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Foreword

Organized in 1898, ASTM has grown into one of the largest voluntary standards development systems in the world. ASTM is a not-for-profit organization which provides a forum for producers, users, ultimate consumers, and those having a general interest (representatives of government and academia) to meet on common ground and write standards for materials, products, systems, and services.

From the work of 132 standards-writing committees, ASTM publishes more than 9,800 standards each year. These standards and other related technical information are sold throughout the world.

ASTM Headquarters has no technical research or testing facilities; such work is done voluntarily by 33,300 technically qualified ASTM members located throughout the world. Membership in the Society is open to all concerned with the fields in which ASTM is active. A membership application may be found at the back of this volume. Additional information may be obtained from Member and Committee Services, ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428; tel. (610) 832-9693.

1997 Annual Book of ASTM Standards

The 1997 *Annual Book of ASTM Standards* consists of 72 volumes, divided among 16 sections, of which this volume is one. It contains approved ASTM standards, provisional standards, and related material. These terms are defined as follows in the *Regulations Governing ASTM Technical Committees:*

Categories:

standard—as used in ASTM, a document that has been developed and established within the consensus principles of the Society and that meets the approval requirements of ASTM procedures and regulations.

Discussion—The term "standard" serves in ASTM as an adjective in the title of documents, such as test methods or specifications, to connote specified consensus and approval. The various types of standard documents are based on the needs and usages as prescribed by the technical committees of the Society.

provisional standard—a document published for a limited period of time by the Society to meet a demand for more rapid issuance of specific documents, such as an emergency situation, regulatory requirements, or other special circumstances.

Discussion—Provisional standards are not full consensus documents because they require subcommittee consensus only. (These documents replace emergency standards and proposals.)

Types:

The various types of ASTM documents are to provide a flexibility of form, communication, and usage for both the technical committees and the myriad users of ASTM documents. The type of ASTM document that is developed and titled is based on the technical content and intended use, not on the degree of consensus achieved. The two categories of ASTM documents (standard and provisional standard) can be of the following forms and types:

classification—a systematic arrangement or division of materials, products, systems, or services into groups based on similar characteristics such as origin, composition, properties, or use.

guide—a series of options or instructions that does not recommend a specific course of action.

Discussion—Whereas a practice prescribes a general usage principle, a guide only suggests an approach. The purpose of a guide is to offer guidance, based on a consensus of viewpoints, but not to establish a fixed procedure. A guide is intended to increase the awareness of the user to available techniques in a given subject area and to provide information from which subsequent evaluation and standardization can be derived.

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§ Approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

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§D 75 – 87 (1992)$^{\epsilon 1}$	Sampling Aggregates

Classification for:

§D 448 – 86 (1993)	Sizes of Aggregate for Road and Bridge Construction

Terminology Relating to:

D 8 – 94	Materials for Roads and Pavements

BITUMINOUS MATERIALS

Specifications for:

D 2993 – 83 (1991)	Acrylonitrile-Butadiene Rubberized Tar
D 3141 – 96	Asphalt for Undersealing Portland-Cement Concrete Pavements
§D 2397 – 94	Cationic Emulsified Asphalt
§D 2027 – 76 (1992)	Cutback Asphalt (Medium-Curing Type)
§D 2028 – 76 (1992)	Cutback Asphalt (Rapid-Curing Type)
§D 2026 – 72 (1993)	Cutback Asphalt (Slow-Curing Type)
§D 977 – 91	Emulsified Asphalt
§D 946 – 82 (1993)	Penetration-Graded Asphalt Cement for Use in Pavement Construction
§D 490 – 92	Road Tar
D 5710 – 95	Trinidad Lake Modified Asphalt
D 5976 – 96	Type I Polymer Modified Asphalt Cement for Use in Pavement Construction.
D 5840 – 95	Type II Polymer Modified Asphalt Cement for Use in Pavement Construction
D 5841 – 95	Type III Polymer Modified Asphalt Cement for Use in Pavement Construction
D 5892 – 96a	Type IV Polymer Modified Asphalt Cement for Use in Pavement Construction
§D 3381 – 92	Viscosity-Graded Asphalt Cement for Use in Pavement Construction

§ Approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

APPENDIX

(Nonmandatory Information)

X1. FORMULAS USED IN DETERMINING VOLUME CORRECTIONS TO A BASE TEMPERATURE

X1.1 *Volume Correction Formulas*—The formulas used in Table 1 were derived from the original tables listed in Guide D 1250 – 80 for Group 0 and 1 Oils in Tables 7.25. A linear regression analysis for the tables is listed below for each factor.

$$A = 1.0211326242 - 3.548988118 \times 10^{-4}\,[T(\text{F})] + 4.49881 \times 10^{-8}\,[T(°\text{F})]^2 \quad \text{(X1.1)}$$

where:
A = volume correction factor, and
T(°F) = temperature of asphalt cement in °F.

$$B = 1.02413769 - 4.0641418 \times 10^{-4}\,[T(\text{F})] + 6.79176 \times 10^{-8}\,[T(°\text{F})]^2 \quad \text{(X1.2)}$$

where:
B = volume correction factor, and
T(°F) = temperature of asphalt cement in °F.

X1.1.1 These two formulas generate the same values as the original table at all temperatures except those listed below:

Factor A

Temperature, °F	D 1250 Table	Calculated Value
7	1.0186	1.0187
49	1.0038	1.0039
59	1.0003	1.0004
246	0.9365	0.9366

Factor B

Temperature, °F	D 1250 Table	Calculated Value
17	1.0174	1.0172
336	0.8952	0.8953
372	0.8823	0.8824
449	0.8554	0.8553
479	0.8451	0.8450
499	0.8383	0.8382

The differences are always in the 4th digit and the difference is never more than one. The 10 exceptions out of 1000 results indicates an exceptionally good fit to the original data.

X1.2 *Temperature Correction to 15°C*—Because the original tables were developed around correcting asphalt cement to a base temperature of 60°F (15.6°C) it was determined to use the formulas used to derive this table in converting to a new base temperature of 15°C. The first step is to convert the 60°F formula to an equivalent 15.6°C formula by replacing (°F) = 32 + 1.8(°C). This results in new (A) and (B) factor formulas listed below:

$$A = 1.00982193004 - 6.3363523212 \times 10^{-4}\,[T(°\text{C})] + 1.45761444 \times 10^{-7}\,[T(°\text{C})]^2 \quad \text{(X1.3)}$$

$$B = 1.01120198386 - 7.2372141648 \times 10^{-4}\,[T(°\text{C})] + 2.20053024 \times 10^{-7}\,[T(°\text{C})]^2 \quad \text{(X1.4)}$$

X1.2.1 To convert to a base temperature of 15°C rather than 15.6°C, a value of 15°C was substituted into the above equations. The result for each factor is listed below:

$$A = 1.0003502$$

$$B = 1.0003957$$

X1.2.2 To convert to a base temperature of 15°C the following adjustment was made to A and B Factor Formulas:

$$A = (1.00982193004 \div 1.0003502) - (6.3363523212 \times 10^{-4} \div 1.0003502)\,[T(°\text{C})] + (1.45761444 \times 10^{-7} \div 1.0003502)\,[T(°\text{C})]^2 \quad \text{(X1.5)}$$

$$A = 1.0094684142 - 6.33413410744 \times 10^{-4}\,[T(°\text{C})] + 1.45710416212 \times 10^{-7}\,[T(°\text{C})]^2 \quad \text{(X1.6)}$$

$$B = (1.01120198386 \div 1.0003957) - (7.2372141648 \times 10^{-4} \div 1.0003957)\,[T(°\text{C})] + (2.20053024 \times 10^{-7} \div 1.0003957)\,[T(°\text{C})]^2 \quad \text{(X1.7)}$$

$$B = 1.0108020095 - 7.2343515319 \times 10^{-4}\,[T(°\text{C})] + 2.1996598346 \times 10^{-7}\,[T(°\text{C})]^2 \quad \text{(X1.8)}$$

These calculated formulas and the resulting table is listed in this practice.

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Standard Specification for Plowable, Raised Retroreflective Pavement Markers[1]

This standard is issued under the fixed designation D 4383; 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 specification covers a type of plowable, retroreflective, raised pavement marker for lane marking and delineation.

1.2 Retroreflective markers are intended for nighttime visibility.

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

1.4 The following precautionary caveat pertains only to the test methods portion, Section 10, of this specification: *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:*

A 536 Specification for Ductile Iron Castings[2]
C 184 Test Method for Fineness of Hydraulic Cement by the 150-µm (No. 100) and 75-µm (No. 200) Sieves[3]
C 430 Test Method for Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve[3]
D 5 Test Method for Penetration of Bituminous Materials[4]
D 36 Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)[5]
D 70 Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials[4]
D 92 Test Method for Flash and Fire Points by Cleveland Open Cup[6]
D 788 Classification System for Poly(Methyl Methacrylate) (PMMA) Molding and Extrusion Compounds[7]
D 1754 Test Method for Effect of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)[4]
D 1856 Test Method for Recovery of Asphalt from Solution by Abson Method[4]
D 2171 Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer[4]
D 2669 Test Method for Apparent Viscosity of Petroleum Waxes Compounded with Additives (Hot Melts)[8]
D 2712 Test Method for Hydrocarbon Traces in Propylene Concentrates by Gas Chromatography[8]
D 3407 Test Methods for Joint Sealants, Hot-Poured, for Concrete and Asphalt Pavements[4]
D 3935 Specification for Polycarbonate (PC) Unfilled and Reinforced Material[9]
D 4402 Test Method for Viscosity Determinations of Unfilled Asphalts Using the Brookfield Thermoset Apparatus[5]
E 284 Terminology of Appearance[10]
E 308 Practice for Computing the Colors of Objects by Using the CIE System[10]
E 808 Practice for Describing Retroreflection[10]
E 809 Practice for Measuring Photometric Characteristics of Retroreflectors[10]
E 811 Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions[10]

2.2 *Federal Specifications:*[11]

FF-W-1825A Wool and Gauze, Metallic
TT-T-291 Thinner, Paint, Mineral Spirits, Regular and Odorless

2.3 *AASHTO Standards:*[12]

AASHTO No. M 237 Epoxy Resin Adhesive for Bonding Traffic Markers to Hardened Concrete
AASHTO No. T 237 Testing Epoxy Resin Adhesive

3. Terminology

3.1 *Definitions:*

3.1.1 *coefficient of luminous intensity,* R_I (specific intensity)—the ratio of the luminous intensity (I) of the retroreflector in the direction of observation to the illuminance (E) at the retroreflector on a plane perpendicular to the direction of the incident light, expressed in candelas per lux (cd/lx) (see Practice E 808 and Terminology E 284).

3.1.1.1 *Discussion*—When values are low the coefficient of (retroreflected) luminous intensity may be given in millicandelas per lux. In inch-pound units, R_I is given in candelas per footcandle (cd/fc). Historically the term specific intensity and symbol (SI) have been used to designate this term but R_I is preferred.

3.1.2 *color*—expressed by chromaticity coordinates according to the CIE (Commission Internationale de l'Eclairage 1931) standard colorimetric system.

[1] This specification is under the jurisdiction of ASTM Committee D-4 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.38 on Highway Traffic Materials.

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[2] *Annual Book of ASTM Standards*, Vol 01.02.
[3] *Annual Book of ASTM Standards*, Vol 04.01.
[4] *Annual Book of ASTM Standards*, Vol 04.03.
[5] *Annual Book of ASTM Standards*, Vol 04.04.
[6] *Annual Book of ASTM Standards*, Vol 05.01.
[7] *Annual Book of ASTM Standards*, Vol 08.01.
[8] *Annual Book of ASTM Standards*, Vol 05.02.
[9] *Annual Book of ASTM Standards*, Vol 08.02.
[10] *Annual Book of ASTM Standards*, Vol 06.01.
[11] Available from U.S. Government Printing Office, Washington, DC 20402.
[12] Available from American Association of State Highway and Transportation Officials, 444 N. Capitol, Washington, DC 20001.

3.1.3 *horizontal entrance angle*—the angle in the horizontal plane between the direction of incident light and the normal to the leading edge of the marker.

3.1.3.1 *Discussion*—This angle corresponds to the second component of the entrance angle $\beta 2$. (See Practice E 808.) The direction given in Practice E 808 should be used when designating this angle.

3.1.4 *observation angle*—the angle at the reflector between the illumination axis and the observation axis. (See Practice E 808.)

3.2 *Description of Term Specific to This Standard:*

3.2.1 *raised retroreflective pavement markers, raised retroreflective marker, retroreflective marker,* and *marker*—used interchangeably in this specification to refer to a molded plastic prismatic retroreflector, the reflecting area of which is covered with an abrasion-resistant lens surface. The terms do not include the metal holder sometimes used to protect markers from plow blades.

4. Classification

4.1 Markers shall be classified as to type, color, and intended application.

4.1.1 *Types of Markers:*

4.1.1.1 *Type A*—Two-way retroreflective markers, one color.

4.1.1.2 *Type B*—One-way retroreflective markers, one color.

4.1.1.3 *Type D*—One-way retroreflective markers, two colors (one-way retroreflective red with nonretroreflecting white surface on opposite side).

4.1.1.4 *Type E*—Two-way retroreflective marker, two colors.

4.1.2 *Color of Markers:*

4.1.2.1 *W*—White.

4.1.2.2 *Y*—Yellow.

4.1.2.3 *R*—Red.

4.1.2.4 *B*—Blue.

4.1.2.5 *G*—Green.

4.1.3 *Intended Application of Markers:*

4.1.3.1 Marker to be mounted in a holder.

4.1.3.2 Marker to be mounted in a recess.

4.1.4 Show classification in the order detailed in 4.1.1 through 4.1.3.2: type, color, and application.

4.2 Holders shall be classified as to the design installed height of the holder above the pavement.

5. Ordering Information

5.1 Orders for markers under this specification should include the following information:

5.1.1 Quantity,

5.1.2 Type of marker—Retroreflective one-way or retroreflective two-way, and

5.1.3 Color of marker.

5.2 Orders for holders under this specification should include the following information:

5.2.1 Design installed maximum height of the holder.

6. Construction Requirements for Retroreflective Markers

6.1 To withstand plowing, raised retroreflective markers are protected either by recessing within a groove below the pavement surface (see Appendix X1), mounting within a holder having metal ramps to deflect plowblades, or by other methods approved by the purchaser.

6.2 *Retroreflective Markers:*

6.2.1 The retroreflective marker shall be the prismatic type molded of polymethyl methacrylate (Classification D 788, Grade 8), impact modified polymethyl methacrylate (Classification D 788, see Note 1) or polycarbonate (Specification D 3935, Grade PC110B34750.)

NOTE 1—A grade has not been stipulated because the committee responsible has not yet assigned a number.

6.2.2 The installed height of the marker shall be not less than 1.5 mm (0.06 in.) below the surface of the road for recessed type markers or below the top of the casting for plow blade deflecting type.

6.2.3 The marker width shall be approximately 102 mm (4 in.).

6.2.4 The angle between the face of the marker and the base shall be no greater than 45°.

6.2.5 Markers to be mounted in a holder may preferably be laminated to an elastomeric pad.

6.2.6 The base of the marker shall be flat within 1.3 mm (0.05 in.). If the bottom of the marker is configurated, the outermost faces of the configurations shall not deviate more than 1.3 mm (0.05 in.) from a flat surface.

6.2.7 Other construction meeting the performance requirements will be acceptable following a six-month road test during the time of the year when weather and traffic conditions are most critical to determine cleanability and durability.

6.3 *Holder:*

6.3.1 The installed height of the holder shall not exceed 10.9 mm (0.43 in.) above the road surface.

6.3.2 The holder shall be nodular iron, conforming to Specification A 536, Grade 72-45-05, hardened to 51-55 HRC.

6.3.3 To minimize plow blade impact and damage to the casting, the plow blade deflecting ramps of the holder shall be angled not more than 6° to the surface of the road.

6.3.4 The ramps shall be so designed that there shall be no vertical surfaces above the road level that can be contacted by the plow blade moving in the normal travel direction of the road.

6.3.5 Surfaces of the holder shall be free of scale, dirt, rust, oil, grease, or any other contaminant which may reduce its bond to the adhesive with which the holder is installed or with which the marker is mounted.

6.3.6 The holder shall be designed to be partially recessed below the pavement surface to withstand plow impact.

6.3.7 Other holder constructions may be acceptable at the option of the purchaser following a six-month road test during the time of the year when weather conditions are most critical to determine durability.

7. Performance Requirements

7.1 *Coefficient of Luminous Intensity Before Abrasion*—Measured in accordance with 10.1 the coefficient of luminous intensity R_I of the retroreflective faces before abrasion shall be not less than the values in Table 1.

7.2 *Abrasion Resistance*—After abrasion in accordance with 10.2, the coefficient of luminous intensity R_I of the retroreflective faces measured in accordance with 10.1 shall

TABLE 1 Coefficient of Luminous Intensity R_I

NOTE—Entrance angle component $\beta 1$ and rotation angle ϵ are 0°.

Entrance Angle $\beta 2$	Observation Angle α	Minimum Value R_I, mcd/lx				
		White	Yellow	Red	Green	Blue
0°	0.2°	279	167	70	93	26
+20°/−20°	0.2°	112	67	28	37	10
Entrance Angle $\beta 2$	**Observation Angle α**	**Minimum Value R_I, cd/fc**				
		White	Yellow	Red	Green	Blue
0°	0.2°	3.0	1.8	0.75	1.0	0.28
+20°/−20°	0.2°	1.2	0.72	0.3	0.4	0.11

be not less than the values in Table 1.

NOTE 2—On two-color units the red lens may not be covered with an abrasion-resistant lens surface and if so should not be abraded.

7.3 *Color*—When the retroreflector is illuminated by a CIE Standard Source A and when measured in accordance with 10.3, the color of the retroreflected light shall fall within the color gamuts given by the following corner points and shown in Fig. 1:

7.3.1 *White*

Point No.	x	y
1	0.310	0.348
2	0.453	0.440
3	0.500	0.440
4	0.500	0.380
5	0.440	0.380
6	0.310	0.283

7.3.2 *Yellow*

Point No.	x	y
1	0.545	0.424
2	0.559	0.439
3	0.609	0.390
4	0.597	0.390

7.3.3 *Red*

Point No.	x	y
1	0.650	0.330
2	0.668	0.330
3	0.734	0.265
4	0.721	0.259

7.3.4 *Blue*

Point No.	x	y
1	0.039	0.320
2	0.160	0.320
3	0.160	0.240
4	0.183	0.218
5	0.088	0.142

7.3.5 *Green*

Point No.	x	y
1	0.009	0.733
2	0.288	0.520
3	0.209	0.395
4	0.012	0.494

7.4 *Lens Impact Strength*—When impacted in accordance with 10.5.1 the face of the lens shall show no more than two radial cracks longer than 6.4 mm (0.25 in.). There shall be no radial cracks extending to the edge of the abrasion-resistant area. There shall be no delamination.

7.4.1 *Temperature Cycling*—When subjected to temperature cycling in accordance with 10.5.2 there shall be no cracking or delamination.

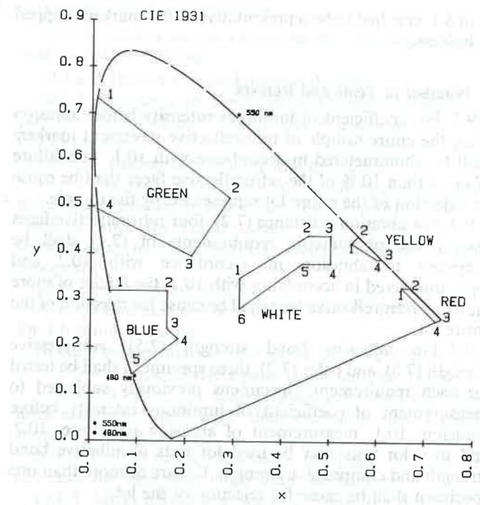


FIG. 1 Color Gamut per 7.3

7.5 *Adhesive Bond Strength:*

7.5.1 For markers intended to be installed in recesses, adhesive bond strength measured in accordance with 10.4.1 shall be not less than 3.4 MPa (500 psi). For adhesives other than those stipulated in 10.4.5 the strength criteria shall be established by the purchaser.

7.5.2 For markers installed in holders, adhesive bond strength measured in accordance with 10.4.2 shall be not less than 45.4 kg (100 lb).

7.5.3 For replacement markers not installed in holders, adhesive bond strength measured in accordance with 10.4.3 shall be not less than 0.08 MPa (12 psi).

7.6 *Compressive Strength*—Tested in accordance with 10.6, a marker shall support a load of 2721 kg (6000 lb) without breakage or significant deformation of the marker. Significant deformation shall be understood to be 3.2 mm (0.13 in.). For markers laminated to an elastomeric pad, remove the pad before testing.

7.7 *Ramp Hardness of Holders*—Measured in accordance with 10.7, the hardness of the ramps shall be 51-55 HRC.

8. Sampling

8.1 For markers supplied not mounted in holders, 26 markers selected at random will constitute a representative sample for each lot consisting of 10 000 markers or less. Forty markers will constitute a representative sample for lots consisting of more than 10 000 markers. The lot size shall not exceed 25 000 markers.

8.2 For markers supplied mounted in holders, the purchaser may require the sample quantities specified in 8.1 or, alternatively for practicality of testing, may require 10 samples of the markers installed in holders and, in addition, require that the manufacturer submit 26 or 40 loose markers,

as in 8.1, certified to be representative of the markers shipped in holders.

9. Number of Tests and Retests

9.1 For coefficient of luminous intensity before abrasion (7.1), the entire sample of retroreflective pavement markers shall be photometered in accordance with 10.1. The failure of more than 10 % of the retroreflective faces shall be cause for rejection of the entire lot represented by the sample.

9.2 For abrasion resistance (7.2), four retroreflective faces passing the photometric requirements of (7.1) shall be subjected to abrasion in accordance with 10.2 and rephotometered in accordance with 10.1; the failure of more than one retroreflective face shall be cause for rejection of the entire lot.

9.3 For adhesive bond strength (7.5), compressive strength (7.6), and color (7.3), three specimens shall be tested for each requirement. Specimens previously subjected to measurement of coefficient of luminous intensity before abrasion, 10.1, measurement of abrasion resistance, 10.2, and to color tests may be used for tests of adhesive bond strength and compressive strength. Failure of more than one specimen shall be cause for rejection of the lot.

9.4 For lens impact strength (7.4.1), resistance to temperature cycling (7.4.2), and ramp hardness of holders (7.7), ten specimens shall be tested for each requirement. Failure of more than one of the specimens in any one test shall be cause for rejection of the entire lot.

9.5 At the discretion of the purchaser, a resample may be taken consisting of double the number of samples originally taken. Tolerances for resamples shall be in the same ratio as specified in 9.1 through 9.4.

10. Test Methods

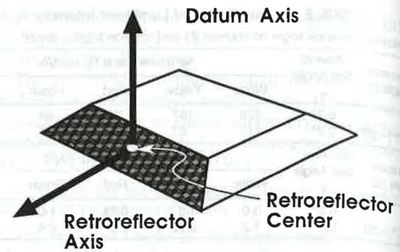
10.1 *Coefficient of Luminous Intensity*—Measure the coefficient of luminous intensity in accordance with Practice E 809 with high resolution angular aperture size in accordance with Table 1 of Practice E 809. Recommended dimensions are as follows: test distance 30.5 ± 0.06 m (100 ± 0.2 ft), receptor diameter 25.4 ± 0.5 mm (1.0 ± 0.02 in.), source diameter 25.4 ± 0.5 mm (1.0 ± 0.02 in.). Other test distances 15.2 m (50 ft) and above may be used provided that the angular aperture requirements are met. Measure the distance from the light source exit pupil to the center of the retroreflective face of the marker. Place the base of the marker on a plane parallel to the illumination axis ($\beta 1 = 0$) and perpendicular to the observation half plane ($\beta 2 = 0$). (See Practice E 809 and Fig. 2.)

10.1.1 If the markers are mounted in a holder photometer the markers in the holder, and if the holder shadows the retroreflective area divide the measured coefficient of luminous intensity by the ratio of the unshadowed retroreflective area to the total retroreflective area for comparison with Table 1.

10.2 *Determination of Abrasion Resistance:*

10.2.1 Select at random four retroreflective faces previously passing the photometric test of 10.1.

10.2.2 Place on the selected retroreflective face a 25.4 ± 5-mm (1 ± 0.2-in.) diameter flat pad of No. 3 coarse steel wool conforming to Federal Specification FF-W-1825A. Apply a load of 22 ± 2 kg (50 ± 0.5 lb) and rub the entire surface 100 times.



Location of retroreflector axis, datum axis and retroreflector center for use in testing raised pavement markers.

Retroreflector Center-located on the surface of the effective retroreflective area, centered both vertically and horizontally.

Retroreflector Axis-extends parallel to the road surface from retroreflector center.

Datum Axis-extends vertically from the road surface plane starting at retroreflector center.

FIG. 2 Position of Marker for Photometry

10.2.3 Photometer in accordance with 10.1.

10.2.4 Remove markers mounted in a holder for abrasion and photometry after abrasion.

10.3 *Color*—Measure color in accordance with Practice E 811 at 0.2° observation angle and 0° entrance angle. The source and receptor angular aperture shall each be 6 min of arc.

10.4 *Adhesive Bond Strength:*

10.4.1 *For Markers Intended to Be Installed in Recesses:*

10.4.1.1 Measure adhesive bond strength in accordance with Sections 12 and 13 of AASHTO No. T 237 but substitute a pavement marker for the concrete block and a 25.4-mm (1.0-in.) diameter plug for the specified 50.8-mm (2.0-in.) plug. Position the pavement marker against a test plate having a hole through which the plug can be inserted and attached to a tensile member.

10.4.1.2 Adhesive used for test should conform to AASHTO No. M 237, Type 1.

10.4.1.3 Conditioning temperature for components shall be 23.0 ± 2.0°C (73.4 ± 3.6°F).

10.4.1.4 Cure the assembly for 24 h at 23.0 ± 2.0°C (73.4 ± 3.6°F).

10.4.1.5 Rate of loading shall be 5.1 mm (0.2 in.)/min.

10.4.2 *For Markers Installed in Holders:*

10.4.2.1 Adhere a 25.4-mm (1.0-in.) diameter pipe plug to the center of the top surface of the marker with epoxy conforming to AASHTO No. M 237, Table I. Allow 24 h

cure at 23.0 ± 2.0°C (73.4 ± 3.6°F).

10.4.2.2 Position the holder against a test plate having a hole through which the plug can be inserted and attached to a tensile member. The hole shall be large enough that it will permit the marker to pass through.

10.4.2.3 Determine force required to separate the marker from the holder at a rate of loading of 5.1 mm (0.2 in.)/min.

10.4.3 *For Replacement Markers Not Installed in Holders:*

10.4.3.1 Remove release paper (if present) from the bottom of the marker. Apply manufacturer-approved adhesive to the face of a sand blasted 25.4-mm (1.0-in.) steel test plug and position the plug on the center of the marker. Apply a compressive force of 75 lb to the test plug for 6 s.

10.4.3.2 Cure 72 h at 23 ± 2°C (73.4 ± 3.6°F).

10.4.3.3 Cut through the adhesive along the circumference of the test plug to limit the area of the adhesive to be tested.

10.4.3.4 Attach the test plug and marker to the platens of a tensile machine and separate the platens at a rate of 5.1 mm (0.2 in.)/min.

10.4.3.5 Conditioning temperature for components shall be 23 ± 2°C (73.4 ± 3.6°F).

10.4.4 *Source of Error:*

10.4.4.1 Variation in thickness of epoxy has been found to influence test results.

10.4.4.2 Lack of parallelism of surfaces of test plug and marker can result in low readings.

10.4.4.3 Variations in adhesive used for testing the marker will affect the test results.

10.4.5 *Precision and Bias:*

10.4.5.1 Since the test is destructive, correlation is affected by differences between test samples. Variations of 20 % within a given lot of markers may be expected.

10.4.5.2 No formal interlaboratory data on precision and accuracy are available. A correlation study to develop these data is planned.

10.5 *Resistance to Lens Cracking:*

10.5.1 Separate markers laminated to an elastomeric pad from the pad before testing.

10.5.2 *Lens Impact Strength*—Condition the markers in a convection oven at 55°C (130°F) for 1 h.

10.5.2.1 While at the elevated temperature, impact the reflective face of the marker by allowing a 190-g (0.42-lb) dart fitted with a 6.4-mm (0.25-in.) radius semispherical head to drop 457 mm (18 in.) perpendicularly onto the approximate center of the reflective surface. For impact testing, set the marker on a steel fixture designed to hold the reflecting face horizontal, and place the fixture on a solid surface such as a concrete floor.

NOTE 3—Markers laminated to an elastomeric pad shall be separated from the pad before testing.

10.5.2.2 Inspect for cracking and delamination.

10.5.3 *Resistance to Temperature Cycling*—Subject samples to 3 cycles of 60°C (140°F) for 4 h followed by −7°C (20°F) for 4 h.

10.5.3.1 Inspect for cracking and delamination.

10.5.4 *Precision and Bias*—No statement is made about either the precision or bias of the test for resistance to lens cracking since the result merely states whether there is conformance to the criteria for success specified in the procedure.

10.6 *Compressive Strength:*

10.6.1 Condition markers at 23.0° ± 2.0°C (73.4° ± 3.6°F) for 4 h prior to testing.

10.6.2 Position marker base down at the center of a 13-mm (0.5-in.) thick flat steel plate larger than the marker.

10.6.3 On top of the marker place a 9.5-mm (0.375-in.) thick elastomeric pad larger than the marker and having a shore A durometer of 60.

10.6.4 On top of the elastomeric pad place a 13 mm (0.5 in.) thick flat steel plate larger than the marker.

10.6.5 Apply a load at a rate of 2.5 mm (0.1 in.)/min.

NOTE 4—Markers laminated to an elastomeric pad shall be separated from the pad before testing.

10.7 *Holder Ramp Hardness Test:*

10.7.1 Prepare spot for test on horizontal surface of ramp close to angled portion by using a hand grinder to remove only a slight amount of metal to smooth surface.

10.7.2 Place the holder in a Rockwell hardness tester with ramps facing upward, and position the holder on the flat anvil of the tester with the smooth area below the indentor.

10.7.3 Check hardness at three locations approximately 1.5 mm (0.06 in.) apart on smooth area, and average the three readings to obtain the hardness.

11. Packaging

11.1 Shipments shall be made in containers which are acceptable to common carriers and packaged in such a manner as to ensure delivery in perfect condition. Any damaged shipments shall be replaced by the contractor. Each package shall be clearly marked as to the name of the manufacturer, type, color, quantity enclosed, and date of manufacture.

12. Keywords

12.1 delineation; plowable markers; raised pavement markers; retroreflective markers

ANNEX

(Mandatory Information)

A1. SPECIFICATION FOR BITUMINOUS ADHESIVE FOR PAVEMENT MARKERS

A1.1 Scope

A1.1.1 This specification establishes the requirements for bituminous installation adhesive to be used for placement of recessed, raised, retroreflective pavement markers. The adhesive shall be suitable for bonding the above markers to portland cement concrete, asphaltic concrete, and chip sealed road surfaces and applicable when road surface and marker temperatures are in the range from 4.4 to 71°C (40 to 160°F). The adhesive properties will not deteriorate when heated to and applied at temperatures up to 218°C (425°F) using either air or oiljacketed melters.

A1.2 General Properties of Adhesive

A1.2.1 The bituminous installation adhesive is an asphaltic material with a homogeneously mixed mineral filler. The adhesive shall not contain rubber polymers since necessary application temperatures cause decomposition, resulting in unsatisfactory performance. The adhesive shall conform to the following requirements:

Property	Minimum	Maximum	Test Method
Softening point, °C (°F)	93 (200)	110 (230)	D 36
Penetration mm × 10^{-1}	10	18	D 5
Flow, mm (in.)	—	5.1 (0.2)	D 3407, as modified in A1.4.1
Heat stability flow, mm (in.)	—	5.1 (0.2)	As in A1.4.2
Viscosity, 204°C (400°F), P	30	75	D 2669, as modified in A1.4.3, or D 4402
Flash point, C.O.C., °C (°F)	288 (550)	—	D 92
Shelf life, years	—	2	

A1.3 General Properties of Filler-Free Material and of Filler Alone

A1.3.1 Asphalt properties determined on the filler-free material derived from the extraction and Abson recovery process as explained in X2.4.4 are as follows:

Property	Minimum	Maximum	Test Method
Penetration, 100 g, 5 s, 25°C (77°F)	25	—	D 5
Viscosity, 135°C (275°F), P	12	100	D 2171
Viscosity ratio, 135°C (275°F)	—	2.2	As explained in A1.4.5

A1.3.2 Filler properties determined using the filler separation technique described in A1.4.6 are as follows:

Property	Minimum	Maximum	Test Method
Filler content, % by weight	65	75	As in A1.4.6
Filler fineness, % passing			
45 µm (No. 325) sieve	75	—	C 430
75 µm (No. 200) sieve	95	—	C 184
150 µm (No. 100) sieve	100	—	C 184

A1.4 Test Methods

A1.4.1 Flow shall be determined in accordance with Section 6 of Test Methods D 3407 with the exception that the oven temperature shall be 70 ± 1°C (158 ± 2°F) and sample preparation shall be in accordance with 7.1 of Test Method D 5.

A1.4.2 Heat stability flow shall be determined in accordance with Section 6 of Test Methods D 3407 with the exception that 1000 g of adhesive shall be placed in a covered quart can, heated to 218°C (425°F) and maintained at this temperature for 4 h prior to preparing the sample panel (6.1).

A1.4.3 Determine viscosity in accordance with Test Methods D 2669 or D 4402. If using Test Method D 2669, use a spindle speed of 10 r/min, and heat the adhesive to approximately 210°C (410°F) and allow to cool; determine viscosity at 204.4 ± 0.5°C (400 ± 1°F). If using Test Method D 4402, the test method describes the spindle and speed to be used with various models.

A1.4.4 Properties of the base asphalt are to be determined on the material obtained from the following extraction and Abson recovery methods. The asphalt shall be extracted by heating the adhesive just to the point where it will easily flow and then transferring 125 to 150 g into 400 mL of trichloroethylene with a temperature of 52 to 65°C (125 to 150°F). This mixture shall be thoroughly stirred to dissolve the asphalt. The trichloroethylene asphalt mixture shall be decanted and the asphalt shall be recovered using the Abson recovery methods, Test Method D 1856, as modified by the following. The extraction methods of Test Method D 2712 shall not apply and there shall be no filtration of the solvent-asphalt mixture. The extraction solution of trichloroethylene and asphalt shall be centrifuged for at least 30 min at 770 times gravity in a batch centrifuge. A continuous centrifuge can be used if the extract solution is charged at a rate not to exceed 150 mL/min while the unit is operating at a speed calculated to produce a centrifuge force of not less than 3000 times gravity, as specified in 9.2 of Test Method D 1856. Decant this solution into the distillation flask, taking care not to include any filler sediment. Apply heat and bubble carbon dioxide slowly to bring the solution temperature to 149°C (300°F). At this point, the carbon dioxide flow is increased to 800 to 900 mL/min. The solution temperature is maintained at 160 to 168°C (320 to 335°F) with this carbon dioxide flow rate for at least 20 min and until the trichloroethylene vapors have been completely removed from the distillation flask. The above extraction-recovery method shall be repeated as necessary to obtain the desired quantity of asphalt. The asphalt recovered shall be used to determine penetration, 135°C (275°F) viscosity, and 135°C (275°F) viscosity ratio.

A1.4.5 The 135°C (275°F) viscosity ratio shall be determined by comparing the 135°C (275°F) viscosity on the base asphalt before and after the Thin-Film Oven Test. The Thin-Film Oven Test shall be performed in accordance with Test Method D 1754. The specific gravity shall be determined by pycnometer in accordance with Test Method D 70 for use in the Thin-Film Oven Test. The 135°C (275°F) viscosity ratio shall be calculated by dividing the viscosity after the Thin-Film Oven Test by the original 135°C (275°F) viscosity.

A1.4.6 To determine the filler content, use the data from the separation described in A1.4.4. The samples used for the asphalt recovery are weighed before the extractions. The extracted filler is weighed after extraction. The bitumen is determined by difference.

A1.4.7 Determine the fineness of the filler according to Test Method C 430 for material finer than the 45 µm (No. 325) sieve. Using a second test sample, determine the percentage of the material passing the 150 µm (No. 100) and 75 µm (No. 200) sieve according to Test Method C 184.

A1.5 Packaging and Labeling

A1.5.1 The adhesive shall be packaged in self-releasing cardboard containers that will stack properly. The containers shall be divided into compartments so that four equal individual parts are obtained from each container. The containers shall have a net weight of approximately 25 kg (55 lb). The label for the container shall clearly show the manufacturer, quantity, lot or batch number, and an indication that the material is bituminous adhesive for pavement markers.

APPENDIX

(Nonmandatory Information)

X1. STORAGE, PLACEMENT, AND INSTALLATION OF PLOWABLE RAISED PAVEMENT MARKERS

X1.1 Storage

X1.1.1 Markers should be stored indoors and should be protected from any source of moisture both during shipment to the jobsite and at the jobsite. The markers should be maintained at a high enough temperature as to preclude moisture condensation, and, at the time of placement, both the markers and their containers should be dry.

X1.2 Placement of Plowable Markers

X1.2.1 Before beginning pavement marker application, the contractor should accurately and adequately lay out, by reference points, the location of all pavement markers to ensure their proper placement. Pavement markers should not be placed on pavement surfaces that show visible evidence of cracking, checking, spalling, or failure of underlying base material. If, during the pre-installation layout operation, it is determined that a marker would be placed at a point with one of the aforementioned pavement surface defects or at a pavement construction joint or within the intersection of a driveway or public street as a result of typical marker spacing, the affected marker should be relocated longitudinally a sufficient distance to a point approved by the engineer. The distance the marker may be relocated should not exceed 10 % of the typical marker spacing. Where it would be necessary to relocate the marker a distance greater than 10 % of the typical marker spacing, the affected marker should be deleted. The reflective face of the marker should be perpendicular to a line parallel to the roadway centerline.

X1.3 Installation of Plowable Markers of the Plow Blade Deflecting Type

X1.3.1 At the time of installation, the pavement marker holder should be free of dirt, dust, oil grease, rust, moisture, or any foreign matter that will impair adhesion to the pavement. It should be the contractor's responsibility to clean each contaminated holder by sand blasting or other acceptable procedure to remove all such foreign matter prior to installation.

X1.3.2 The pavement should be machined to match the bottom contour of the marker holder. The holders should be installed within seven days after the slots are cut into the pavement.

X1.3.3 The adhesive should be an epoxy adhesive complying with the formulations given in Table X1.1.

X1.3.4 The epoxy adhesive should be mixed by combining components A and B in a ratio of 1:1 by volume. The epoxy adhesive requires that the mixing operation and placing of the pavement markers be done rapidly. Any mixed batch that becomes so viscous that it cannot be readily extruded from under the holder under light pressure should not be used. The adhesive should be maintained at 15 to 27°C (60 to 80°F) before mixing. Any heating of the epoxy should be by the application of indirect heat. The adhesive should not be heated above 49°C (120°F).

X1.3.5 During installation of the holders with epoxy adhesive, the ambient temperature and pavement temperature should be at least 10°C (50°F).

X1.3.6 Before installing the markers, the recesses should be brushed or blown clean of loose material and should be dry. Sufficient epoxy should be placed in the recess to ensure that all voids beneath and around the holder are filled so as to create a watertight seal around the holder. The holder should be hand placed into the recess in such a manner as to ensure that the tips of the holder's snowplow deflecting surface(s) are below the pavement surface.

TABLE X1.1 Epoxy Adhesive Formulation

Components	Parts By Weight
Component A:	
Epoxy resin (EPON 828 or equal)	100.0
Titanium dioxide	8.0
No. 13 talc	37.0
Component B:	
N-Aminoethyl piperazine (Jefferson or equal)	25.0
Nonyl phenol	50.0
Talc (Fiberline C-400, Sierra or equal)	70.0
Molacco Black	0.12
Cabasil[A]	0.5

[A] Cabasil was added to inhibit settling.

X1.4 Installation of Recessed Plowable Markers

X1.4.1 *Recommended Dimensions of Groove for Recessed Markers:*

X1.4.1.1 Groove length should be 1.1 m (42 in.) minimum from leading edge of the reflective marker to the beginning of the groove.

X1.4.1.2 Groove depth should be sufficient to accommodate the reflective marker with the top of the marker flush with or recessed to 1.5 mm (0.06 in.) below the pavement surface.

X1.4.1.3 Groove bottom may parallel the pavement surface or be tapered.

X1.4.2 *Application of Recessed Plowable Markers:*

X1.4.2.1 Before installing markers the recesses should be brushed or blown clean of loose material and should be dry.

X1.4.2.2 The marker should be positioned with its top surface flush to 1.5 mm (0.06 in.) below the pavement surface.

X1.4.2.3 Markers should be cemented to the pavement with Rapid Set Type adhesive conforming to AASHTO No. M 237, Type 1, Standard Set Type adhesive conforming to AASHTO No. 237, Type 2, or with bituminous adhesive corresponding to the requirements of Annex A1. The engineer should be the judge as to when Rapid Set Type adhesive has set sufficiently to bear traffic. If rapid set adhesive is to be used the engineer should determine that deterioration of the adhesive caused by accumulated water will not be a problem.

X1.4.2.4 Regardless of the type of adhesive used, markers should not be placed under the following conditions:

(*1*) When either the pavement or the air temperature is 0°C (32°F) or less when using rapid set epoxy, 10°C (50°F) or less when using standard set epoxy or 4.4°C (40°F) or less when using bitumen.

(*2*) If the relative humidity of the air is greater than 80 %.

(*3*) If the pavement is not surface dry.

(*4*) On new asphalt concrete surfacing until the surfacing has been opened to public traffic for a period of not less than 14 days.

X1.4.2.5 The adhesive should be placed uniformly on the groove surface or on the bottom of the marker in a quantity sufficient to result in complete coverage of the area of contact of the marker with no voids present and with a slight excess after the marker has been pressed in place. The marker should be placed in position and pressure applied until the top surface of the marker is flush with the pavement surface. Excessive adhesive around the edge of the marker, excess adhesive on the pavement, and adhesive on the exposed surfaces of the markers should be immediately removed. Soft rags moistened with mineral spirits conforming to Federal Specification TT-T-291 or kerosine may be used, if necessary, to remove adhesive from exposed faces of pavement markers. No other solvent should be used. The marker should be protected against impact until the adhesive has hardened to the degree designated by the engineer.

X1.4.2.6 The adhesive requires that the mixing operation and placing of the markers be done rapidly. When hand mixing the Standard Set Type adhesive, not more than 1 L (1 qt), and the markers should be aligned and pressed into place within 5 min after mixing operations are started. Any mixed batch which becomes so viscous that the adhesive cannot be readily extruded from under the marker on application of slight pressure should not be used. Rapid Set Type adhesive should not be mixed by hand.

X1.4.2.7 The Rapid Set Type adhesive should be mixed by a two-component type automatic mixing and extrusion apparatus. When machine mixing the Standard Set Type adhesive or the Rapid Set Type adhesive, the markers should be placed within 60 s after the adhesive has been mixed and extruded and no further movement of the marker should be allowed. In addition, no more than 90 s should be permitted between the time the adhesive is pumped into the mixing head and the time this adhesive is in place on the roadway and not subject to further movement. The mixed adhesive should not remain in the mixing head for more than 45 s. Adhesive remaining in the mixing head longer than this period should be wasted before resuming the operation. Automatic mixing equipment for the epoxy adhesive should use positive displacement pumps and should properly meter the 2 components in the specified ratio, ±5 % by volume of either component. At the beginning of each day and at any other time ordered by the engineer, the ratio should be checked by the contractor in the presence of the engineer. This check should be made by disconnecting the mixing heads, or using suitable bypass valves, and filling two suitable containers with the unmixed components. The mixing head should properly mix the two components so that there is no trace of black or white streaks in the mixed material.

X1.4.2.8 Voids in a cured, undisturbed sample of the mixed adhesive obtained from the extrusion nozzle should not exceed 4 %.

X1.4.2.9 Bituminous adhesive should be dispensed from a thermostatically controlled melter-applicator at a temperature of 191 to 218°C (375 to 425°F). The adhesive should be stirred frequently to ensure even heating. The adhesive should be dispensed in a puddle larger than the bottom of the marker, and the marker should be dropped onto the puddle as quickly as possible, preferably within 5 s of adhesive placement. The marker should be pressed lightly onto the adhesive. The adhesive will set up in approximately 2 min and typically requires no protection from traffic.

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Designation: D 4460 – 85 (Reapproved 1991)

Standard Practice for Calculating Precision Limits Where Values are Calculated from Other Test Methods[1]

This standard is issued under the fixed designation D 4460; 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 describes techniques for calculating precision limits when values are calculated from two other methods having precision limits.

1.2 *This standard does not purport to address all of the safety problems, 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 1188 Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens[2]

D 2041 Test Method for Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures[2]

D 3203 Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures[2]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[3]

3. Definitions

3.1 For definitions of terms used in this document, consult Practice E 177, or a standard dictionary, or a statistical text from Refs. **(1, 2, and 3)**.[4]

4. Significance and Use

4.1 Precision limits for a test result which is calculated by addition, subtraction, multiplication, or division of two other test results that have valid precision limits can be calculated directly. This saves the cost and delay of conducting an interlaboratory study.

4.2 At the heart of statistical theory is the concept of a frequency distribution of a random variable. The precision limit of the random variable is determined by the standard deviation of the variable. The standard deviation of a random variable that is the sum, difference, product, or quotient of two other random variables can be calculated simply so long as the individual variables are independent and the standard deviations are small relative to their mean values. These restrictions are usually met in ASTM methods. In those cases where these restrictions are not met, other methods can be used. Only cases complying with the restrictions are covered in this standard.

5. Procedure

5.1 The standard deviation on which precision limits for a test result are based can be calculated from the following equations:

$$\sigma_{x \pm y} = \sqrt{\sigma_x^2 + \sigma_y^2} \quad (1)$$

where:

$\sigma_{x\pm y}$ = standard deviation for determining precision limits of a test result for a new standard based on either an addition or subtraction of test results from two other standards,

σ_x = standard deviation from precision statement of one of the standards on which new standard is based, and

σ_y = standard deviation from precision statement of other standard on which new standard is based.

The distributions of the test results from the two standards should be independent.

$$\sigma_{xy} = \sqrt{\bar{y}^2\sigma_x^2 + \bar{x}^2\sigma_y^2} \quad (2)$$

where:

σ_{xy} = standard deviation for determining precision limits of test results for a new standard based on the products of two other test results from two other standards,

σ_x = standard deviation from precision statement of one of the standards on which new standard is based,

$\bar{x}$ = mean or average value of X variable,

σ_y = standard deviation from precision statement of other standard on which new standard is based, and

$\bar{y}$ = mean or average value of Y variable.

$$\sigma_{\frac{x}{y}} = \sqrt{\frac{\bar{y}^2\sigma_x^2 + \bar{x}^2\sigma_y^2}{\bar{y}^4}}$$

where

$\sigma_{\frac{x}{y}}$ = standard deviation for determining precision limits of test results for a new standard based on the quotient of two test results from two other standards.

σ_x, σ_y, $\bar{x}$, $\bar{y}$ = definitions given above.

An example in Appendix X1. illustrates how the equations are applied.

[1] This practice is under the jurisdiction of ASTM Committee D-4 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.94 on Statistical Procedures and Evaluation of Data.

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[2] *Annual Book of ASTM Standards*, Vol 04.03.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.