameter in the direction of load application expressed in inches (millimetres).

3.2.2 *initial inside diameter (d)*—the average of the inside diameters as determined for the several test specimens and expressed in inches (millimetres).

3.2.3 *load (F)*—the load applied to the pipe to produce a given percentage deflection. Expressed as newtons per metre or pounds-force per linear inch.

3.2.4 *mean radius (r)*—the mid-wall radius determined by subtracting the average wall thickness from the average outside diameter and dividing the difference by two. Expressed as inches (millimetres).

3.2.5 *pipe deflection (P)*—the ratio of the reduction in pipe inside diameter to the initial inside diameter expressed as the percentage of the initial inside diameter.

3.2.6 *pipe significant events*:

3.2.6.1 *liner cracking or crazing*—the occurrence of a break or network of fine breaks in the liner visible to the unaided eye.

3.2.6.2 *rupture*—a crack or break extending entirely or partly through the pipe wall.

NOTE 2—The significant events listed may or may not occur in a specific pipe material.

3.2.6.3 *wall cracking*—the occurence of a break in the pipe wall visible to the unaided eye.

3.2.6.4 *wall delamination*—the occurrence of any separation in the components of the pipe wall visible to the unaided eye.

3.2.7 *pipe stiffness (PS)*—the value obtained by dividing the force per unit length of specimen by the resulting deflection in the same units at the prescribed percentage deflection.

3.2.8 *stiffness factor (SF)*—the product of pipe stiffness and the quantity 0.149 r^3.

3.2.9 *Discussion*—The "pipe stiffness" and "stiffness factor" are related as follows:

$$PS = F/\Delta y \tag{1}$$

$$SF = EI = 0.149\, Fr^3/\Delta y = 0.149\, r^3 (PS) \tag{2}$$

NOTE 3—See Appendix X2 for information relating PS, *E*, and Δy.

4. Summary of Test Method

4.1 A short length of pipe is loaded between two rigid parallel flat plates at a controlled rate of approach to one another. Load-deflection (of the pipe diameter) data are obtained. If cracking, crazing, delamination, or rupture occurs, the corresponding load and deflection are recorded.

5. Significance and Use

5.1 The external loading properties of plastic pipe obtained by this test method are used for the following:

5.1.1 To determine the stiffness of the pipe. This is a function of the pipe dimensions and the physical properties of the material of which the pipe is made.

5.1.2 To determine the load-deflection characteristics and pipe stiffness which are used for engineering design (see Appendix X1).

5.1.3 To compare the characteristics of various plastics in pipe form.

5.1.4 To study the interrelations of dimensions and deflection properties of plastic pipe and conduit.

5.1.5 To measure the deflection and load-resistance at any of several significant events if they occur during the test.

6. Apparatus

6.1 *Testing Machine*—A properly calibrated compression testing machine of the constant-rate-of-crosshead movement type meeting the requirements of Test Method D 695 shall be used to make the tests. The rate of head approach shall be 0.50 ± 0.02 in. (12.5 ± 0.5 mm)/min.

NOTE 4—Hydraulic testing machines that may vary slightly from these rate limits are commonly used and are satisfactory for testing RTRP and RPMP pipe 24-in. (610-mm) size and larger.

6.2 *Loading Plates*—The load shall be applied to the specimen through two parallel steel bearing plates. The plates shall be flat, smooth, and clean. The thickness of the plates shall be sufficient so that no bending or deformation occurs during the test, but it shall not be less than 0.25 in. (6.0 mm). The plate length shall equal or exceed the specimen length and the plate width shall not be less than the pipe contact width at maximum pipe deflection plus 6.0 in. (150 mm).

NOTE 5—For some types of testing machines a greater plate thickness

may be required to limit plate bending.

6.3 *Deformation (Deflection) Indicator*— The change in inside diameter, or deformation parallel to the direction of loading, shall be measured with a suitable instrument meeting the requirements of Test Method D 695, except that the instrument shall be accurate to the nearest 0.010 in. (0.25 mm). The instrument shall not support the pipe test specimen or the plate or affect in any way the load deflection measurements. Changes in diameter are measured during loading by continuously recording plate travel or by periodically computing it.

7. Test Specimens

7.1 For thermoplastic pipe, the test specimen shall be a piece of pipe 6 ± 1/8 in. (150 ± 3 mm) long.

7.2 For reinforced thermosetting resin pipe, the minimum test specimen length shall be three times the nominal pipe diameter or 12.0 in. (300 mm), whichever is smaller. For pipe larger than 60 in. (1524 mm) in diameter, the minimum specimen length shall be 20 % of the nominal diameter adjusted to the nearest 1 in. (25.4 mm).

7.3 The ends of specimens shall be cut square and shall be free of burrs and jagged edges.

7.4 No less than three specimens shall be tested for each sample of pipe.

NOTE 6—For quality control testing a single specimen may be used with the thinnest wall at the top.

7.5 Certain RTRP pipes exhibit surface irregularity because the production process is inside diameter controlled. To assure accurate test results by parallel-plate loading, the test specimen must be uniformly loaded along its entire bearing surface. If surface irregularities (resin-rich areas) along the outside diameter prevent the bearing load from being uniformly distributed along the length of the specimen, the outside surface along the loading line shall be sanded smooth by hand. This sanding shall only be done if the reinforcement is not damaged. Note that sanding shall be done only along the plate contact lines.

8. Conditioning

8.1 Condition pipe for at least 4 h in air, at a temperature of 73.4 ± 3.6°F (23 ± 2°C), and conduct the test in a room maintained at the same temperature.

8.2 When a referee test is required, condition specimens for at least 40 h at 73.4 ± 3.6°F (23 ± 2°C) and 50 ± 5 % relative humidity and conduct the test under the same conditions.

9. Procedure

9.1 Make the following measurements on each specimen:

9.1.1 Determine the length of each specimen to the nearest 1/32 in. (1 mm) or better, by making and averaging at least four equally spaced measurements around the perimeter.

9.1.2 Measure the wall thickness of each specimen in accordance with Test Method D 2122. Make at least eight measurements equally spaced around one end and calculate the average wall thickness.

9.1.3 Determine whether a line of minimum wall thickness exists along the length of the specimen and if so mark it for use in 9.2.1.

NOTE 7—On RTRP and RPMP pipe measurements may be made at both ends.

9.1.4 Determine the average outside diameter to the nearest 0.01 in. (0.2 mm) using a circumferential wrap tape or by averaging the maximum and minimum outside diameters as measured with a micrometer or caliper.

9.1.5 For OD-controlled pipe calculate the average pipe inside diameter (ID) by subtracting two times the average of all wall thicknesses (9.1.2) from the average of all outside diameters (9.1.4). For ID-controlled pipe determine the average ID by measuring the maximum and minimum inside diameters. Use this average ID as the basis for computing the percentage of deflection for all specimens in that lot of pipe.

9.2 Locate the pipe section with its longitudinal axis parallel to the bearing plates and center it laterally in the testing machine.

9.2.1 If an orientation of minimum wall thickness has been found, place the first specimen so the thinnest wall is at the top and rotate successive specimens 35 and 70°. If no minimum wall thickness was identified, use any base line.

9.3 With the deflection indicator in place, bring the upper plate into contact with the specimen with no more load than is necessary to hold it in place. This establishes the beginning point for subsequent deflection measurements.

9.4 Compress the specimen at a constant rate of 0.50 ± 0.02 in. (12.5 ± 0.5 mm)/min.

NOTE 8—For larger sizes of pipe made from relatively low-modulus materials, creep may affect the results of this test because of the loading rate specified.

9.5 Record load-deflection measurements continuously or intermittently with reference to the relative movement of the bearing plates. If measurements are made intermittently, make and record such measurements at increments of not more than 5 % of the average inside diameter of the specimen. Refer to Annex A1.

9.6 Observe and note the load and deflection at the first evidence of each of the following significant events when and if they occur:

9.6.1 Liner cracking or crazing.

9.6.2 Wall cracking.

9.6.3 Wall delamination.

9.6.4 Rupture.

9.7 Record type and position of each event with respect to the corresponding load and deflection. Discontinue the test when either of the following occur:

9.7.1 The load on the specimen fails to increase with increasing deflection (maximum point on load-deflection plot has been reached).

9.7.2 The specimen deflection reaches 30 % of the average inside diameter or the required maximum deflection.

10. Calculation

10.1 Calculate the pipe stiffness, PS, for any given deflection as follows:

$$PS = F/\Delta y \qquad \text{lbf/in./in. (kPa)}$$
(3)

NOTE 9—Refer to Appendix X3 for additional information on units.

10.2 When required, calculate the stiffness factor, SF, for any given deflection as follows:

$$SF = 0.149\, r^3 \cdot PS \qquad \text{in.}^3 \cdot \text{lbf/in.}^2 \ (\text{Pa} \cdot \text{m}^3)$$
(4)

10.3 When required, calculate the percentage pipe deflection, P, as follows:

$$P = \Delta y/d \times 100$$
(5)

11. Report

11.1 Report the following information:

11.1.1 Complete identification of the material tested, including type, source, manufacturer's code, previous history (if any), and product identification by standard number.

11.1.2 Dimensions of each specimen, including average outside diameter, average wall thickness, average inside diameter, liner thickness and reinforcement thickness where applicable, and average length.

11.1.3 Whether or not the outside diameter of the specimen was sanded.

11.1.4 Conditioning temperature, time, and environment.

11.1.5 The load and deflection at which any of the following events occurred:

11.1.5.1 Liner cracking or crazing,

11.1.5.2 Wall cracking,

11.1.5.3 Wall delamination, and

TABLE 1 Pipe Stiffness—Precision Statistics[A]

Material	Deflection Level, %	Average	S_{mean}	S_r[B]	S_R[B]	r	R	Standard Deviation of Cell Averages[C]	Repeatability Standard Deviation[C]	Reproduceability Standard Deviation[C]	Repeatability Limit (95 %)[C]	Reproduceability Limit (95 %)[C]
A	2.5	772.3	54.95	84.69	101.0	237.1	282.7	7.11	11.0	13.1	30.7	36.6
B	2.5	380.2	20.52	18.12	27.37	50.72	76.64	5.40	4.77	7.20	13.3	20.2
C	2.5	463.9	79.07	57.82	97.96	161.9	274.3	17.0	12.5	21.1	34.9	59.1
A	5.0	755.7	33.30	80.30	86.93	224.8	243.4	4.41	10.6	11.5	29.7	32.2
B	5.0	356.1	19.13	15.32	24.51	42.89	68.62	5.37	4.30	6.88	12.0	19.3
C	5.0	419.4	37.80	27.74	46.89	77.68	131.3	9.01	6.61	11.2	18.5	31.3
A	7.5	724.8	27.85	76.14	81.07	213.2	227.0	3.84	10.5	11.2	29.4	31.3
B	7.5	332.6	16.87	13.94	21.88	39.02	61.27	5.07	4.19	6.58	11.7	18.4
C	7.5	371.7	26.70	18.82	32.66	52.69	91.45	7.18	5.06	8.79	14.2	24.6

[A] Terms are used as specified in Practice E 177.
[B] S_r = standard deviation of repeatability (variation of replicate samples by same laboratory).
   S_R = standard deviation of reproducibility (variability between laboratory).
[C] Precision statistics as percent of average.

11.1.5.4 Rupture.

11.1.6 The reason for terminating the test.

11.1.7 If required, a plot on cartesian coordinates of the load in pounds-force per inch (or newtons per metre) versus deflection in inches (or millimetres) for each specimen tested. Each of the following occurrences shall be noted on the plots where applicable:

11.1.7.1 Liner cracking or crazing,

11.1.7.2 Wall cracking, and

11.1.7.3 Wall delamination.

11.1.8 Pipe stiffness, $F/\Delta y$, at 5 and 10 % deflection, for each specimen. If any cracking, crazing, or delamination occurred below 5 % deflection, calculate pipe stiffness at that percent deflection where cracking or delamination occurred and note this in the report.

11.1.9 When specifically requested determine the stiffness factor, SF, at 5 and 10 % deflection, for each specimen. If any cracking, crazing, or delamination occurred below 5 % deflec-

tion, calculate apparent stiffness factor at the percent deflection where cracking or delamination occurred and note this in the report.

11.1.10 Date of test.

12. Precision and Bias

12.1 *Precision*[5]—An interlaboratory study of pipe stiffness was conducted in accordance with Practice E 691 with seven laboratories participating, each obtaining nine results at three deflection levels on three pipe samples. The pipe samples were C = 4 in. corrugated PE pipe, A = 6 in. SDR 26 ABS dwv pipe, and B = 12 in. SDR 35 PVC sewer pipe. Information regarding the precision is found in Table 1.

12.2 *Bias*—Data obtained using this test method are believed to be reliable since accepted techniques of analysis are used. However, because no reference method is available, no bias statement is made.

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[5] Supporting data are available from ASTM International Headquarters. Request RR: F17-104.

ANNEX

(Mandatory Information)

A1. PLOTTING LOAD VERSUS DEFLECTION

A1.1 The load versus deflection plot is typically a smooth curve. In some cases, for example, when the curve is generated automatically, the apparent zero point is in error: for example, Fig. A1.1. In such cases, the initial straight line portion of the curve shall be extrapolated back, and this intercept be used as the (0,0) point.
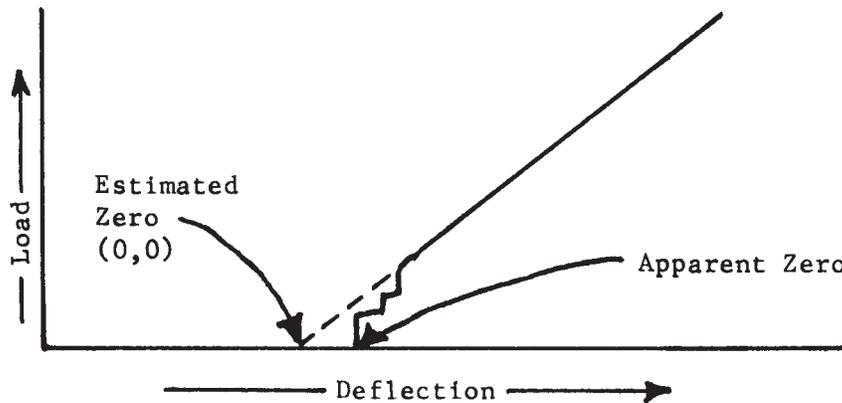
FIG. A1.1 Method of Estimating the Origin

APPENDIXES

(Nonmandatory Information)

X1. METHOD OF APPLYING PIPE STIFFNESS FOR ENGINEERING DESIGN

X1.1 The PS determined by this test method can be used to calculate approximate deflections under earth load. Accordingly, the following modified Spangler equation is one available expression that can be used to give approximations of deflections occurring in plastic pipe under earth load:

$$x = \frac{D_e K W_c}{0.149\, PS + 0.061\, E'}$$

where:

x = horizontal deflection of pipe, in. (or mm), (may be taken also as the vertical deflection),

K = bedding constant, dependent upon the support the pipe received from the bottom of the trench,

W_c = vertical load per unit of pipe length, lbf/in. (or N/m) of pipe,

PS = $F/\Delta y$ = pipe stiffness (as determined by test), lbf/in./in. or (kPa),

D_e = deflection lag factor, and

E' = modulus of soil reaction, psi (or kPa).

X1.2 Pipe stiffness also relates to handling and installation characteristics of a pipe during the very early stages of soil consolidation around the pipe. There can be a minimum pipe stiffness below which pipe becomes difficult to install. Local conditions and installation practice must be considered in selecting this minimum for a particular project and in assigning specific values to be used in the above equations for pipe deflection. Beyond these statements no representation in regard to limiting maximum or minimum pipe stiffness values determined in accordance with the provision of this test method is made or implied.

X2. PS AND SF VERSUS DEFLECTION

X2.1 The EI of a pipe is a function of the material's flexural modulus (E) and the wall thickness (t) of the pipe, since $I = t^3/12$. As such it is a fixed value for any given set of material and dimensional parameters. However, the quantities pipe stiffness (PS) and stiffness factor (SF) are computed values determined from the test resistance at a particular deflection. These values are highly dependent on the degree of deflection, for as the pipe deflects the radius of curvature changes. The greater the deflection at which PS or SF are determined, the greater the magnitude of the deviation from the true EI value. By application of the correction factor $C = [1 + (\Delta y/2d]^3$ the measured PS or SF values can be related to the true EI of the

pipe as long as the pipe remains elliptical. Therefore:

$$PS = \frac{F}{\Delta y} C = \frac{F}{\Delta y}\left(1 + \frac{\Delta y}{2d}\right)^3$$

$$EI = (SF) = 0.149\, r^3\, (PS)$$

X2.2 Use of the load deflection values from this test method to calculate a material flexural modulus should incorporate this correction. Also, it should be recognized that in the study of the behavior of deflected pipe it is the term EI which was used in developing much of the theory of flexible pipe.

X3. UNITS FOR PS AND SF

X3.1 The pipe stiffness value is calculated by dividing the force per unit length by the deflection. In the inch-pound system of units, this is pounds-force per inch of length per inch of deflection, lbf/(in.·in.): this is commonly expressed as lbf/in.^{2} or psi. In SI, with the force expressed in newtons per metre of length and the deflection in millimetres, the PS is expressed in kilopascals (kPa). Although PS units are dimensionally the same as those for pressure and stress, they are

different quantities and should not be confused one with the other.

X3.2 The stiffness factor is calculated from PS and the mean radius of the tube, in inches or millimetres. These units are in.^{3}·lbf/in.^{2} or mm^3·kPa which can be expressed dimensionally as lbf·in. or µN·m.