INTERNATIONAL

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Standard Test Method for Wind Resistance of Asphalt Shingles (Uplift Force/Uplift Resistance Method)[1]

This standard is issued under the fixed designation D7158/D7158M; 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 test method covers the procedure for calculating the wind resistance of asphalt shingles when applied in accordance with the manufacturer's instructions, and sealed under defined conditions. Shingle designs that depend on interlocking or product rigidity to resist the wind cannot be evaluated using this test method. The method calculates the uplift force exerted on the shingle by the action of wind at a specified velocity, and compares that to the mechanical uplift resistance of the shingle. A shingle is determined to be wind resistant at a specified basic wind speed when the measured uplift resistance exceeds the calculated uplift force for that velocity (3-second gust, ASCE 7).

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values 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 *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]

D228/D228M Test Methods for Sampling, Testing, and Analysis of Asphalt Roll Roofing, Cap Sheets, and Shingles Used in Roofing and Waterproofing

D1079 Terminology Relating to Roofing and Waterproofing

D3161/D3161M Test Method for Wind-Resistance of Steep Slope Roofing Products (Fan-Induced Method)

D3462/D3462M Specification for Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules

D6381/D6381M Test Method for Measurement of Asphalt Shingle Mechanical Uplift Resistance

2.2 *ASCE Standard:*[3]

ASCE 7-10 Minimum Design Loads for Buildings and Other Structures

ASCE 49-12 Wind Tunnel Testing for Buildings and Other Structures

2.3 *ANSI/UL Standard:*

ANSI/UL 2390–04 Test Method for Wind Resistant Asphalt Shingles with Sealed Tabs[4]

3. Terminology

3.1 *Definitions:*

3.1.1 For definition of terms used in this test method, refer to Terminology D1079.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *sealant—as it relates to steep roofing shingles*, is defined as factory-applied or field-applied typically asphaltic material designed to seal the shingles to each other under the action of time and temperature after the shingles are applied to a roof.

3.2.2 *seal—as it relates to steep roofing shingles*, is the bonding that results from the activation of the sealant under the action of time and temperature.

3.2.3 *sealed*—the condition of the shingles after they are subjected to the conditioning procedure described in 10.3.

4. Types and Classes of Shingles

4.1 Shingles are classified based on their resistance to wind velocities determined from measured data (Section 11), calculations of uplift force (Section 12), and interpretation of results (Section 13), as follows:

4.1.1 *Class D*—Passed at basic wind speeds up to and including 185 km/h [115 mph].

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[1] This test method is under the jurisdiction of ASTM Committee D08 on Roofing and Waterproofing and is the direct responsibility of Subcommittee D08.02 on Steep Roofing Products and Assemblies.

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[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.

[3] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

4.1.2 *Class G*—Passed at basic wind speeds up to and including 241 km/h [150 mph].

4.1.3 *Class H*—Passed at basic wind speeds up to and including 306 km/h [190 mph].

5. Summary of Test Method

5.1 The uplift force induced by wind passing over the surface of asphalt shingles is determined by calculation involving the uplift coefficients obtained from pressures measured above and below the shingle at the windward and leeward sides of the sealant, taking into account the desired basic wind speed classification and the uplift rigidity of the shingle. The calculated uplift force (F_T) for each of the possible classifications is compared to the measured uplift resistance (R_T) of the sealed shingle to establish the wind resistance classification of the shingle.

5.2 The method involves three steps:

5.2.1 Uplift coefficients are determined by measuring pressure differences above and below the shingle as air moves over the surface of a deck of sealed shingles under controlled conditions.

5.2.2 The uplift forces acting on the shingle are calculated, using the wind uplift coefficients, shingle sealant configuration and a specific basic wind speed.

5.2.3 Shingle uplift resistance to that specific basic wind speed is determined by comparing the calculated uplift forces acting on the sealant to the uplift resistances measured with Test Method D6381/D6381M. Uplift resistances from Procedure A and Procedure B are applied against the uplift forces in a manner detailed in the calculation section.

5.3 This test method is applicable to any asphalt shingle surfaced with mineral granules where the shingle above is affixed to the surface of the shingle below with a sealant (factory or field applied) applied in a pattern aligned parallel to the windward edge of the shingle.

NOTE 1—It is not prohibited to use this test method for research purposes using variations in the number and placement of fasteners. If this is done, the report shall include details of the number and placement of fasteners.

6. Significance and Use

6.1 The wind resistance of sealed asphalt shingles is directly related to the ability of the sealed shingle to resist the force of the wind acting to lift the shingle from the shingle below. This test method employs the measured resistance of the shingle to mechanical uplift after sealing under defined conditions, in a calculation which determines whether this resistance exceeds the calculated force induced by wind passing over the surface of the shingle. Natural wind conditions differ with respect to intensity, duration, and turbulence; while these conditions were considered, and safety factors introduced, extreme natural variations are beyond the means of this test method to simulate.

6.2 Many factors influence the sealing characteristics of shingles in the field; for example, temperature, time, roof slope, contamination by dirt and debris, and fasteners that are misaligned or under driven and interfere with sealing. It is beyond the scope of this test method to address all of these influences. The classification determined in this test method is based on the mechanical uplift resistance determined when representative samples of shingles are sealed under defined conditions before testing.

6.3 The calculations that support the Classes in 4.1 use several standard building environment factors. These include the 3-s wind gust exposure from ASCE 7-10, installation on Category I through IV buildings for all slopes, surface ground roughness B or C, and installation on buildings 60 ft tall or less.

NOTE 2—The assumptions used in the calculations for the classes in 4.1 cover the requirements for the majority of the asphalt shingle roofs installed. If environmental factors are outside those used in the calculations for these classes, such as surface ground roughness D, building heights greater than 60 ft tall, and other exposures as defined by ASCE 7-10, other calculations are required. Consult the shingle manufacturer for the specific shingle's DCp, EI, L, L1, and L2 values needed to complete these calculations.

6.4 The test to determine uplift coefficients is conducted with a wind velocity of 15.6 ± 1.3 m/s [35 ± 3 mph]. Research data obtained during the development of this test procedure, as well as standard wind modeling practices, provides for data extrapolation to other wind speeds. In order to simulate the raised shingle edge that is inherent behavior under high wind exposure, shims are inserted under the windward edge of the shingle as appropriate based on wind speed and uplift rigidity of the shingle being investigated. This test method provides a means of measuring shingle uplift rigidity which is used to determine the correct shim thickness. Additionally, this test method allows for the use of a default value for uplift rigidity (EI) of 7175 N-mm^2 [2.5 lbf-in.^{2}], if a rigidity measurement is not made. This default value is conservative since the lowest EI measured in the development of this program was 14 350 N-mm^2 [5.0 lbf-in.^{2}].

NOTE 3—The entire field of wind engineering is based on use of small-scale models in wind tunnels using wind speeds much lower than the full-scale values. Building Codes permit testing of this type to replace the analytical provisions of the Building Code through the provisions of ASCE 7-10. (See Appendix X1 for details and references.)

7. Apparatus

7.1 The apparatus described in Test Method D6381/D6381M, Procedure A, modified as described below, is used to determine the uplift rigidity of the shingle being evaluated.

7.2 The apparatus described in Test Method D3161/D3161M, modified as described below, is used to determine the wind uplift coefficient of the shingle being evaluated.

7.3 Air flow instrumentation capable of continuously measuring and recording time-averaged velocity accurate to ±0.45 m/s [±1.0 mph] and a method of traversing the measurement device above the test deck is used to measure velocities of the air flow.

7.4 Air pressure instrumentation capable of continuously measuring and electronically recording the time-averaged pressures of 2.5 to 311 Pa [0.01 to 1.25 in. of water] is used to measure the pressure above and below the shingle on the test deck.

7.5 Shims of thickness 1 ± 0.05 mm [0.04 ± 0.002 in.] and a maximum length and width of 5.1 by 5.1 mm [0.2 by 0.2 in.] are used to lift the windward edge of the shingle during part of the wind uplift coefficient measurements (see 11.2.5). Shims of other thicknesses, but a minimum of 0.1 mm [0.004 in.], and a maximum width and length of 5.1 by 5.1 mm [0.2 by 0.2 in.], are used as required, alone or in combination, to lift the windward edge to the height calculated from the shingle deflection (see 11.2.13).

NOTE 4—The modifications to the Test Method D3161/D3161M apparatus to induce turbulence, the air flow and pressure measurement instrumentation, and the shims employed, are consistent with the procedure developed for Test Method ANSI/UL 2390 for shingle wind resistance testing.

7.6 The apparatus described in Test Method D6381/D6381M is used to determine the mechanical uplift resistance of the shingle being evaluated. The selection of Procedure A or B in Test Method D6381/D6381M is dictated by the magnitude of the forces in front of (F_F) and behind (F_B) the sealant as calculated using the measured wind uplift coefficient and the geometry of the shingle being evaluated (see 12.2).

8. Preparation of Apparatus

8.1 *Shingle Uplift Rigidity*—Use a metal shim 90 by 90 mm [3.5 by 3.5 in.] with thickness equal to or greater than that of the jaw of the pendant clamp in Test Method D6381/D6381M to allow insertion of the jaw of the pendant clamp without deflecting the specimen before the test begins. Insert the shim all the way to the base ("stop") of the specimen clamp on the lower fixture. The second specimen clamp on the lower fixture is not used in this test. The same "stop" shall be used each time for both the shim and the specimens. See Fig. 1.

8.2 *Shingle Wind Uplift Coefficient:*

8.2.1 Install devices to induce the desired turbulent air flow from the fan-induced wind apparatus used in Test Method D3161/D3161M as follows:

8.2.1.1 Install a turbulence grid as shown in Fig. 2 in the air flow exit orifice of the fan-induced wind apparatus.

8.2.1.2 Install a bridge panel with roughness strips between the air flow orifice of the apparatus used in Test Method D3161/D3161M and the test deck as shown in Fig. 3.

8.2.1.3 The overall arrangement of a modified Test Method D3161/D3161M apparatus is shown schematically in Fig. 4.

8.2.1.4 Test decks shall be constructed in accordance with Test Method D3161/D3161M, with the shingles applied in accordance with the manufacturer's instructions. The test deck sits on an adjustable stand, and is fixed at 910 mm [36 in.] from the air flow orifice. A rigid bridge with roughness strips (as shown in Fig. 4) is placed between the orifice and the test deck, and there is no step between the bridge and the deck. The bridge and the deck are both set at a slope of 1.6 ± 0.5 degrees. A minimum of 4 ft [1.2 m] of clear space shall be maintained at the sides and back of the test panel deck.

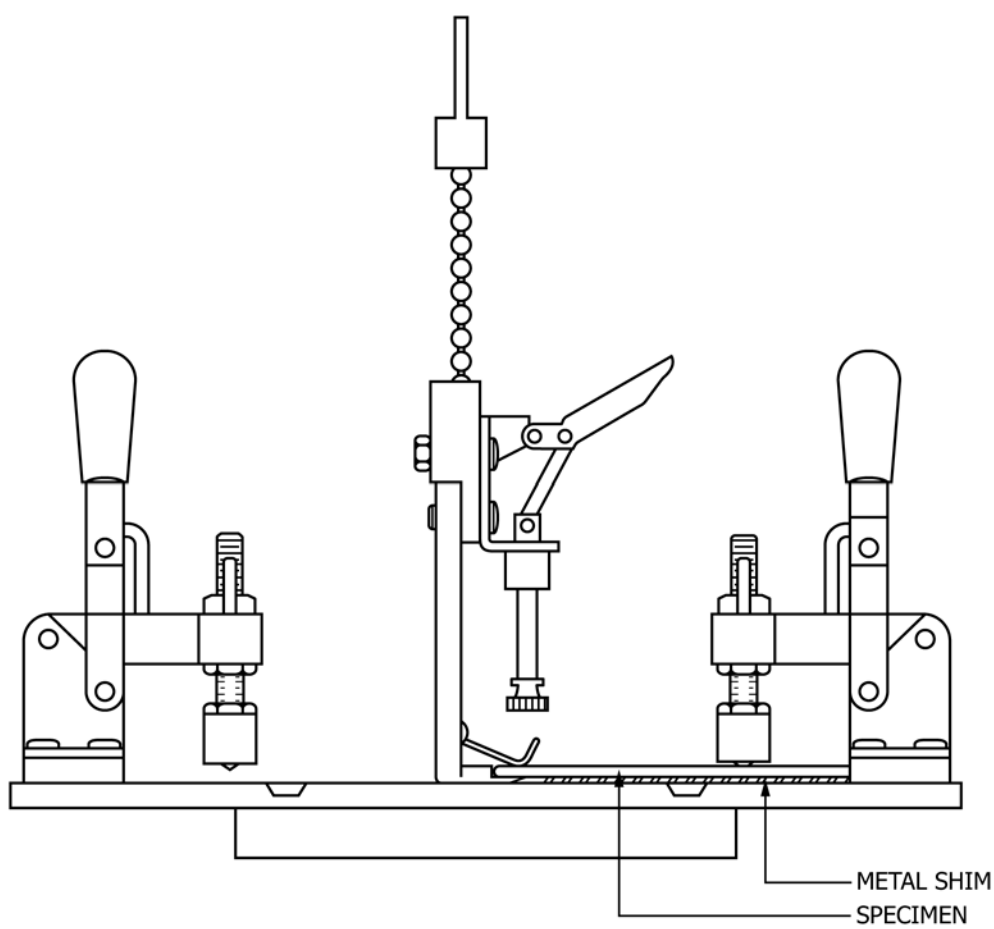
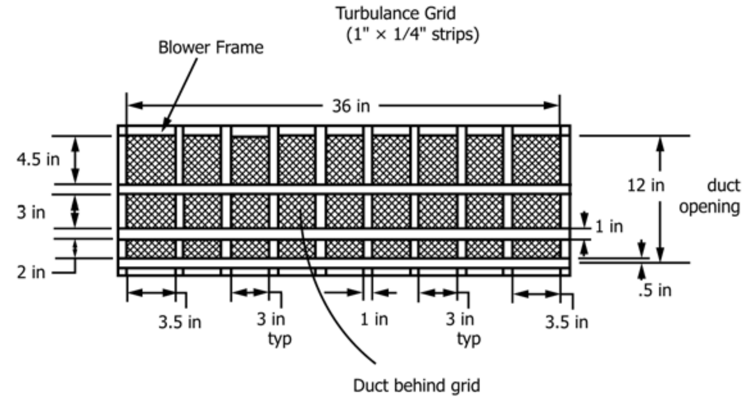
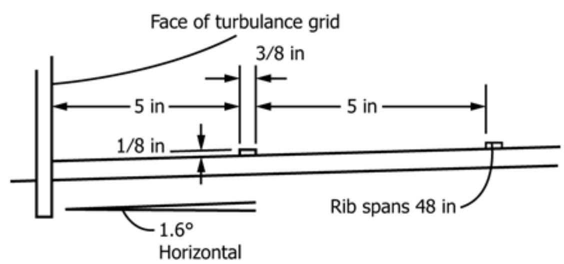


FIG. 1 Apparatus Used in Test Method D6381/D6381M Modified for this Test Method Using a Metal Shim and Using Only One Specimen Clamp



NOTE 1—1 in. = 25.4 mm.

FIG. 2 Turbulence Grid Installed at Air Flow Exit Orifice of Apparatus Used in Test Method D3161/D3161M



NOTE 1—1 in. = 25.4 mm.

FIG. 3 Bridge Panel with Roughness Strips Installed Between Air Flow Exit Orifice of Apparatus Used in Test Method D3161/D3161M and Test Deck

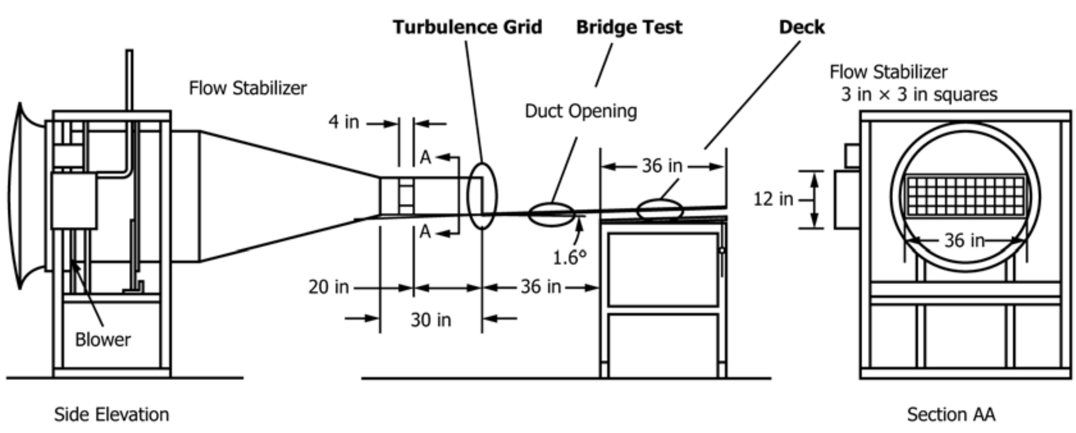


FIG. 4 Overall Schematic of Test Arrangement for Determination of Wind Uplift Coefficient

8.2.1.5 The measurement area, as shown in Fig. 5, is an area of 305 by 178 mm [12 by 7 in.] with the long direction perpendicular to the airflow. The area is centered 635 mm [25 in.] from either side of the 1.27 m [50 in.] dimension of the test deck. The front edge of the measurement area shall be the first course of shingles located within the measurement area with its windward edge at least 356 mm [14 in.] from the edge of the test deck closest to the air source.

8.2.1.6 Calibrate the air flow as follows: A vertical velocity profile of time-averaged (mean) velocity shall be measured at the center of the measurement area at 12.7 and 25.4 mm [0.5 and 1.0 in.] above the surface, and at every 25.4 mm [1.0 in.] above the previous measurement to a height of 152 mm [6 in.]. The velocity will increase with distance from the surface, reach a peak value, and begin to decrease with additional height. Record the maximum velocity and its height. This maximum velocity shall be at least 15.6 ± 1.3 m/s [35 ± 3 mph]. A horizontal profile of time-averaged velocities across the measurement area shall be made at the height of maximum velocity (see Note 5) in the vertical profile, and progressing in 25.4 mm [1.0 in.] steps in both horizontal directions perpendicular to the airflow within the boundaries of the 305 mm [12 in.] wide

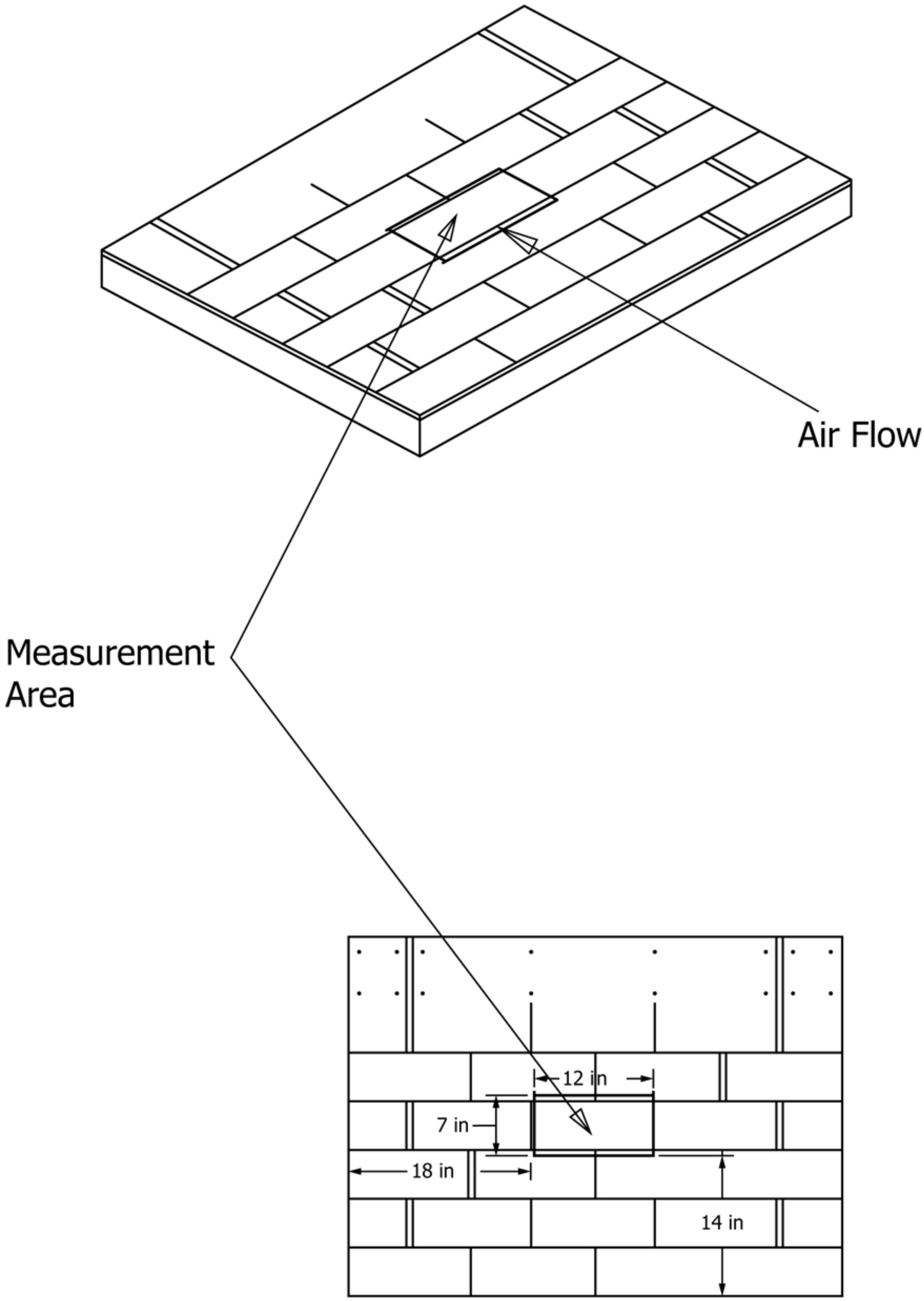


FIG. 5 Typical Test Deck Showing Area where Measurements are Made Using Pressure Taps

measurement area. All velocities in the horizontal profile shall be within ±5.0 % of the maximum velocity recorded in the vertical profile.

NOTE 5—This height has been demonstrated to occur at approximately 102 mm [4 in.].

8.2.2 *Installation of Pressure Taps in the Test Decks:*

8.2.2.1 Pairs of pressure taps, used to measure uplift pressure, shall be installed in at least four places on one shingle (or section of shingle for multi-layered shingles) (see Fig. 6). Four pairs of taps shall be used when the shingle under test has a single sealant stripe pattern, and two additional pairs of taps shall be installed, on a line centered between the most windward and second-most windward stripes, to measure uplift pressure for shingles with multiple parallel sealant stripe patterns.

8.2.2.2 The first shingle having its windward edge within the measurement area shall be tapped. The distance L shall be measured and recorded. Two lines of pressure taps shall be placed at L/2 and at L/2 + 76 mm [L/2 + 3 in.] from the windward edge. For standard 3-tab shingles, pressure taps shall be placed 51 and 76 mm [2 and 3 in.] on either side of the flow centerline as shown in Fig. 6. In situations where the specified locations do not provide sufficient space for pressure differentials to be determined, other locations near the windward edge

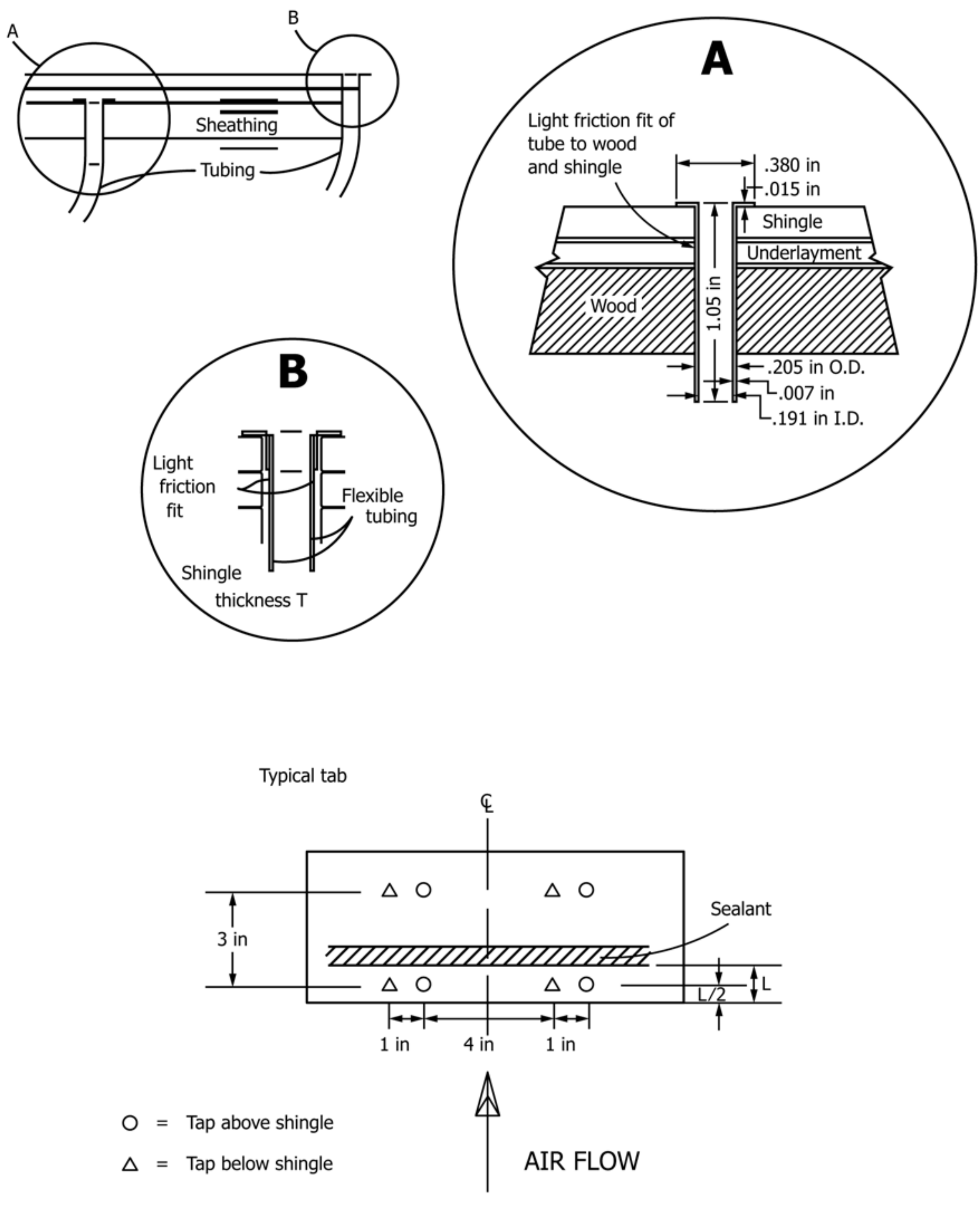


FIG. 6 Pressure Tap Details and Installation Locations on Selected Shingle in Measurement Area (Single Stripe Sealant Pattern Shown)

and near the center of the shingle that do provide the pressure differentials shall be selected. Additional taps are not prohibited. For laminated tabs, or other tab or sealant designs, the taps shall be located in the same manner, proportioned to the area being measured.

8.2.2.3 Each pressure tap is a tube with ID of 4.9 to 6.4 mm [0.19 to 0.25 in.]. The bottom pressure tap shall have a tube long enough to project below the sheathing panel for connection to a pressure measurement device. The top pressure tap shall pass through a hole drilled in the shingle, and sheathing below the shingle, and have a light friction fit, as shown in detail B of Fig. 6. The flexible tubing shall be long enough so that it can maintain connection to a pressure measurement device after moving up with the deflected shingle.

8.2.2.4 A pressure measurement device is connected to each of the pressure tubes below the deck sheathing. The pressure measurement device shall be capable of measuring pressures of 2.5 to 311 Pa [0.01 to 1.25 in. of water]. Time-average pressure measurements shall be made at each tube. Seal each pressure tap tube during measurements of other taps so that no flow occurs through the taps. (Plug or pinch the flexible connecting tube under the deck.)

8.2.3 *Measurements of sealant location* and stripe patterns, which influence the position of the pressure taps, are used in the calculation of wind uplift force.

8.2.3.1 The following information shall be measured, or determined from the manufacturer's installation instructions, for the shingle being evaluated (see Fig. 7):

(1) Exposure—The transverse dimension of the shingle (parallel to the roof slope) not overlapped by the shingle directly above it as installed on the roof.

(2) L—The distance measured from the windward edge of the most windward sealant pattern stripe to the windward edge of the affixed shingle as installed on the roof.

(3) L1—The distance measured from the centerline of the sealant stripe pattern to the windward edge of the affixed shingle as installed on the roof. For shingle designs with two or more parallel stripes of sealant, the distance is measured from

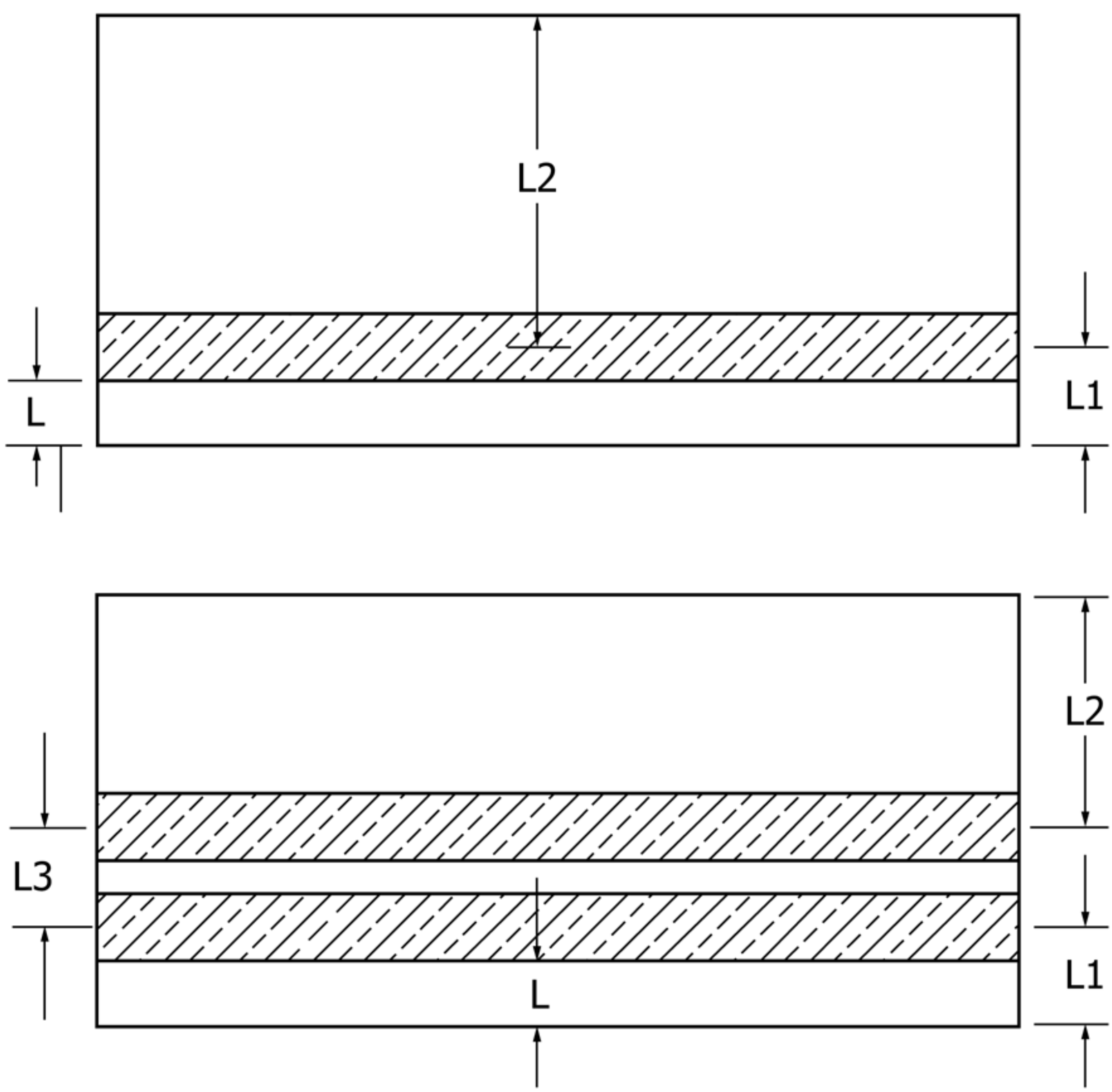


FIG. 7 Measurements Required for Calculation of Uplift Coefficients for Shingles with Single and Double Sealant Stripe Configurations

the centerline of the most windward strip of sealant to the windward edge of the affixed shingle as installed on the roof.

(4) L2—The distance measured from the centerline of the sealant stripe pattern of the affixed shingle to the windward edge of the shingle directly above as installed on the roof. For shingle designs with two (or more) parallel stripes of sealant, the distance is measured from the centerline of the second (from the windward) stripe of sealant of the affixed shingle to the windward edge of the shingle directly above as installed on the roof.

(5) L3—The distance from centerline to centerline of the two most windward sealant stripes for those shingle designs that include two (or more) parallel stripes of sealant.

8.3 *Shingle Mechanical Uplift Resistance*—Prepare the apparatus of Test Method D6381/D6381M to perform procedure A or B as dictated by the results of the wind uplift coefficient measurements and the shingle geometry (see 12.2).

9. Sampling, Test Specimens, and Test Units

9.1 *Shingle Uplift Rigidity:*

9.1.1 Ten representative samples for test shall be selected using the sample selection procedures in Test Methods D228/D228M. Specimens shall be cut from the windward edge of the representative shingle samples.

9.1.2 The test specimens shall be 95 by 102 mm [3¾ by 4 in.] with one of the 95 mm sides being representative of the windward edge (lower exposed edge) of the shingle.

9.2 *Shingle Wind Uplift Coefficient:*

9.2.1 Prepare the test decks for determination of the wind uplift coefficient in accordance with Test Method D3161/D3161M except as described below. Four decks are required for each shingle being evaluated.

9.2.2 Install pressure taps as directed in 8.2.2 before the deck is sealed.

9.2.3 Install shims as directed in 11.2.4 after the deck is sealed, and after testing in the un-shimmed condition, in 11.2.2.

9.3 *Shingle Mechanical Uplift Resistance:*

9.3.1 Sample in accordance with Test Method D6381/D6381M using Procedure A or B as dictated by the measured wind uplift coefficients and the shingle geometry (see 12.2).

10. Conditioning

10.1 Condition the specimens for determination of shingle uplift rigidity on a flat surface at 23 ± 2.5°C [73 ± 4°F] for at least 2 h, and conduct the test at the same temperature.

10.2 Condition the test panel for determining the wind uplift coefficient in accordance with Test Method D3161/D3161M.

10.3 Seal the specimens for mechanical uplift testing at a temperature of 57 to 60°C [135 to 140°F] for a continuous period of 16 h.

10.3.1 After sealing, condition the specimens for the shingle mechanical uplift test at 23 ± 2.5°C [73 ± 4°F] for at least 1h and conduct the test at the same temperature.

11. Procedure

11.1 *Determination of the Shingle Uplift Rigidity (EI):*

11.1.1 The value for shingle uplift rigidity (EI) needed in the calculation of the wind uplift coefficient shall be determined by one of two methods: *(a)* testing shingle rigidity in accordance with the following sections, or *(b)* by selecting a conservative value of 7175 N-mm^2 [2.5 lbf-in.^{2}] for shingles that comply with Specification D3462/D3462M.

11.1.2 The conditioned shingle specimen, weather-side up, is inserted in the Test Method D6381/D6381M fixture (see Fig. 1) over the shim, with the specimen's leading edge overhanging the shim near the centerline of the device and with its side edges flush with both the shim and the fixture. This overhang provides space for the bottom portion of the pendant clamp to be inserted without lifting the specimen. Specimens with sealant on their lower surface shall have the sealant covered by release paper or film to prevent sticking to the fixture or shim.

11.1.3 Specimens shall be tested by clamping them (see Fig. 1) and measuring the distance, l_{test}, from their leading edge (the windward edge) to the front edge of the clamp. A load is then uniformly applied to lift the free, unclamped, leading edge, and the load required to deflect the shingle by specified amounts is measured.

11.1.4 The "load versus deflection" data, averaged from ten tests shall be used to calculate the in-place (that is, applied to roof) shingle uplift rigidity (EI).

11.1.5 The tester shall be zeroed with the top (pendant) assembly hanging freely. At the start of the test, the lower fixture will support the pendant assembly so that the load reading will be negative. As the test progresses (the crosshead moves) the load will pass through zero, and this becomes the "zero" point for measuring both load and deflection.

11.1.6 Record the following information required to calculate the shingle uplift rigidity.

11.1.6.1 The distance, l_{test}, from the exposed end of the specimen to the front edge of the clamp holding the specimen in place on the fixture (measured to the nearest 1 mm [0.04 in.]),

11.1.6.2 Δf, the load at deflections of 5 and 13 mm [0.2 and 0.5 in.], and

11.1.6.3 Δδ, the amount of deflection.

11.1.7 Calculate the average Δf/Δδ using the loads recorded at the two specified deflections for the 10 specimens, where:

SI Units:
$\Delta f\ (N) = \Sigma(f13 - f5)/10$ for n = 1, 2...10, and
$\Delta\delta\ (mm) = \Sigma(\delta13 - \delta5)/10$ for n = 1, 2...10
U.S. Customary Systems Units:
$\Delta f\ (lbf) = \Sigma(f0.5 - f0.2)/10$ for n = 1, 2...10, and
$\Delta\delta\ (in.) = \Sigma(\delta0.5 - \delta0.2)/10$ for n = 1, 2...10)

11.1.8 Calculate the shingle uplift rigidity, EI, as follows using the averaged values of Δf/Δδ and l_{test}.

$$EI = (\Delta f/\Delta\delta)\cdot(l^3_{test})/3 \quad (1)$$

11.2 *Determination of the Shingle Wind Uplift Coefficient (DCp):*

11.2.1 A minimum of four panels are evaluated without shims and re-evaluated with shims as directed below.

11.2.2 With the test deck in position, and without shingle-lifting shims in place, start the air-flow test apparatus and adjust it to produce an air velocity of 15.6 ± 1.3 m/s [35 ± 3 mph] as measured at the reference velocity position illustrated in Fig. 8, or positions aligned with each respective set of tap locations. For multi-layer (laminated) shingles, the reference velocity position shall be aligned with the respective set of tap locations. The ambient temperature shall be 23 ± 3°C [75 ± 5°F]. (See Appendix X1, Background, to correlate test velocity and design wind speed.)

11.2.3 Measure the mean pressures at each of the pressure taps installed on the deck, and the mean air velocity (Uref) at the reference velocity position. Record the pressures at each tap location at 1-s time intervals for a minimum of 30 s. The mean air velocity (Uref) is not required to be measured at the reference velocity position when the dynamic pressure of the air flow (P) is measured directly at the reference velocity position with a Pitot-static probe using the following equation:

$$P = \frac{1}{2}\rho Uref^2 \quad (2)$$

where:

P = the mean pressure difference across a Pitot-static probe recorded at 1-s time intervals for a minimum of 30 s,
ρ = air density, and
$Uref$ = mean air velocity, calculated from P above.

For P converted to lbf/ft^2 and Uref to mph, use the numerical coefficient 0.00256 for (½ ρ).

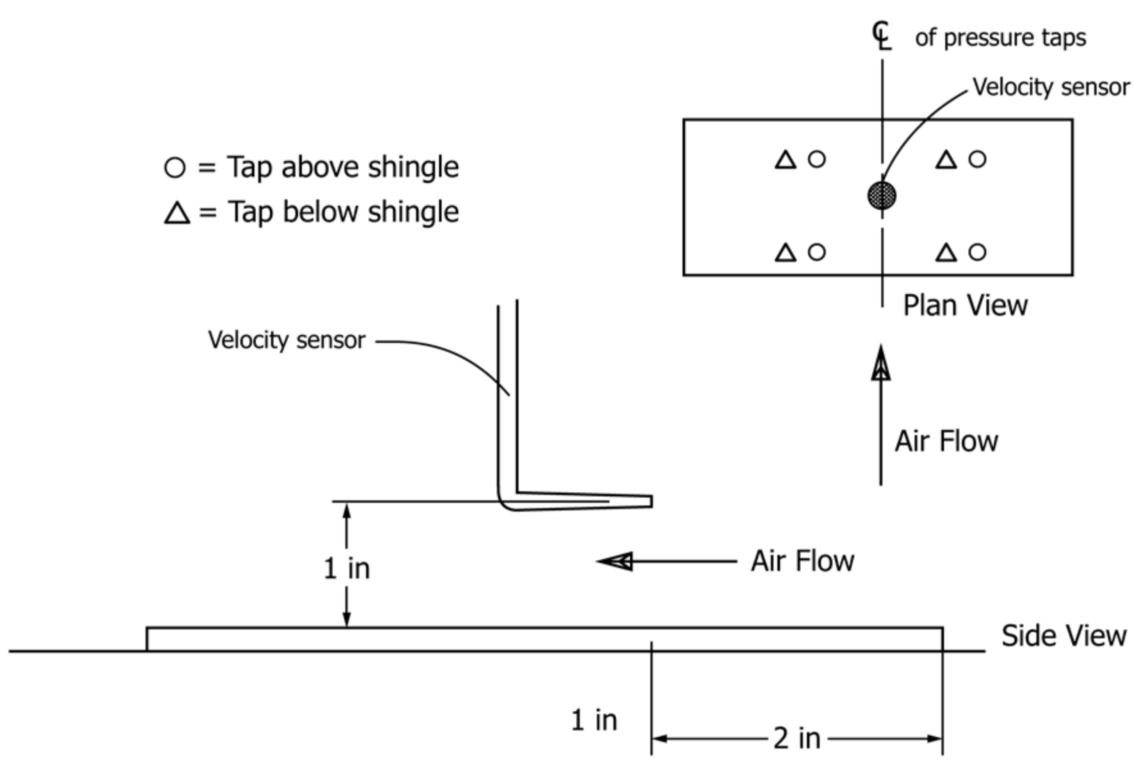
For P converted to N/m^2 and Uref to m/s, use the numerical coefficient 0.613 for (½ ρ).

11.2.4 Turn off the airflow and insert shims having thickness of 1.0 mm [0.04 in.] under the windward edge of selected shingles on the test deck to simulate the raised edge of the shingles in high wind. Shim locations at the instrumented shingle are shown in Fig. 9. Place shims immediately in front of the two taps measuring pressure on top of the shingle, and in at least three other locations at least 25.4 mm [1.0 in.] away from the shims in front of the pressure taps and from each other, with one of the shims placed between the two pressure-tap shims. The test deck is to be discarded if the sealant bond is damaged due to the placement of the shims. The shims shall be no wider than 5.1 mm [0.2 in.] perpendicular to the air flow, no longer than 5.1 mm [0.2 in.] in the direction of air flow, and not project out past the windward edge of the shingle.

11.2.5 Place shims in similar locations under the windward edge of the shingles in the course directly in front of (to windward) the instrumented shingle.

11.2.6 When open gaps, or overhangs, occur due to a multi-layered shingle design, additional shims, equal in thickness to that of the underlying layer(s), shall be first placed in the gap and then the shims required for the test shall be placed on top of these base shims to provide the desired raised shingle edge.

11.2.7 Repeat the air flow test and make pressure measurements at a velocity of 15.6 ± 1.3 m/s [35 ± 3 mph] with the shims in place. (Standard wind modeling practice provides for data extrapolation to other wind speeds, see ASCE 7-10 and ASCE 49-12).



NOTE 1—1 in. = 25.4 mm.

FIG. 8 Velocity Sensor Placement

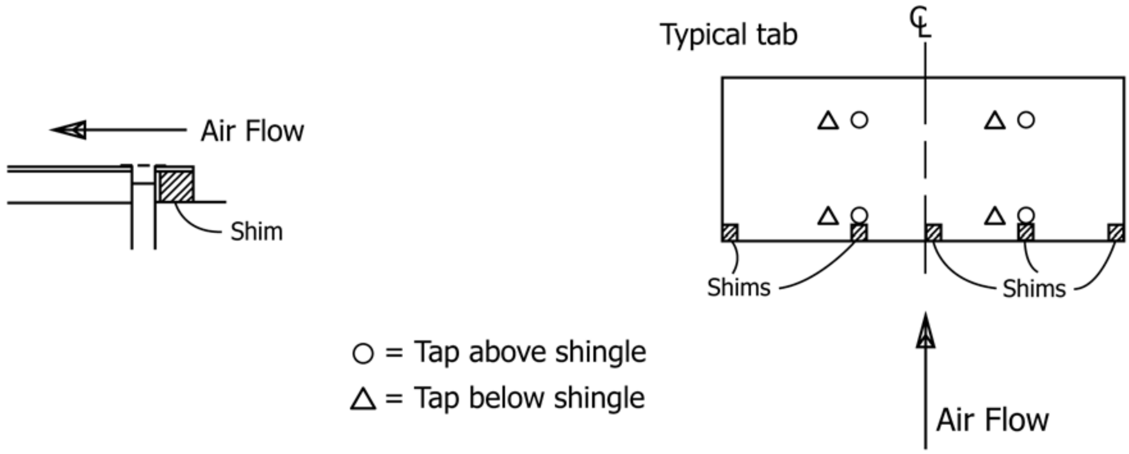


FIG. 9 Placement and Location of Shims in Measurement Area

11.2.8 When the shim thickness exceeds 3.0 mm [0.12 in.], the velocity sensor shall be repositioned to the nearest location from the pressure measurement tap positions, within the measurement area, where no shims are used.

11.2.9 The highest values of four tests on each of four different decks, both with and without shims, shall be averaged to determine the value of DCp with shims and DCp without shims (eight tests in total for the shingle being evaluated).

11.2.10 Shingle wind uplift coefficients, DCp's, shall be calculated from the measured data at each pressure tap above and below the shingle. The formula for DCp is:

$$DCp = (P_{top} - P_{bottom})/\left(\left(\frac{1}{2}\right)\rho\, U_{ref}^{\ 2} C_u\right) \tag{3}$$

where:

DCp = pressure coefficient (dimensionless, negative value is lift),

P_{top} = measured time-averaged pressure on the top of the shingle recorded as lbf/ft^2 or N/m^2 to correspond with the denominator (Eq 3),

P_{bottom} = measured time-averaged pressure on the top of the bottom shingle recorded as lbf/ft^2 or N/m^2 to correspond with the denominator (Eq 3),

U_{ref} = mean air velocity recorded as mph or m/s,

ρ = air density at 25°C and 1 atmosphere (use 1.225 kg/m^3 or 0.00238 slugs/ft^3 or (lb-sec^2)/ft^4), and

C_u = unit conversion constant (1.000 for SI units or 2.151 for inch-pound units).

The constant 0.00256 = (½)ρ C_u in inch-pound units and is used in the remainder of this test method.

11.2.10.1 The highest value of the measured time-averaged pressures for each location (windward or leeward side of sealant) is to be used to calculate F in 12.1.

11.2.11 The wind uplift coefficient measured at the windward side of the sealant pattern is identified as DCp1. The wind uplift coefficient measured at the leeward side of the sealant pattern is identified as DCp2. When two sealant stripes are used, the wind uplift coefficient measured between the two sealant stripes is identified as DCp3.

11.2.12 Use the DCp1, measured with shims in place (see 11.2.7), to calculate the deflection represented by the shim height as follows:

$$\text{Deflection (mm)} = f \times DCp1 \times L^4/EI \tag{4}$$

$$\text{Deflection [in.]} = f \times DCp1 \times L^4/EI$$

where:

L = the distance measured from the windward edge of the lowermost sealant pattern to the windward edge of the affixed shingle tab as installed on the roof in mm [in.],

EI = the value of shingle rigidity, in N-mm^2 when using deflection (mm), [lbf-in.^{2} when using deflection [in.]], as determined in 11.1.1, and

f = as defined in the table below:

Design Wind Speed	*f* (SI Units)	*f* [inch-pound units]
185 km/h [115 mph]	0.051	0.29
241 km/h [150 mph]	0.087	0.50
306 km/h [190 mph]	0.140	0.80

11.2.13 When the calculated deflection is less than 1.0 mm [0.04 in.], linearly interpolating the DCp between tests run at 0 and 1.0 mm [0 and 0.04 in.] is not prohibited by these requirements. When the calculated deflection is greater than 1.0 mm [0.04 in.], the tests specified in 11.2.6 shall be repeated using a thicker shim, or multiple shims of appropriate thickness, stacked evenly upon one another, with total thickness equal to the calculated deflection.

11.3 *Determination of the Mechanical Uplift Resistance of the Sealed Shingle:*

11.3.1 Test the specimens in accordance with Test Method D6381/D6381M, using Procedure A and B as dictated by the measured wind uplift coefficients and the shingle geometry (see 12.2). For shingle designs with two parallel or more stripes of sealant, the most windward and second-most windward sealant stripes shall be tested separately. Use a thin release tape (<0.1 mm [<0.004 in.] thick) to cover the adjoining sealant strip and ensure that only the sealant stripe being tested bonds during the test.

12. Calculation

12.1 *Calculation of the Uplift Force (F_T) Acting on the Sealed Shingle:*

12.1.1 The value of the uplift force, (F_T), defined as N [lbf] per 95.3 mm [3.75 in.] length of shingle tab uplift resistance required to prevent the tab from lifting, is calculated using the following equation:

$$(F_T) = F_F + F_B \tag{5}$$

where:

F_F = $V^2 \times DCp1 \times L1 \times Ka \times Kb$

F_B = $V^2 \times DCp2 \times L2/2 \times Ka \times Kb$

and where:

DCp1 = the wind uplift coefficient measured between the windward side of the windward sealant stripe pattern and the windward edge of the shingle,
DCp2 = the wind uplift coefficient measured between the leeward side of the leeward sealant stripe pattern and the windward edge of the shingle directly above as installed on the roof,
DCp3 = the wind uplift coefficient measured between sealant stripes of dual stripe patterns,
F_T = the strength design load for a 3-s gust of wind V m/s [mph],
Ka = as defined in Appendix X1,
Kb = as defined in Appendix X1,
L1 = the distance measured from the centerline of the sealant pattern to the windward edge of the affixed shingle tab as installed on the roof, see Fig. 7,
L2 = the distance measured from the centerline of the sealant pattern of the affixed shingle tab to the windward edge of the shingle directly above as installed on the roof, see Fig. 7,
L3 = the distance measured from centerline to centerline of the sealant patterns for those shingle designs that include two like parallel sealant patterns, see Fig. 7, and
V = the basic wind speed, expressed in m/s [mph].

12.1.1.1 Standard conditions for evaluation are based on a strength design with gust winds of V = 84.9 m/s [190 mph] and Ka = 1. See Appendix X1 for evaluation of F_T at other wind gust speeds. As noted in Appendix X1, Ka = 1 for buildings >0 to <18.3 m [>0 to <60 ft] in exposure B or C and Risk Categories I through IV in flat terrain; and Kb = 0.000177 when using the units used in Appendix X1 (Kb is unit dependent).

12.1.2 For shingle designs with two or more parallel stripes of sealant, the uplift force on each sealant stripe is calculated separately using the following equations:

$$F_{T1} = F_{F1} + F_{B1} \tag{6}$$

$$F_{T2} = F_{F2} + F_{B2}$$

where:

F_{T1} = strength design load for a 3-s gust of wind V m/s [mph] on the windward (first) stripe of sealant,
F_{F1} = $V^2 \times$ DCp1 $\times$ L1 $\times$ Ka $\times$ Kb,
F_{B1} = $V^2 \times$ DCp3 $\times$ L3/2 $\times$ Ka $\times$ Kb,
F_{T2} = strength design load for a 3-s gust of wind V m/s [mph] on the leeward (second from windward) stripe of sealant,
F_{F2} = $V^2 \times$ DCp3 $\times$ L3/2 $\times$ Ka $\times$ Kb, and
F_{B2} = $V^2 \times$ DCp2 $\times$ L2/2 $\times$ Ka $\times$ Kb.

NOTE 6—Symbols are defined in 12.1.1 and Fig. 7.

12.2 *Determination of the Uplift Resistance of the Shingle,* using Test Method D6381/D6381M, and considering the distribution of the total uplift force acting on the shingle:

12.2.1 The relative contribution to the total resistance (R_T) determined by Test Method D6381/D6381M Procedure A or Procedure B, or both, is illustrated in the following examples (see 12.2.3 and 12.2.4) to allow the relative magnitude and distribution of resistances to be suitably applied against the corresponding forces. A simple "total force to total resistance" comparison is not suitable for two reasons: *(1)* Components of the actual resistance mechanism of the shingle, as measured by Procedure A, are included in the resistance measured by Procedure B. A simple sum of the values would result in an overstated total resistance. *(2)* A simple sum of Procedures A and B is also unsuitable when most of the resistance is at the sealant (Procedure B) and most of the force is in front of the sealant (resisted by the action of Procedure A).

12.2.2 The uplift force acting on the shingle results in both a peeling force on the shingle in the area in front of the sealant and a perpendicular force on the shingle at the sealant. Test Method D6381/D6381M includes two procedures to evaluate these different force applications. Procedure A lifts the shingle with a peeling action. Performing Procedure A generates resistance R_A. Procedure B measures the uplift resistance to a force applied with a perpendicular lifting action so that a force with balanced components in front of and behind the sealant is applied to the shingle, over the sealant location. This generates a predominately perpendicular lift, as well as some peeling action at each edge of the sealant. Performing Procedure B results in resistance R_B. These two resistances include considerable overlap, and thus cannot simply be summed together. The means of apportioning the two resistances is detailed below.

12.2.3 *Calculation Case 1*—See Fig. 10 when $F_F > F_B$. The apportionment of the peeling and perpendicular resistances, R_A and R_B, is dictated by the mechanisms within the two Test Method D6381/D6381M Procedures. Procedure B applies an uplift force equally to the shingle on both sides of the sealant. Therefore, the F_B component is considered to be applied equally to both sides of the sealant. For the purposes of apportioning the resistance value, R_A, the F_F component is reduced by the magnitude of F_B that is assigned to be in front of the sealant. Applying this force distribution, the following equation is generated:

"Peeling"	+	"Perpendicular"
$R_T = [(F_F - F_B)/F_T] \times R_A$	+	$[(2F_B)/F_T] \times R_B$

with the constraint that R_T shall not exceed $3R_A$.

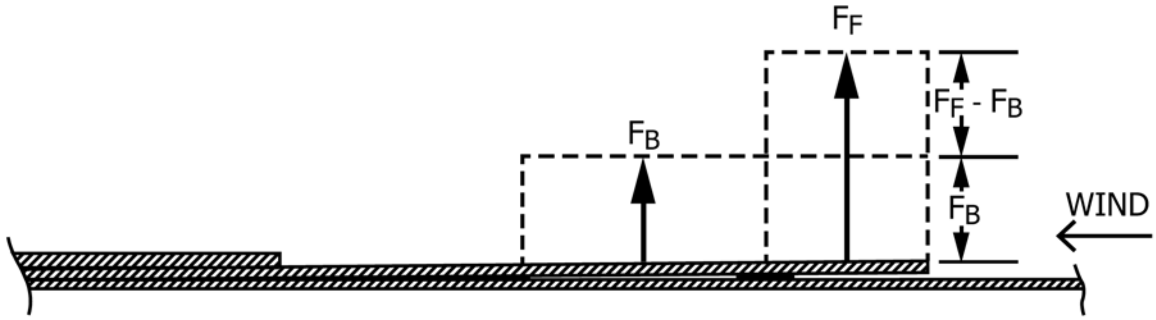


FIG. 10 Wind Uplift Force Distribution on a Shingle—Case 1

12.2.3.1 If $R_A \geq F_T$ or $R_T \geq F_T$, (the total uplift resistance provided by the sealant is greater than the total uplift force induced by the air flow over the shingle) then the shingle passes the criteria for the basic wind speed used in the calculation of F_T.

NOTE 7—Resistance values determined by Procedure B are always greater than those derived from Procedure A. The constraint that R_T shall not exceed $3R_A$ represents a conservative approach so that results from Procedure B should not be allowed to overwhelm those from Procedure A.

12.2.4 *Calculation Case 2*—See Fig. 11 when $F_F < F_B$. As in Case 1, the apportionment of the peeling and perpendicular resistance is dictated by the mechanisms within the two Test Method D6381/D6381M Procedures. Procedure B applies an uplift force distributed equally to the shingle on both sides of the sealant. The F_F component is applied to both sides of the sealant, and the F_B component is reduced by the magnitude of F_F that is applied behind the sealant to balance the F_F applied in front of the sealant. Applying this force distribution, the following equation is generated:

"Peeling"	+	"Perpendicular"
$R_T = [(F_B - F_F)/F_T] \times R_A$	+	$[(2F_F)/F_T] \times R_B$

with the constraint that R_T shall not exceed $3R_A$.

12.2.4.1 If $R_A \geq F_T$ or $R_T \geq F_T$, (the total uplift resistance provided by the sealant is greater than the total uplift force induced by air flow over the shingle) then the shingle passes the criteria for the basic wind speed used in the calculation of F_T.

12.2.5 For shingle designs with two parallel sealant stripes, the resistance of each sealant stripe is calculated similarly. For the most windward (first) stripe of sealant, the total uplift force, R_{T1}, is calculated by substituting F_F1 for F_F. F_{T1} for F_T, and F_{B1} for F_B and proceeding as described in 12.2.3 or 12.2.4. For the leeward (second) stripe of sealant, the total uplift force, R_{T2}, is calculated by substituting F_{F2} for F_F, F_{T2} for F_T, and F_{B2} for F_B and proceeding as described in 12.2.3 or 12.2.4. Calculation of force on the third stripe of sealant (if present) is not required.

13. Interpretation of Results

13.1 When the calculated uplift force (F_T) for the specified basic wind speed exceeds the measured uplift resistance (R_T) of the shingle under evaluation, then the shingle is considered to have failed the criteria for wind resistance at that basic wind speed.

13.2 When the measured uplift resistance (R_T) for the shingle under evaluation equals or exceeds the calculated uplift force (F_T) at the specified basic wind speed, then the shingle is considered to have passed the criteria for wind resistance at that basic wind speed.

13.3 For shingle designs with two parallel sealant stripe patterns, when the total resistance for each stripe of sealant is greater than or equal to the calculated total uplift force for that stripe of sealant, then the shingle is considered to have passed the criteria for wind resistance at that velocity. If the resistance of either sealant stripe is less than the calculated uplift force for that stripe of sealant, then the shingle is considered to have failed the criteria for wind resistance at that velocity.

NOTE 8—For shingles that comply with Specification D3462/D3462M and are applied in accordance with the manufacturer's instructions, the fastener pull-through resistance is such that the failure mode in this test method does not involve failure of the fasteners.

NOTE 9—The safety factors and conservative values that are discussed elsewhere in this test method, and in the Appendix, shall apply to any interpretation of results enumerated in Section 13.

14. Report

14.1 The report shall include the following information:

14.1.1 Details of the shingle being evaluated.

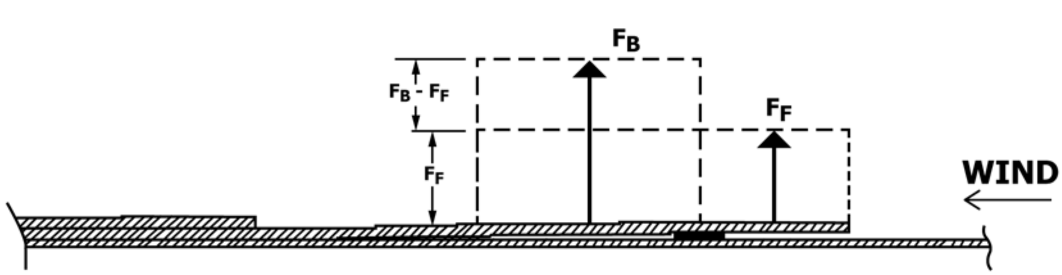


FIG. 11 Wind Uplift Force Distribution on a Shingle—Case 2

14.1.2 Photo or drawing of the shingle in electronic format.

14.1.3 Values for L, L1, L2, Exposure, and L3 (when applicable).

14.1.4 The measured uplift rigidity of the shingle (when the conservative value is not used).

14.1.5 The thickness of the shim used when determining DCp at specified wind velocity.

14.1.6 Wind uplift coefficients DCp1, DCp2, and, when applicable, DCp3.

14.1.7 The specified basic wind speed chosen to be used in the calculation of uplift force.

14.1.8 The calculated uplift force induced at the specified basic wind velocity. For shingle designs with two (or more) parallel stripes of sealant, report the calculated uplift force induced at the specified wind velocity for each of the two individual most windward stripes of sealant.

14.1.9 The mechanical uplift resistance measured on the shingle being evaluated. For shingle designs with two (or more) parallel stripes of sealant, report the mechanical uplift resistance for each of the two individual most windward stripes of sealant, measured on the shingle being evaluated.

14.1.10 A statement that the shingle being evaluated passes the requirements for wind resistance at the specified basic wind speed when the measured uplift resistance exceeds the calculated uplift force at that velocity. Or, a statement that the shingle being evaluated fails the requirements for wind resistance at the specified basic wind speed when the measured uplift resistance is less than the calculated uplift force at that velocity.

14.1.11 The classification of the shingle based on the basic wind speed used in the calculation of the uplift force. Report the classification at the highest basic wind speed for which passing results were achieved.

14.1.12 If calculations of F_T are done at other wind velocities, report all values of Ka, Kb, Exposure, and Risk Categories used in the calculations.

15. Precision and Bias

15.1 No statement is made about either precision or bias of this test method, since the result merely states whether there is conformance to the criteria for success specified in the procedure.

16. Keywords

16.1 asphalt shingles; calculated wind resistance; factory-applied sealant; fan-induced wind; field-applied sealant; roofing; sealant bond strength; shingle mechanical uplift resistance; shingle uplift pressure coefficients; shingle uplift rigidity; wind resistance; wind uplift force

APPENDIX

(Nonmandatory Information)

X1. BACKGROUND INFORMATION ON THE UPLIFT COEFFICIENT TEST PROCEDURE

X1.1 General

X1.1.1 The background contained in this appendix is based on research conducted by Cermak Peterka Petersen, Inc., Wind Engineering Consultants, Fort Collins, CO 80524. The research results are contained in "Development of a Shingle Uplift Coefficient Test Standard," Final Report, dated June 22, 2000. The Asphalt Roofing Manufacturers Association (ARMA) sponsored the research and the Final Report was made to ARMA. This background information was updated under the direction of Dr. Peterka in 2015 for compatibility with ASCE 7-10.

X1.1.2 This background is based on information developed by ARMA and is used with the permission of ARMA.

X1.1.3 ASTM Subcommittee D08.02 gratefully acknowledges the significant contributions made by ARMA to the understanding of issues relating to wind resistance of asphalt shingles and greatly appreciates the ability to use information gained under ARMA sponsorship in the development of this test method.

X1.1.4 This same work, and the information derived from it, was also used in the development of the ANSI/UL Standard 2390 that has been used by Underwriters Laboratories in the Classification of wind-resistant asphalt shingles. Dr. Peterka was consulted in the development of the test apparatus, the instrumentation, and the procedure for calculating the results, including the safety factors and assumptions built into the calculations.

X1.2 Other references that outline the procedures and validity of this type of wind modeling are as follows:

ASCE 49-12, American Society of Civil Engineers Standard Number 49, Wind Tunnel Testing for Buildings and Other Structures, 2012.

Cermak, J. E., "Laboratory Simulation of the Atmospheric Boundary Layer," *AIAA Journal*, Vol 9, September 1971.

Cermak, J. E., "Applications of Fluid Mechanics to Wind Engineering," A Freeman Scholar Lecture, *ASME Journal of Fluids Engineering*, Vol 97, No.1, March 1975.

Cermak, J. E., "Aerodynamics of Buildings," *Annual Review of Fluid Mechanics*, Vol 8, 1976, pp. 75–106.

Peterka, J. A., Cermak, J. E., Cochran, L. S., Cochran, B. C., Hosoya, N., Derickson, R. G., Harper, C., Jones, J., and Metz, B., "Wind Uplift Model for Asphalt Shingles," *Journal of Architectural Engineering,* Vol 3, No. 4, December 1997, pp. 147–155.

NOTE X1.1—All of the testing and computation performed as part of the ARMA-funded work was done in U.S. Customary Units. This has been retained in this Appendix of background information for clarity. The text of the test method includes the appropriate SI units.

X1.3 Background Information for 11.2

X1.3.1 Standard wind modeling practice provides for extrapolation of data collected at lower wind speeds to higher wind speeds (see ASCE 7-10 and ASCE 49-12). The combination of testing at 35 mph with the use of metal shims of appropriate thickness will simulate shingle deflection at 190 mph [306 km/h]. Uplift coefficient data are gathered at two or more shim thicknesses. The wind uplift coefficients generated in this test method are constant for a given deflection of the shingle.

X1.3.2 The wind load at the shingle's sealant, F_T, is calculated using the area of the shingle multiplied by the uplift coefficients generated in 11.2, multiplied by the basic wind speed, V, squared (see equations in 12.1.1 and 12.1.2) in a manner similar to the way the velocity pressure, qz = 0.00256KhKtKdV^2(Cp − Cpi), is calculated in ASCE 7-10. This calculation incorporates the "importance factor" used in ASCE 7-02 into the velocity as used in ASCE 7-10, plus an additional "safety factor." The 190 mph [306 km/h] design gust wind speed is the standard condition reflected in this test method, but other wind speeds can be chosen when unique conditions are to be considered.

X1.3.3 "Safety factor" refers to a conservative bias (specifying higher loads than are actual) by (*1*) using the largest measured wind speedup factor (2.5) on a collection of roofs, (*2*) selecting the worst wind direction where Kd = 1.0 while ASCE 7-10 uses 0.85 and evidence in the literature indicates the "true" unbiased value may be closer to 0.75, (*3*) selecting the largest strength design wind speed in the continental US (190 mph) when lower strength design speeds occur over most of the US, and (*4*) selecting a strength design wind speed that includes Risk Category III and IV buildings when the large majority of applications are for Risk Category II buildings.

X1.4 Background Information for 12.1.1 and 12.1.2

X1.4.1 The force equation from 12.1.1:

$$F_T = F_F + F_B$$

$$F_T = V^2 \times DCp1 \times L1 \times Ka \times Kb + V^2 \times DCp2 \times L2/2 \times Ka \times Kb \quad \text{(X1.1)}$$

X1.4.1.1 Force is equal to the velocity (squared); times the uplift coefficient in the front of the sealant; times the test specimen length; times a coefficient (Ka) to account for building height, exposure, and terrain; times a coefficient (Kb) to account for the strength design and dimensions, plus velocity pressure from behind the sealant times the area; times a coefficient (Ka) to account for building height, exposure, and terrain; times a coefficient (Kb) to account for the strength design and dimensions.

X1.4.1.2 Derivation of Ka and Kb:

(*1*) Ka is the product of KhKtKd (from ASCE 7-10).

(*2*) Kh = 1.0 for exposure C at 10 m [32.8 ft] for building heights less than or equal to 60 ft [18.3 m]; exposure D is to use values from ASCE 7-10.

(*3*) Kt = 1.0 no terrain multiplier. Terrain multipliers shall be used if building is on a steep hill or escarpment over 60 ft [18.3 m].

(*4*) Kd = 1.0 directionality factor equals one, as shingles are exposed from all directions. A less conservative approach could be to permit Kd = 0.85 as in ASCE 7-10.

(*5*) See ASCE 7-10 for information on exposures, terrain multipliers, and directionality factors.

(*6*) Kb = 0.000177.

(*7*) Kb is a constant that converts the wind speed to a strength design load for the 3.75 in. [95.3 mm] specimen. It is derived as follows:

(*8*) From ASCE 7-10:

(*9*) Velocity Pressure (the pressure exerted by the wind at the specified velocity)

(*10*) qz = 0.00256KhKtKd V^2 (Cp − Cpi)

(*11*) qz = Velocity Pressure

(*12*) 0.00256 = 1/2 ρ (ρ is the density of air)

X1.4.1.3 The following is referenced as Ka:

(*1*) Ka = KhKtKd

(*2*) Kh = 1.0 for exposure C at 10 m [32.8 ft]

(*3*) Kt = 1.0 no terrain multiplier

(*4*) Kd = 1.0 directionality factor equals one, as shingles are exposed from all directions

(*5*) Ka = 1 is considered standard conditions

(*6*) Ka can also be calculated using information in ASCE 7-10 (see Example 3 in X1.4.1.3).

(*7*) Cp = external pressure coefficient

(*8*) Cpi = internal pressure coefficient

X1.4.1.4 Thus Eq X1.1 becomes:

$$qz = 0.00256\, V^2 \times Ka \times (Cp - Cpi) \quad \text{(X1.2)}$$

or

$$qz = 0.00256\, V^2 \times 1.0 \times (Cp - Cpi) \quad \text{(X1.3)}$$

(*1*) Cp − Cpi is replaced with DCp, the mean uplift coefficient for shingles.

$$qz = 0.00256 V^2 DCp \quad \text{(X1.4)}$$

X1.4.1.5 To properly account for loads:

(*1*) V^2 is replaced by Uroof^2

(*2*) Uroof^2 is the square of the peak gust speed just above the shingle.

(*3*) From Peterka 1997:

$$(Uroof/Uref) = 2.5 \quad \text{(X1.5)}$$

(*4*) No gust wind speeds were found on the roof surface that exceeded 2.5 times the mean approach wind speed.

(*5*) Uref is the mean wind speed approaching the building at mean roof height.

X1.4.1.6 From ASCE 7-10, V/1.53 = Uref; converts 3-s gust speed to mean wind speed.

$$Uroof = (V/1.53)(Uroof/Uref) \quad \text{(X1.6)}$$

(*1*) Combining Eq X1.5 and X1.6 gives a design speed with a return period of about 1700 years (2.5/1.53) = 1.634.

$$Uroof = 1.63V \text{ 1700 year design} \quad \text{(X1.7)}$$

(*2*) The load factor from ASCE 7-10 is 1.0 (1.0$^{(0.5)}$ = 1.0 load factor as expressed as a factor on wind)

(*3*) [(2.5/1.53)1.0$^{(0.5)}$] = 1.634

$$Uroof = 1.63\ V \text{ failure strength design case} \quad (X1.8)$$

X1.4.1.7 From Peterka 1997:

$$DP = 1/2\rho Uref^2 (Uroof/Uref)^2\ DCp \quad (X1.9)$$

(1) DP is the peak uplift pressure on a shingle, ρ is air density.

(2) DCp is the mean uplift pressure coefficient on the shingle as measured in this test protocol.

(3) Simplify Eq X1.9.

$$DP = 1/2\rho Uroof^2\ DCp \quad (X1.10)$$

X1.4.1.8 Inserting Eq X1.8 into Eq X1.10 and dividing by 144 to convert lbf/ft^2 (psf) to psi gives uplift pressure for strength design.

$$DP = 0.0000472V^2\ DCp \quad (X1.11)$$

(1) DP is in psi and V is miles per hour.

(2) Using 3.75 in., the length of the specimen used in D6381/D6381M, and multiplying it times 0.0000472 gives 0.000177 = Kb.

X1.4.1.9 The uplift pressure must be multiplied by the area to which it is applied to obtain the force on the sealant. Therefore, the length from the windward edge to the centerline of the sealant (L1) and the length from the centerline of the sealant to the leading edge of the next shingle (L2) are to be measured and used to define the area over which the pressure is applied, and is then used to determine the force.

X1.4.1.10 Therefore, the equation for strength design uplift force on the sealant is:

$$F_T = V^2 \times DCp1 \times L1 \times Ka \times Kb + V^2 \times DCp2 \times L2/2 \times Ka \times Kb \quad (X1.12)$$

or

$$F_T = V^2 \times DCp1 \times L1 \times 1.0 \times 0.000177 + V^2 \times DCp2 \times L2/2 \times 1.0 \times 0.000177$$

X1.4.1.11 The standard evaluation will use 190 mph (see Note X1.2) for strength design test data permitting Risk Category III to be included.

Substituting: V = 190 mph

$$F_T = 190^2 \times DCp1 \times L1 \times 1.0 \times 0.000177 + 190^2 \times DCp2 \times L2/2 \times 1.0 \times 0.000177 \quad (X1.13)$$

NOTE X1.2—Evaluation of shingles for design wind speeds other than 190 mph is also possible. Shingles are evaluated for wind speeds other than 190 mph by substituting in the wind speed required in both Eq X1.13 and in the equation in 11.2.12 to determine shim heights.

X1.4.1.12 When shingles differing from three tab or standard laminates are evaluated by this method, these "non-typical" shingles' EI are determined for the test shingle, and shim heights determined based on the "standard" (190 mph) design wind speed.

X1.4.2 *Example 1:*

X1.4.2.1 The following is an example of how to determine the force on the shingle sealant strip.

Standard Case.

$$F_T = F_F + F_B \quad (X1.14)$$

$$F_T = V^2 \times DCp1 \times L1 \times Ka \times Kb + V^2 \times DCp2 \times L2/2 \times Ka \times Kb$$

(1) Using V = 190 mph

(2) $F_T = 190^2 \times DCp1 \times L1 \times Ka \times Kb + 190^2 \times DCp2 \times L2/2 \times Ka \times Kb$

(3) For a shingle with a 1-in. section (L) as measured in front of the sealant, a 4-in. section as measured behind the front edge of the sealant, a sealant width of ⅝ in.; a coefficient of 0.67 (as measured) in front of the sealant (DCp1) and a coefficient of 0.13 (as measured) (DCp2) behind the sealant.

(4) L1 = 1 in. + (⅝ in./2) = 1 + 5⁄16 = 1.31 in.

(5) L2 = 4 in. – ⅝ in./2 = 4 in. – 5⁄16 in. = 3.69 in.

(6) Ka = 1 for standard residential structure

(7) Shim height from test = 0.21 in.

(8) $F_T = 190^2 \times 0.67 \times 1.31 \times 1.0 \times 0.000177 + 190^2 \times 0.13 \times 1.85 \times 1.0 \times 0.000177$

(9) F_T = 5.61 lb/3.75 in. + 1.54 lb/3.75 in.

(10) Or:

(11) F_T = 7.15 lb/3.75 in.

(12) The 3.75-in. of sealant strip needs to resist a force of 7.15 lb. A shingle of this design, which has a load resistance for the sealant strip of 7.15 lb, will meet the building code loads for all locations in the U.S.

X1.4.2.2 DCp1 = measured pressure coefficient in front of seal strip. L1 is the length in front of the seal strip and ½ of the width of the seal strip, providing the area on which the uplift is effective in front of the seal strip.

(1) DCp2 = measured pressure coefficient behind the seal strip.

(2) L2/2 is half the distance from the center of the seal strip to the windward edge of the next shingle.

X1.4.3 *Example 2:*

X1.4.3.1 This will involve the same shingle, which has a 1 in. length in front of the sealant (L1 = 1.31) and a 4 in. length behind the sealant (L2 = 3.69) and coefficients of 0.67 for DCp1 and 0.13 for DCp2. In this example the evaluation is for strength design of 115-mph gust wind speed.

$$F_T = F_F + F_B \quad (X1.15)$$

$$F_T = V^2 \times DCp1 \times L1 \times Ka \times Kb + V^2\ DCp2 \times L2/2 \times Ka \times Kb$$

(1) $F_T = 115^2 \times DCp1 \times L1 \times 1.0 \times 0.000177 + 115^2 \times DCp2 \times L2/2 \times 1.0 \times 0.000177$

(2) $F_T = 115^2 \times 0.67 \times 1.31 \times 1 \times 0.000177 + 115^2 \times 0.13 \times 1.85 \times 1.0 \times 0.000177$

(3) F_T = 2.05 lb/3.75 in. + 0.56 lb/3.75 in.

(4) F_T = 2.61 lb/3.75 in.

X1.4.4 *Example 3:*

X1.4.4.1 This will involve the same shingle, which has a 1 in. length in front of the sealant (L1 = 1.31) and a 4 in. length behind the sealant (L2 = 3.69) and coefficients of 0.67 for DCp1 and 0.13 for DCp2. In this example the roof is assumed to be located on a 200-ft bluff overlooking Lake Michigan and the roof is on an 80 ft mean height section of an amphitheater roof (a Risk Category III structure whose failure could pose a substantial risk to human life). The wind speed from ASCE 7-10, Figure 26.5-1B, is 120 mph.

$$F_T = F_F + F_B \quad (X1.16)$$

$$F_T = V^2 \times DCp1 \times L1 \times Ka \times Kb + V^2 \times DCp2 \times L2/2 \times Ka \times Kb$$

(1) $F_T = 120^2 \times DCp1 \times L1 \times Ka \times 0.000177 + 120^2 \times DCp2 \times L2/2 \times Ka \times 0.000177$

(2) In this case it is necessary to evaluate for Ka.

(3) Lake Michigan is in a 120 mph Risk Category III wind zone by ASCE 7-10.

(4) The 200 ft bluff is at the shore line so exposure D is operative exposure.

(5) The bluff is 100 ft long and 200 ft high therefore Lh is 50 ft. A terrain multiplier will need to be used. Since the building is greater than 60 ft tall it is necessary to evaluate the velocity pressure at the roof height.

(6) Since it is an amphitheater and it seats more than 300 persons Risk Category III is required.

X1.4.4.2 From ASCE 7-10, $Ka = Kh \times Kzt \times Kd = 1.38 \times 2.62 \times 1.0 = 3.62$

(1) $Kh = 1.38$ for exposure D at 80 ft.

(2) $Kzt = 2.62$ terrain multiplier.

(3) $Kd = 1.0$ directionality factor equals one, as shingles are exposed from all directions.

(4) $Kzt = (1 + K1 + K2 + K3)^2$

(5) $K1 = 0.95$

(6) $K2 = (1 - \{x\}/\mu Lh) = (1 - 100/1.5 \times 50) = -0.33$

(7) $K3 = \exp[-\gamma z/Lh] = \exp[-(2.5 \times 200/50)] = \exp[-10.0] = 0.00005$

(8) $Kzt = (1 + 0.95 - 0.33 + 0.00005)^2$

(9) $Kzt = (1.62)^2 = 2.62$

$$F_T = 120^2 \times DCp1 \times L1 \times Ka \times 0.000177 + 120^2 \times DCp2 \times L2/2 \times Ka \times 0.000177 \quad (X1.17)$$

(10) $F_T = 120^2 \times 0.67 \times 1.31 \times 3.629 \times 0.000177 + 120^2 \times 0.13 \times 1.85 \times 3.629 \times 0.000177$

(11) $F_T = 8.10$ lb/3.75 in. + 2.22 lb/3.75 in.

(12) $F_T = 10.32$ lb/3.75 in.

X1.5 Resistance Factors Used in this Standard

X1.5.1 This standard effectively uses a resistance factor of 1.0 applied to the tested reference uplift resistance values, R_A and R_B, used to determine R_T for the loading conditions addressed in the standard (Section 12.2). As derived from testing of 10 samples in accordance with D6381/D6381M, the resistance values represent the average of the tested values.

X1.5.2 Until such a time that the uncertainty and bias in resistance for a representative sample of all manufactured products can be more definitively assessed and the relationship to long-term performance and failure modes in actual use better understood, it is advisable that the resistance factor of 1.0 as implied in this standard by the absence of an explicit resistance factor not be altered. While such an assessment also may eventually allow for the resistance factor to be adjusted to account for the strength variability of individual products as measured by D6381/D6381M tests, there is a lack of data to do so at this time.

X1.6 Conservatism in Load Determination

X1.6.1 This standard uses strength-based wind loads (for example, 700-year return period or greater depending on the risk category of building per ASCE 7-10) with conservative biases which also must be considered together with the resistance factor as a part of overall reliability and performance achieved by use of this standard.

X1.6.2 Intentional biases in applied load were included in this standard by assigning conservative values in the wind uplift model. A rough estimate of the magnitudes of these biases include, a value of 2.0 could be used in place of 2.5 as the nominal wind speed acceleration factor (based on Figure 11 in Peterka et al[5]) giving a load increase factor of $(2.5 / 2.0)^2 = 1.58$. A Risk Category II wind speed for South Florida that does not include Risk Category III or IV structures is 170 mph (Figure 26.5-1A in ASCE 7-10) giving an added load increase factor of $(190 / 170)^2 = 1.25$. Cumulatively, these conservative biases in the treatment of loads produce a load increase factor of about $1.58 \times 1.25 = 2.0$ in the use of this standard.

[5] Peterka, J. A., Cermak, J. E., Cochran, L. S., Cochran, B. C., Hosoya, N., Derickson, R. G., Harper, C., Jones, J., and Metz, B., "Wind Uplift Model for Asphalt Shingles," *Journal of Architectural Engineering*, Vol. 3, No. 4, December 1997, pp. 147–155.