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American National Standard for Roof Mounted Rigid Photovoltaic Module Systems

October 2024

Foreword

NOTE: This foreword is introductory only and is not part of American National Standard FM 4478.

This standard is intended to verify that the product as described will meet minimum specific stated conditions of performance, safety and quality, useful in determining the potential suitability for end-use conditions of these products. It describes minimum performance requirements for materials that are intended for use in roof assemblies by evaluating the ability of the materials and, in turn, the system components to withstand simulated wind uplift resistance.

ANSI/FM 4478 was originally published in October 2014. In this edition, tests were added for electrical performance, electrical safety and gravity load resistance .

This American National Standard has been developed according to the essential requirements of due process for standards development of the American National Standards Institute (ANSI). FM Approvals is an ANSI-accredited standards developer (ASD).

Approval of an American National Standard requires verification by ANSI that the principles of openness and due process have been followed and that a consensus of those directly and materially affected by the standard has been achieved. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution. Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached.

The American National Standards Institute does not develop standards nor will it in any circumstances give an interpretation of any American National Standard. Requests for interpretations of this test standard should be addressed to FM Approvals.

ANSI regulations require that this American National Standard shall be revised, reaffirmed or withdrawn within five years of the date of publication.

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TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 Purpose **1**
1.2 Scope **1**
1.3 Basis for Requirements **1**
1.4 System of Units **1**
1.5 Normative References 1
1.6 Terms and Definitions 2

2 GENERAL INFORMATION 3

2.1 Product Information **3**

3 GENERAL REQUIREMENTS 5

3.1 Review of Documentation **5**
3.2 Calibration **5**
3.3 Markings **5**
3.4 Manufacturer's Installation Instructions **5**
3.5 Test Sample Production **5**
3.6 Seismic Loads **5**

4 PERFORMANCE REQUIREMENTS 8

4.1 Combustibility From Above the Roof Deck **8**
4.2 Wind Uplift Resistance for Rigid Photovoltaic Module with the Panel Attached To or Through the Roof Cover **8**
4.3 Wind Uplift Resistance for Rigid Photovoltaic Module Loose Laid and Ballasted. **10**
4.4 Hail Damage Resistance Test .... Error! Bookmark not defined.
4.5 Gravity Load Resistance Test (Optional) .... Error! Bookmark not defined.

APPENDIX A: TEST PROCEDURES **132**

APPENDIX B: TEST PROCEDURES **13**

APPENDIX C: TEST PROCEDURES **16**

APPENDIX D: TEST PROCEDURES .... **ERROR! BOOKMARK NOT DEFINED.**

APPENDIX E: TEST PROCEDURES 180

1. INTRODUCTION

1.1 PURPOSE

This standard states the testing requirements for roof mounted rigid photovoltaic module systems that are used with a roof assembly.

1.2 SCOPE

1.2.1 This standard applies to all rigid photovoltaic modules intended to be 1) mechanically fastened through or adhered to a single-ply, polymer-modified bitumen sheet, built-up roof, liquid applied roof cover or steep slope roof, 2) mechanically fastened or adhered to a metal roof cover assembly using clamps or other types of fasteners, adhesive or welding or 3) loose laid and ballasted over a fully adhered single-ply, polymer-modified bitumen sheet or built-up roof cover assembly.

1.2.2 This standard also applies to panels secured to racks and/or rack framing which are independently secured to the building structure, roof deck or metal roof cover or ballasted. It also applies to the rack itself and its securement.

1.2.3 The standard is intended to evaluate only those hazards investigated and is not intended to determine suitability for the end use of a product.

1.2.4 This standard evaluates rigid photovoltaic module systems for their performance in regard to fire from above the structural deck, simulated wind uplift, susceptibility from hail storm damage, gravity load and seismic performance requirements.

1.2.5 This standard only addresses the photovoltaic module and racking, it does not address any other electrical component utilized to supply the generated electrical power to the building.

1.2.6 This standard does not apply to flexible photovoltaic modules.

1.3 BASIS FOR REQUIREMENTS

1.3.1 The requirements of this standard are based on experience, research and testing, and/or the standards of other organizations. The advice of manufacturers, users, trade associations, jurisdictions and/or loss control specialists was also considered.

1.4 SYSTEM OF UNITS

Units of measurement used in this Standard are United States (U.S.) customary units. These are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. The first value stated shall be regarded as the requirement. The converted equivalent value may be approximate. Conversion of U.S. customary units is in accordance with ANSI/IEEE/ASTM SI 10.

1.5 NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the cited edition applies:

American National Standard Institute

Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls, ANSI/FM 4473

Evaluating the Simulated Wind Uplift resistance of Roof Assemblies Using Static Positive and/or Negative Differential Pressures, ANSI/FM 4474

Flat Plate Photovoltaic Modules and Panels, ANSI/UL 1703

American Iron and Steel Institute

North American Specification for the Design of Cold-Formed Steel Structural Members, 2007 Edition, AISI S100-200

American Society of Civil Engineers	*Minimum Design Loads for Building and Other Structures*, Standard ASCE/SEI 7-05
ASTM	*Standard Test Methods for Fire Tests of Roof Coverings,* ASTM E108 *Standard Specification for Concrete Roof Pavers,* ASTM C1491
Structural Engineers Association of California	*Wind Design for Solar Arrays,* PV2-2017

1.6 TERMS AND DEFINITIONS

For purposes of this standard, the following terms apply:

Adhesive	Adhesive is used in construction to adhere components together. Depending on the use, the adhesive could be in either a liquid form, semi liquid form, reactive liquid form or a solid form as in a tape or as in hot asphalt which is solid until heated.
Anchored	For the purpose of this document, an anchored system is a system that is secured to the roof structure or any part of the roof assembly.
Ballast	Material used to impede movement of the photovoltaic module or frame resulting from wind forces. Ballast does not impede lateral (sliding) earthquake movement since both the lateral force and resisting frictional force are functions of the weight, but may resist earthquake overturning. For the purposes of this document, the only acceptable ballast shall be concrete paver blocks.
Coefficient of Friction	The ratio of the force that maintains contact between an object and a surface and the frictional force that resists the motion of the object.
Crack	During wind uplift testing, when a component is stressed to the point that it separates from itself while continuing to maintain the applied uplift pressure without catastrophic failure of the test assembly.
Crease	During wind uplift testing, when a component is stressed to the point that it bends at a sharp, defined angle, without breaking. For insulation boards, often a crack will form on the opposite face.
Deck	The deck is the structural component of the roof assembly to which the roof system is secured.
Delamination	Separation of the plies in a roof membrane or system in any laminated roofing material or component, e.g., laminated layers of rigid insulation or the felt plies in a built-up roof or separation of any membrane from the substrate to which it is adhered. This includes the separation of the photovoltaic modules from the roof cover.
External Seam Clamps	A securement for attaching photovoltaic modules or racking to the seams of a standing seam roof.
Fasteners	A fastener is a mechanical securement device used alone or in combination with other components such as a stress distributor to secure various components of a roof assembly.
Frame or Racking System	Used to fix solar modules to the roof assembly.
Fully Adhered	Fully adhered describes components such as photovoltaic modules that have been bonded to the substrate using a compatible adhesive throughout the entire surface.
Mechanically Fastened	Mechanically fastened describes components that have been attached to the substrate at defined intervals using fasteners with, or without, stress distributors.
Metal Panel	(1) A single metal sheet formed into a specified profile. (2) A composite assembly formed to a specified profile and consisting of an insulating core or batten material with an exterior metal skin.

Minor delamination	In wind uplift testing, an area approximately 1% of the test sample. For a 12 x 24 ft (3.7 x 7.3 m) test an area of 3 ft2 (0.28 m2); for a 5 x 9 ft (1.5 x 2.7 m) test an area of 0.5 ft2 (0.05 m2), whereby two adhered components which are intended to be in contact are not in contact.
Permanent Deformation	Any displacement of a panel or component that remains after the load has been removed. Panel deflection that can be removed by mechanical means not involving special equipment and without additional displacement shall not be considered permanent deformation.
Photovoltaic Module	A device that converts solar energy into electricity using the photovoltaic effect.
Rated Wind Load	The wind resistance rating given to a roof assembly based on ultimate failure load in psf (kPa).
Rigid Photovoltaic Module System	An arrangement of photovoltaic cells or material, mounted on a surface and/or in a frame that are not able to be bent or flexed without damage with the cells exposed freely to incoming sunlight.
Roof Assembly	A system of interacting roof components (including the roof deck) designed to weatherproof and, normally, to insulate a building's top surface.
Roof Cover	The exterior surface of a roof assembly designed to protect the building components from the weather.
Roof System	A group of interacting roof components (not including the roof deck) designed to weatherproof and, normally, to insulate a building's top surface. The roof system includes the rigid photovoltaic module if it is fully adhered or mounted directly above the roof cover and no air space exists between the roof cover and the photovoltaic module.
Service Wind Load	The calculated uplift load resulting from a windstorm that a roof assembly must resist. The service load is equal to one half of the rated load in psf (kPa).
Standing Seam Roof Cover	The standing seam roof cover generally consists of metal sheets or panels, field seamed to adjacent sheets by a roll-forming machine to create an upstanding seam (rib) of folded metal along the sheet sidelaps. The panels are secured to the building framing with clips. The clip, which contains metal tabs, is roll-formed into the panel seam.
Stress Distributor/Plate	A metal or plastic disk or bar designed to distribute a concentrated load over a larger surface area.
Weld	A type of securement whereby metal or plastic materials are joined together through heat or solvent fusion.
Wind Deflector	A component of the photovoltaic panel or racking system that is designed to turn the flow of air away from the underside of the photovoltaic panel.

2. GENERAL INFORMATION

2.1 PRODUCT INFORMATION

Rigid photovoltaic modules are submitted in panels or a panel array. They can be installed using either mechanical fasteners, clips, mounting brackets, adhesives, welding or loose laid and/or ballasted.

3. GENERAL REQUIREMENTS

3.1 REVIEW OF DOCUMENTATION

During the initial investigation and prior to physical testing, the manufacturer's specifications and details of installation shall be reviewed to assess the ease and practicality of installation and use.

3.2 CALIBRATION

Each piece of equipment used to verify the test parameters shall be calibrated within an interval determined on the basis of stability, purpose, and usage. A copy of the calibration certificate for each piece of test equipment is required. The certificate shall indicate that the calibration was performed against working standards whose calibration is certified and traceable to an acceptable reference standard and certified by an ISO/IEC 17025 accredited calibration laboratory. The test equipment shall be clearly identified by label or sticker showing the last date of the calibration and the next due date. A copy of the service provider’s accreditation certificate as an ISO/IEC 17025 accredited calibration laboratory should be available. When the inspection equipment and/or environment is not suitable for labels or stickers, other methods such as etching of control numbers on the measuring device are allowed, provided documentation is maintained on the calibration status of thus equipment.

3.3 MARKINGS

3.3.1 Marking on the product or, if not possible due to size, on its packaging or label accompanying the product, shall include the following information:

- name and address of the manufacturer or marking traceable to the manufacturer;
- date of manufacture or code traceable to date of manufacture or lot identification;
- model number, model type, and/or product name, as appropriate.

When hazard warnings are needed, the markings shall be universally recognizable and permanent.

3.3.2 The product trade name, model number, or model type identification shall correspond with the manufacturer's catalog designation.

3.3.3 All markings shall be legible and durable.

3.4 MANUFACTURER’S INSTALLATION INSTRUCTIONS

The manufacturer shall provide the user with printed instructions to demonstrate proper installation procedures to be followed by installers.

3.5 TEST SAMPLE PRODUCTION

All products submitted for testing shall be representative of production run material.

3.6 SEISMIC LOADS (OPTIONAL)

Rigid photovoltaic modules, installed at locations within Zones 50 year, 100 year, 250 year or 500 year, shall be designed in accordance the Design Procedure for Seismic Design of Rigid Photovoltaic Modules to withstand the seismic loading experienced in these areas. Rigid photovoltaic modules located in >500 year zones are considered non-seismic and do not require analysis for seismic design. The design shall be certified by a Professional Engineer competent in this area of practice. Calculations shall be submitted to verify compliance with design requirements for the range of rigid photovoltaic modules.

The Design Procedure for Seismic Design of Rigid Photovoltaic Modules is as follows:

3.6.1 General

The rigid photovoltaic modules and racking systems (if used) shall be rated (certified) for a base shear coefficient (acceleration) at the mounting level. The manufacturer shall demonstrate (through tests or analysis) that the rigid photovoltaic modules and racking systems (if used) shall remain intact and operational when subjected to the rated base shear coefficient. The anchorage of the rigid photovoltaic modules and racking systems (if used) to the supporting structure shall be designed for the base shear, overturning moment about the two principal axes and torque about the vertical axis. The supporting structure shall be designed for the loads transmitted from the rigid photovoltaic modules. The seismic loads calculated according to this standard are intended for use in Load and Resistance Factor Design (LRFD) or Strength Design, also known as Ultimate Limit State Design, and shall, therefore, be used in LRFD load combinations with a load factor of 1.0 applied to the seismic loads.

If the weight of the rigid photovoltaic module and racking systems (if used) exceeds 25% of the seismic weight of the supporting structure, the dynamic interaction between the rigid photovoltaic modules and the supporting structure shall be considered in calculating the base shear coefficient; the simple procedure presented in this standard cannot be used for such rigid photovoltaic modules and an alternative design method satisfactory to the certification agency must be used. The procedure presented in this standard cannot be used for unanchored, ballast only systems.

3.6.2 Nomenclature

A_p – base shear coefficient (acceleration in g's).

S_{DS} – 0.2 second (short period) 5% damped design spectral response acceleration (g's)

a_p – dynamic amplification factor. Equal to 1 for rigid photovoltaic modules.

R_p – component response modification factor. Equal to 1.5 for rigid photovoltaic modules.

z – height of the base of the rigid photovoltaic module above ground, in feet. Need not exceed the value of the average roof height "h".

h – average roof height of the supporting structure measured from the ground, in feet.

$\bar{h}$ – height of the center of gravity (C.G.) of the rigid photovoltaic module from the base of the rigid photovoltaic modules, in feet

S_{MS} – 0.2 second (short period) 5% damped free surface spectral acceleration adjusted for site soil properties.

F_p – design base shear

W_p – weight (dead load) of the rigid photovoltaic module, in lbs.

M_p – design overturning moment.

I_p – component importance factor = 1.0

3.6.3 Base Shear Coefficient

The seismic base shear coefficient shall be calculated as follows:

$$F_{\mathrm{p}} = A_p W_p = \frac{0.4 a_p S_{\mathrm{DS}} W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right) \qquad (1)$$

A_p shall not be less than 0.3 I_p S_{DS} and need not be more than 1.6 I_p S_{DS}

Note that $\frac{z}{h} \leq 1$

3.6.4 Short-period design spectral response acceleration (S_{DS})

The short-period design spectral response acceleration SDS for which the rigid photovoltaic modules and racking systems (if used) will be rated should equal or exceed the largest value for locations at which they are expected to be installed.

For sites within the USA, the short-period design spectral response acceleration S_{DS} shall be calculated according to the ASCE 7 standard, as follows.

The MCE_R (risk targeted maximum considered earthquake) value of the 5% damped 'firm' rock spectral acceleration at 0.2 second (S_S) is read from the maps in ASCE 7. This is multiplied by the NEHRP (National Earthquake Hazard Reduction Program) soil amplification factor F_a (2) to obtain the free-surface spectral accelerations S_{MS}:

$$S_{MS} = S_S \times F_a \quad (2)$$

S_{DS} shall be taken as two-thirds of S_{MS}:

For locations outside the USA, S_{MS} shall be estimated as the 475-year return period value of 0.2 second period 5% damped "firm" rock spectral acceleration adjusted for local soil conditions multiplied by a factor of 1.8, or the 2,475 year return period value of 0.2 second period, 5% damped "firm" rock spectral acceleration adjusted for local soil conditions. The 0.2 second period, 5% damped "firm" rock spectral acceleration at 475- or 2475-year return periods can be estimated as the corresponding peak ground acceleration multiplied by a factor of 2.5. SDS shall be taken as two-thirds of this estimated S_{MS}. If the 475-year or 2475-year accelerations are not available, SDS can be estimated from other sources acceptable to FM Approvals, or a SDS value of 1.6 can conservatively be used.

3.6.5 Design Loads for Supporting Structure

The design base shear is calculated as follows:

$$F_p = A_p \cdot W_p \quad \text{(3) see equation (1) above}$$

The design overturning moment is calculated as follows:

$$M_p = F_p \cdot \bar{h} \quad (4)$$

Where applicable, the torque produced by mass eccentricity shall be considered in the design of the support structure.

3.6.6 Design Loads for Base Anchors

The design loads (shear, overturning moment and torque) applied to the base anchors shall be based on R_P equal to 1.5.

3.6.7 LRFD Load Combinations

Examine load combinations below to determine the design loads:

3.6.7.1 Operational Condition Dead Load

(1.2 × Dead Load) + [1.0 × Seismic Load (F_p)] + (0.2 × Roof Snow Load)

Note that the roof snow load should be based on a mean recurrence interval of 50-years.

3.6.7.2 Operational Condition Minimum Dead Load

(0.9 × Dead Load) + [1.0 × Seismic Load (Fp)]

4. PERFORMANCE REQUIREMENTS

This standard is intended to evaluate a rigid roof-mounted photovoltaic module for its performance as it relates to fire from above the structural deck, simulated wind uplift, susceptibility from hail storm damage, seismic performance requirements (optional) and gravity load testing (optional).

Tests of alternate constructions are permitted to be waived if considered less hazardous than those previously tested.

The use of screening tests are permitted to be used to determine critical components to be used for full scale testing or to evaluate components as alternate to those already tested and found to be satisfactory via the full the scale tests described in sections 4.1 through 4.5 below. Alternate components must perform to an equal or higher level than the component qualified via full scale testing.

When a test specimen fails to meet the acceptance criteria for a given classification or rating, two successful test specimens of the same or similar construction must meet the acceptance criteria to qualify for the given classification or rating.

Prior to testing, samples shall be permitted to cure for a maximum period of 28 days.

4.1 COMBUSTIBILITY FROM ABOVE THE ROOF DECK

Testing for combustibility from above the roof deck and/or rigid photovoltaic module shall be in accordance with a modified version of the ASTM E108 Class A Spread of Flame Test. The modifications are as follows:

The samples shall have rigid PV on top of the roof covers. The length of the test deck for the Spread of Flame test shall be 8 ft (2.4 m) minimum to a maximum of 16 ft (4.9 m). The samples shall be long enough to accommodate 2 panels if the combined length of 2 panels is greater than 13 ft. (4.0 m) or long enough to accommodate 3 panels if the combined length of 2 panels is less than 13 ft. (4.0 m). If the combined length of 2 panels is less than 13 ft. (4.0 m) and the combined length of 3 panels is longer than 16 ft. (4.9 m) then the test shall be run with 2 panels. The test deck sample shall be minimum 3 ft – 4 in. (1 m) wide up to a maximum of 6 ft -8 in. (2 m) wide. The samples shall be wide enough to accommodate 2 panels in a tent shape arrangement or 1 panel if the slopes are south facing.

4.1.1 Conditions of Acceptance for Combustibility from Above the Roof Deck

4.1.1.1 There shall be no fire damage to the roof cover nor to the PV panel within 6 in. (152 mm) of the end of the last PV module.

4.2 WIND UPLIFT RESISTANCE FOR RIGID PHOTOVOLTAIC MODULE WITH THE PANEL ATTACHED TO OR THROUGH THE ROOF COVER

For wind uplift resistance, the rigid photovoltaic module is tested using two methods. These two methods are simulated wind uplift pressure test with the photovoltaic module attached to a test frame using a pleated air bag and tensile loading of the fasteners/clips. The rating assigned to the assembly shall be the lower rating obtained during all testing.

4.2.1 Rigid Photovoltaic Simulated Wind Uplift Pressure Test

Testing for simulated wind uplift resistance shall be in accordance with Test Procedure, Appendix B. The reduced wind pressure loading shall be applied to the PV system using a pleated airbag. The minimum rating in psf required for certification is 45 psf (1.4 kPa) for Class 1-45. The maximum rating in psf available is 990 psf (47.3 kPa) for Class 1-990. Ratings between 1-45 and 1-990 are available in 15 psf (0.72 kPa) increments. The rating assigned to the assembly shall be the maximum simulated uplift resistance pressure which the assembly maintained for one (1) minute without ultimate failure. Adjustments to the pressure applied over the test area are made to account for the tributary area of only the PV panels and mounting system.

In addition, the assembly must maintain one-half the service wind load (50% of the ultimate failure pressure) for one (1) minute without visible cracking or visible creasing.

- Multiple cracks in the same component, which would impair performance is indicative of catastrophic failure, shall not be permitted.
- Crack length in excess of one half the minimum component dimension; e.g., >24 in. (1220 mm) for a 48 x 96 in. (1220 x 2440 mm) component shall not be permitted.

4.2.1.1 Conditions of Acceptance for Rigid Photovoltaic Simulated Wind Uplift Pressure Test

4.2.1.1.1 All fasteners and stress plates shall: a) remain securely embedded into, or through, the roof deck and other structural substrates to which they are being fastened to or through; b) not pull through, become dislodged, disconnected or disengaged from plates, battens, seams or substrates; c) not fracture, separate or break.

4.2.1.1.2 All components shall: a) not fracture, break or pull through, or over, fastener heads, plates or battens; b) not delaminate or separate from their facers or adjacent components to which they have been adhered; c) be permitted to deflect between points of mechanical securement provided that the insulation boards do not fracture, crack or break.

EXCEPTION: Visible cracking or visible creasing, when less than or equal to one half the minimum component dimension, shall be permitted provided ultimate failure does not occur as noted in 4.2.1.

4.2.1.1.3 All membranes shall: a) not tear, puncture, fracture or develop any through openings; b) not delaminate or separate from adjacent components.

EXCEPTIONS: 1) Mechanically fastened membranes shall be permitted to separate and deflect from adjacent components at locations where they are not fastened, 2) partially adhered membranes shall be permitted to separate and deflect from adjacent components at locations where adhesive placement was not intended, 3) tearing of membrane at fastener/stress distributors is allowed up to ultimate failure, 4) minor areas of delamination are allowed provided they do not continue to grow in size by more than 50% from the end of one pressure level through the end of the following pressure level.

4.2.1.1.4 All adhesives shall maintain full contact between all the surfaces of all components to which it has been applied to, or comes in contact with, without any separation, delamination, fracture, cracking or peeling of the adhesive or its bond.

EXCEPTION: Minor delamination is allowed provided it does not continue to grow in size by more than 50% from the end of one pressure level through the end of the following pressure level.

4.2.1.1.5 All roof decks shall: a) maintain their structural integrity during the entire classification period; b) not fracture, split, crack, or allow for fastener withdrawal.

4.2.1.1.6 Stresses induced to steel roof decking shall be determined by rational analysis and shall not exceed the allowable stresses per the latest edition of the *North American Specification for the Design of Cold-Formed Steel Structural Members,* AISI S100-200.

4.2.1.1.7 All photovoltaic modules shall: a) not puncture, fracture, crack or develop any through openings; b) not delaminate or separate from the frame.

EXCEPTION: Mechanically fastened modules shall be permitted to separate and deflect from adjacent components at locations where they are not fastened.

4.2.1.1.8 All other components, including seams, base sheets, base plies, plies and cap plies, shall not tear, puncture, fracture, disengage, dislodge, disconnect, delaminate or develop any through openings. See allowable exceptions given above.

4.2.2 Pull Out and Pull Through Tests for Photovoltaic Clamp/Frame Combinations, Pull Through Tests for Photovoltaic Frame/Fastener Combinations and Pull Out Tests Fastener/ Roof Deck Combination

Testing for simulated wind uplift resistance shall be in accordance with Test Procedure, Appendix B. The minimum rating granted shall be 60 psf (0.7 kPa). Ratings shall be stated in 15 lbs/ft^2 (0.7 kPa) increments. The maximum rating available is 990 psf (11.6 kpa). The rating assigned to the assembly shall be the maximum simulated uplift pressure which the assembly maintained for one (1) minute without failure.

4.2.2.1 Conditions of Acceptance for Pull Out and Pull Through Tests for Photovoltaic Clamp/Frame Combinations, Pull Through Tests for Photovoltaic Frame/Fastener Combinations Pull Out Tests Fastener/ Roof Deck Combinations using Tensile Loading are as follows:

4.2.2.1.1 The result reported shall be the highest force attained by the sample during the test.

4.2.2.1.2 The overall sample results shall be determined based on the average of three (3) tests. If the standard deviation of the three values divided by the mean is greater than 20%, up to two additional tests shall be required. The results of all tests shall be used to determine the final average.

4.2.2.1.3 The sample result from the above tensile testing will be the load determined in lbf (N). The total area of the rigid photovoltaic module will be divided by the total number fasteners/clamps used to secure the module, the result will be the contributory area for each fastener/clamp in ft^2 (m^2). The rating shall be the load determined from the tensile testing divided by the contributory area rounded down to the next multiple of 15 psf (0.72 kPa).

4.3 WIND UPLIFT RESISTANCE FOR RIGID PHOTOVOLTAIC MODULE LOOSE LAID AND BALLASTED

Installation of the rigid photovoltaic module if loose laid or ballasted shall be in accordance with SEOC PV2 2017 (2nd edition) or ASCE 7 (2016 edition). Mechanical connects such as clips, fasteners, plates, bars, screws, bolts, clamps need to meet the requirement of 4.2.2. The rating assigned to the assembly shall be the lower rating obtained during all testing.

4.3.1 Rigid Photovoltaic Simulated Wind Uplift Evaluation

Three ratings are available: 60 psf (2.9 kPa); 75 psf (3.6 kPa) and 90 psf (4.3 kPa). These systems shall only be used as loose laid and ballasted over fully adhered single ply, BUR, Liquid Applied or Modified bitumen roof covers.

4.3.1.1 Conditions of Acceptance for Rigid Photovoltaic Loose Laid and Ballasted - Prescriptive Method

4.3.1.1.1 The combined average uniform weight of the photovoltaic module, racking, concrete paver blocks and all components shall be equal to, or greater than, the loads outlined in SEOC PV2 2017 (2nd edition) or ASCE 7 (2016 edition). Load sharing share be limited to not more than 2 PV modules.

4.4 HAIL DAMAGE RESISTANCE TEST

Testing for hail damage resistance shall be in accordance with Test Procedure, Appendix D. The minimum rating required is Class 2.

4.4.1 Conditions of Acceptance for Hail Damage Resistance

4.4.1.1 After completion of the impact testing, the photovoltaic module shall show no signs of cracking or splitting, misaligned external surfaces, or rupture when examined under 10X magnification.

4.5 GRAVITY LOAD RESISTANCE TEST (OPTIONAL)

Testing for gravity load resistance shall be in accordance with Test Procedure, Appendix E.

4.5.1 Conditions of Acceptance for Rigid Photovoltaic Simulated Gravity Load Pressure Test

4.5.1.1 All fasteners, clamps, racking, framing and stress distributors shall: a) remain securely embedded into, or through, the substrates to which they are being fastened to or through; b) not pull/push through, become dislodged, disconnected, or disengaged from plates, battens, seams or substrates; c) not fracture, separate or break.

4.5.1.2 All components shall: a) not fracture, break or pull/push through, or over, fastener heads, plates or battens; b) not delaminate or separate from their facers or adjacent components to which they have been adhered; c) be permitted to deflect between points of mechanical securement provided that the components do not fracture, crack or break.

4.5.1.3 All adhesives shall maintain full contact between all the surfaces of all components to which it has been applied to, or comes in contact with, without any separation, delamination, fracture, cracking or peeling of the adhesive or its bond.

4.5.1.4 All photovoltaic modules shall: a) not puncture, fracture, crack or develop any through openings; b) not delaminate or separate from the frame.

EXCEPTION: Mechanically fastened modules shall be permitted to separate and deflect from adjacent components at locations where they are not fastened.

APPENDIX A:

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APPENDIX B: Test Procedures
Wind Uplift Resistance for Rigid Photovoltaic Modules

B-1 INTRODUCTION

B-1.1 The 12 x 24 ft (3.7 x 7.37 m) Simulated Wind Uplift Pressure Test Procedure Wind Uplift Tests for Rigid Photovoltaic Modules are designed to evaluate the performance of rigid photovoltaic modules to resist wind uplift forces on building roofs. The test method described below utilizes a nominal 12 x 24 ft (3.7 x 7.37 m) test sample. A larger test sample and test apparatus shall be permitted to be used.

B-1.2 The objective of the test is to provide a method of evaluating the uplift resistance of a completed roof assembly and its individual components when applied within a completed assembly.

B-1.4 The test method is designed to measure the stability of the roof assembly on its supports and to evaluate the ultimate strength of the individual components in the completed roof under static conditions which simulate the uplift loads imposed by wind forces on the roof system.

B-1.5 This standard is not intended to be used to evaluate loose laid ballasted roof assemblies.

12X24 FT (3.7 X 7.37 M) SIMULATED WIND UPLIFT PRESSURE TEST

B-2 DESIGN OF THE TEST APPARATUS

B-2.1 The 12 x 24 ft (3.7 x 7.37 m) Simulated Wind Uplift Test Apparatus is a steel pressure vessel arranged to apply and maintain air pressure at pre-established pressure levels from below the test sample.

B-2.2 The pressure vessel shall measure a minimum of 24 ft x 12 ft x 2 in deep (7.3 m x 3.7 m x 51 mm). It shall be fabricated from nominal 8 in. (203 mm) deep steel channel sections as the perimeter structure with nominal 6 in (152 mm) deep steel beams spaced 2 ft ± 1 in (0.6 m ± 25 mm) on center (o.c.) running parallel to the 12 ft (7.3 m) side. Other structural shapes, sizes and materials of construction shall be permitted to be used as long as the frame will provide a rigid base for the test sample. The bottom of the pressure vessel shall be sheathed with a minimum 7 ga (4.8 mm) thick steel plate spot welded to the top of the steel beams and continuously welded to the inside perimeter channels.

B-2.3 The air supply into the sealed vessel is provided by an inlet manifold construction with a nominal 4 in (102 mm) diameter PVC pipe. Four openings, equally spaced, penetrate the bottom steel plate and serve as the air inlet on the bottom of the pressure vessel. A ¼ in ±⅛ in (6.4 mm ± 3.2 mm) opening on the bottom of the vessel serves as the manometer connection. A gasket shall be placed between the top channel of the pressure vessel and the sample construction frame to minimize air leakage when the sample is clamped in place.

B-2.4 Air shall be supplied to the inlet manifold by a Turbo Pressure Blower, or equivalent, having the capability of generating 600 ft^2/min (17 m^2/min) or as needed to attain the desired uplift pressure. Pressure readings are obtained from a water filled manometer calibrated to be read directly in lbs/ft^2 (kPa) and capable of being read in minimum increments of 2 lbs/ft^2 (0.1 kPa). As an alternative, other types of pressure measuring devices shall be permitted to be used provided that the alternative device(s) have an equivalent or tighter gradation and tolerance levels.

B-3 TEST SAMPLE

B-3.1 The components for a test sample are assembled to the desired specifications (thickness, profile and strength of deck or purlins, application method and rate for the adhesives or fasteners, applicable size and thickness of insulation and type of roof) and shall be permitted to cure under laboratory conditions for a period of time not to exceed 28 days.

B-3.1.1 Construction of the roof assembly (except for the deck) shall be excluded from the test sample if both of following conditions are met:

- Roof cover is fully adhered.

- The rigid photovoltaic module is mechanically fastened through the roof cover to the structure, purlins or deck.

B-3.2 When steel decking is used; it shall be secured to a frame capable of withstanding the anticipated loads. This test specimen frame typically includes a structural steel support located along the center line and parallel to the 24 ft (7.3 m) side. In addition, three intermediate structural steel supports are located parallel to the 12 ft (3.7 m) side 6 ft (1.8 m) o.c. The steel deck is then applied parallel to the 24 ft (7.3 m) side. It is welded to the perimeter angle iron with ½ in (13 mm) diameter puddle welds 12 in (305 mm) o.c. along the entire perimeter. In addition, it is fastened at all supports [6 ft (1.8 m) spans for 1½ in (38 mm) deep 22 ga (0.75 mm) steel] 12 in (305 mm) o.c. with fasteners. All deck side laps are fastened with fasteners spaced at a maximum of 30 in (763 mm) o.c. Other structural roof deck assemblies and configurations may be used if requested by the test sponsor. Their application shall be in accordance with the manufacturer's specifications and requirements.

Note 1: The method of securing the steel deck to the test frame shall be permitted to vary when a specific test, as requested by a test sponsor, dictates.

Note 2: When the size of the test frame is different than the minimum size as permitted by Paragraph B-2.2 above, the steel deck shall be installed parallel to the longer dimension.

Note 3: When testing standing seam type roof assemblies, it is permissible to install the panels perpendicular to the long dimension.

B-3.3 Prior to installing the rigid photovoltaic modules, a minimum 0.006 in. (0.15 mm) thick polyethylene sheet or unreinforced EPDM is positioned in the frame so that all loads may be carried directly by the photovoltaic modules.

B-3.4 When ready for testing, the test specimen frame containing the test sample is placed on the pressure vessel and clamped in place. Clamps shall be permitted to be spaced 24 in ± 6 in (0.6 m ± 0.15 m) on center around the perimeter of the apparatus, or as needed, if excessive air leakage occurs during the test. In addition, the test specimen frame is secured to the pressure vessel as needed with intermediate support clips located near the centerline of the pressure vessel. The appropriate connections are then made to the air supply and the manometer.

B-4 CONDUCT OF TEST

B-4.1 Air is introduced from below the sample until the pressure level reaches 15 psf (0.7 kPa) for 4.2 tests or 40 psf (1.9 kPa) for 4.3 tests with a tolerance of +2 lbs/ft^2, -0 lbs/ft2 (+0.1 kPa, -0 kPa). The air shall be introduced at a rate that will increase the resulting pressure 1.5 lbs/ft2 /sec ± 1 lbs/ft2 2/sec (0.07 kPa/sec ± 0.05 kPa/sec). Upon reaching the target pressure, the pressure level shall be maintained for a period of 60 seconds. The air and clamps shall be permitted to be adjusted as necessary in order to maintain a constant reading. While the sample is being maintained at this pressure level, the sample shall be visually examined to ensure that it continues to meet the Conditions of Acceptance.

B-4.1.1 Upon mutual agreement between the test sponsor and the testing entity, the 15 psf (0.7 kPa) pressure level noted above may be omitted. This results in the initial pressure level being 30 psf (1.4 kPa) for 4.2 tests. Subsequent pressure increases shall be as described in B-4.2.

B-4.1.2 Depending on the type of assembly being tested, it is not always possible to adhere to the 1.5 lbs/ft^2/sec ± 1 lbs/ft^2/sec (0.07 kPa/sec ± 0.05 kPa/sec) rate of increase needed to reach the next pressure level. In these situations, the rate of increase between pressure levels shall be conducted as evenly as practical. The 60 second time period required to attain the next pressure level shall not start until the new pressure level has been reached.

B-4.2 After 60 seconds, the pressure level shall be increased in 15 psf (0.7 kPa) or 20 psf (0.9 kPa) increments by introducing additional air at the rate and within the tolerance described above. Upon reaching the next level, the pressure shall be maintained for a period of 60 seconds. The supply air and clamps shall be permitted to be adjusted as necessary in order to maintain a constant reading. While the sample is being maintained at this pressure level, the sample shall be visually examined to ensure that it continues to meet the Conditions of Acceptance. After maintaining this pressure for 60 seconds, the air is allowed to exhaust until no upward pressure is acting on the roof. The sample is again inspected to ensure that it continues to meet the Condition of Acceptance. This procedure is repeated with each successive pressure increased by 15 psf (0.7 kPa) or 20 psf (0.9 kPa) increments.

B-4.3 The sequence described in B-4.2 above shall be repeated until the sample fails, additional pressure levels are unable to be attained or maintained, or at the discretion of the test sponsor. Failure is considered to occur when the Conditions of Acceptance (as defined in section 4.2 and 4.3 of this document) are no longer being met or until the pressure level is no longer able to be maintained.

B-4.4 Upon completion of the test, the sample shall be examined and any item not conforming to the Conditions of Acceptance noted.

B-5 RESULTS

B-5.1 The results of the 12 x 24 ft (3.7 x 7.37 m) Simulated Wind Uplift Pressure Test shall be stated in increments of 15 psf (0.7 kPa) of uplift resistance.

B-5.2 The uplift resistance rating shall be the highest level attained by the assembly that was held for the full 60 seconds and continued to meet the Conditions of Acceptance. In the case of Section 4.3 tests, rounding down to the nearest multiple of 15 may be required.

B-7.3 When ready for testing, the test specimen frame containing the test sample is placed on the pressure vessel and clamped in place. Clamps shall be permitted to be spaced 24 in ± 6 in (0.6 m ± 0.15 m) on center around the perimeter of the apparatus, or as needed, if excessive air leakage occurs during the test. In addition, the test specimen frame is secured to the pressure vessel as needed with intermediate support clips located near the centerline of the pressure vessel. The appropriate connections are then made to the air supply and the manometer.

APPENDIX C: Test Procedures
Pull Out and Pull Through Tests for Photovoltaic Clamp/Frame Combinations, Pull Through Tests for Photovoltaic Frame/Fastener Combinations and Pull Out Tests Fastener/ Roof Deck Combinations Using Tensile Loading

C-1 INTRODUCTION

C-1.1 The Pull Out/Pull Through Tests for Rigid Photovoltaic Clamp/ Photovoltaic Frame Combinations Test Procedure is designed to assess the pull out/pull through strength of the clamps or other attachment component used to secure the rigid photovoltaic module to the frame or racking system using tensile loading.

C-1.2 The Pull Through Tests for Photovoltaic Frame/Fastener Combinations Test Procedure is designed to assess the strength of the photovoltaic frame or racking system in resisting pull though of the fasteners using tensile loading.

C-1.3 The Pull Out Tests for Fastener/Roof Deck Combinations Using Tensile Loading Test Procedure is designed to assess the pull out strength of fasteners into various roof decks by using tensile loading.

C-2 DESIGN OF THE TEST APPARATUS

C-2.1 Any load testing equipment capable of the loads and strain rates is acceptable.

C-2.2 Clamp Pull Out and Pull Through: The test jig is made of steel and is capable of securing the photovoltaic clamps, mounting brackets, frame or racking system. The test jib must be strong enough to resist bending or deformation during the test.

C-2.3 Fastener Pull Out: The test jigs included two solid metal plates made of minimum 0.5 in (13 mm) thick steel. The plates are a minimum 6 x 6 in (150 x 150 mm), one with a 0.5 in (13 mm) diameter hole in the center and the other with a 1 in. (25 mm) diameter hole in the center.

C-3 TEST SAMPLE

C-3.1 Clamp Pull Out of Frame: The test sample consists of a minimum of one full clamp and a section of the photovoltaic frame large enough to secure to the apparatus.

C-3.2 Clamp Pull Through of Fastener: The test sample consists of a minimum of one full clamp and the fastener to be evaluated.

C-3.3 Fastener Pull Out: The test sample consists of a minimum 6 x 6 in. (150 x 150 mm) piece of the decking to be evaluated with the fasteners secured into the center of the sample

C-4 CONDUCT OF TEST

C-4.1 When ready for testing:

C-4.1.1 Clamp Pull Out of Frame: The clamp or mounting bracket of the test sample to be evaluated is placed on the section of frame or racking system. The frame and clamp are secured using separate test jigs described in C-2.2. The test jig securing the frame is secured to one stationary jaw of the tensile machine while the test jig securing the clamp is secured to the other end of the tensile machine.

C-4.1.2 Clamp Pull Through of Fastener: The clamp or mounting bracket of the test sample is secured using the test jigs described in C-2.2. The test jig is then placed on the underside of the opening in the stationary platform with the fastener head facing down. The fastener tip is then secured in the tensile machine stationary jaw.

C-4.1.3 Fastener Pull Out The fastener of the test sample to be evaluated is placed through the hole in the test jig. The test jig is then placed on the underside of the opening in the stationary platform with the fastener head facing down. The fastener tip is then secured in the tensile machine stationary jaw.

C-4.2 Force is exerted in a direct line perpendicular to the plane of the test jig and clamp, mounting bracket, frame or racking system or roof deck interface at a crosshead speed of 2 in./min (51 mm/min).

C-4.3 Continue the testing described in C-4.2 above until the sample fails, higher forces are unable to be attained or maintained, or at the discretion of the test sponsor. Failure is considered to occur when the Conditions of Acceptance (as defined in Section C-5 of this document) are no longer being met or until the tensile force is no longer able to be maintained.

C-4.4 Upon completion of the test, the sample shall be examined and any item not conforming to the Conditions of Acceptance noted.

C-5 CONDITIONS OF ACCEPTANCE

C-5.1 The surface of the test jig shall remain flush with the surface of the moving crosshead.

C-6 RESULTS

C-6.1 The result shall be the highest force attained by the sample during the test.

C-6.2 The overall sample results shall be determined based on the average of three (3) tests. If the standard deviation of the three values divided by the mean is greater than 20%, up to two (2) additional tests shall be conducted to bring the standard deviation of all values divided by the mean to less than, or equal to, 20%. If after five (5) tests the standard deviation of all five (5) values divided by the mean remains greater than 20%, the results of all five (5) tests shall be used to determine the final average.

APPENDIX D: Test Procedures
Determining the Susceptibility to Hail Damage of Rigid Photovoltaic Modules

D-1 INTRODUCTION

D-1.1 The Hail Damage Test Procedure is designed to assess the potential for damage to a rigid photovoltaic module. It was developed to determine the potential for to the photovoltaic module resulting from hail storms when the module is installed over its tested substrate.

D-1.2 The objective of the test is to provide a method of evaluating the susceptibility to hail damage of rigid photovoltaic modules when installed over a roof assembly.

D-2 DESIGN OF THE TEST APPARATUS

D-2.1 **Ice Ball Launcher** – a device capable of propelling ice balls at speeds necessary to develop intended kinetic energy. The device utilizes flex bands to launch ice balls in a range of diameters and at speeds appropriate for simulated hailstone impact testing. Aiming accuracy of the launcher must be sufficient to assure that the ice balls strike the specified target impact areas; otherwise, the surrounding area must be masked for protection against inadvertent impacts.

D-2.2 **Ice Ball Molds –** devices used for casting spherical ice balls of appropriate diameters.

D-2.3 **Speed Meter –** a device capable of measuring the velocity of ice balls within $\pm$ 1 mph (0.45 m/s).

D-3 TEST SAMPLE

D-3.1 Test Sample - At least one rigid photovoltaic module and mounting system if the mounting system is exposed above the module.

D-3.2 Ice Ball Preparation - Molds of water for casting spherical ice balls of 1-1/2, 1-3/4, and 2 in. (31.8, 38.1, 44.5 and 50.8 mm) diameters are placed in a freezer at a controlled temperature of -7° ± 7°F (-22 ± 4°C) until frozen solid (a minimum of 48 hours). Acceptable ice balls will be free of cracks and air bubbles and will meet the following criteria within +/- 10% of the values listed:

Class	Nominal ice ball diameter (in. [mm])	Mass (lbs [gr])
2	1-1/2 [38.1]	0.0584 [26.5]
3	1-3/4 [44.5]	0.0928 [42.1]
4 or VSH	2 [50.8]	0.1385 [62.9]

D-3.2.1 Ice Balls shall be molded as follows:

- The bottom half of the room temperature mold is filled to a point just below the top edge with water.
- The top half of the mold is placed on the bottom, gently pressing the pieces together.
- The mold is placed in the freezer overnight.
- Using ice water; perform the second fill by placing a small amount of water into the mold very slowly three times. Between pours allow a brief time period to prevent cracking. The fill the mold to approximately 90%.
- The mold is placed in the freezer for a minimum of 6 hours.
- Using ice water, completely fill the mold.
- The mold is placed in the freezer for a minimum of 2 hours.
- Remove ice balls by gently separating the mold.

D-4 CONDUCT OF TEST

D-4.1 Position the test sample so the trajectory of the ice ball is perpendicular (90° ± 5 degrees) to the test panel.

D-4.2 Determine and identify target impact locations of the test specimen that are particularly sensitive to impact damage using the table below.

Impact location #	Location
1	A corner of the module, not more than 2 in. (51 mm) from either edge
2	An edge of the module, not more than 0.5 in. (13 mm)
3-5	Randomly in the middle of the module (at points that are most vulnerable to hail damage)

D-4.3 Launch an ice ball at a target impact point based upon examination of vulnerability. Each target location shall be impacted twice, with a maximum 0.5 in. (13 mm) distance between impacts. Impact locations will include, but are not limited to edges, corners, unsupported areas, overlaps and joints. The outside edge of the ice ball shall be a minimum 1/4 in. (6.4 mm) from the edge of the test specimen. Provide a minimum 6 in. (152 mm) distance between impact locations so that the effects of each impact location are independent.

D-4.4 Record the mass of the ice ball with a calibrated scale, the speed of each Ice Ball with the calibrated Speed Meter, and calculate the kinetic energy of each ice ball impact using the following equation:

$KE = (mV_t^2)/64.34$

Where: KE = ice ball kinetic energy (foot pound)

The kinetic energy must be equal to or greater than the impact kinetic energy shown below:

Class	Nominal Ice Ball Diameter (in. [mm])	Kinetic Energy (ft-lb [j])
2	1-1/2 [38.1]	7.77 [10.4]
3	1-3/4 [44.5]	14.95 [20.3]
4	2 [50.8]	26.81 [36.4]
VSH	2 [50.8]	53-58 [72-79]

D-4.5 After impact testing, visually scrutinize top and bottom surfaces of the test specimen. Record any damage to the specimen such as splits, punctures, fractures, disengagement of lap elements, exposure of materials not so intended, etc.

D-4.6 Monitor the sample during the test and record the effect of the test on the sample. The sample shall be examined post hail. Failure is considered to occur when the Conditions of Acceptance (as defined in Paragraph 4.4.1 of this standard) are no longer being met.

D-5 RESULTS

D-5.1 The hail rating shall be stated as Class 2, Class 3, Class 4 or VSH.

APPENDIX E: Test Procedures
Gravity Load Resistance Test

For gravity load resistance, the rigid photovoltaic module will be tested using two methods. These two methods are simulated gravity load pressure test with the photovoltaic module attached to a test frame inversely using a pleated air bag, and structural loading of the fasteners/clips. The rating assigned to the assembly shall be the lowest rating obtained during all testing.

Testing for simulated gravity load resistance shall be in accordance with the 5 × 9 Simulated Wind Uplift Pressure Test Procedure outlined in ANSI/FM Approvals 4474 with the following modifications.

The pressure load shall be applied to a PV module mounted upside down using a pleated airbag. Air is introduced by opening the air supply valve on the blower until the pressure level reaches one half of the pressure load requested by the test sponsor. For example, if the test sponsor wants a rating of 32 psf (1.5 kPa) then introduce air to a pressure level of 16 psf (0.75 kPa) with a tolerance of +2 psf, -0 psf (+0.1 kPa, -0 kPa). Upon reaching ½ of the requested rating pressure, the pressure level shall be maintained while the perimeter clamps are checked and that there are minimal air leaks from the pressure vessel. Adjustments shall be permitted as necessary in order to maintain a constant reading. While the sample is being maintained at this pressure level, the sample shall be visually examined to ensure that it continues to meet the Conditions of Acceptance.

After 60 minutes, the pressure level shall be increased to the full pressure rating requested with a tolerance of +2 psf, -0 psf (+0.1 kPa, -0 kPa). Upon reaching the next pressure level, the pressure shall be maintained for a period of 60 minutes. The supply air and clamps shall be permitted to be adjusted as necessary in order to maintain a constant reading. While the sample is being maintained at this pressure level, the sample shall be visually examined to ensure that it continues to meet the Conditions of Acceptance.

The rating assigned to the assembly shall be the maximum simulated gravity load which the assembly maintained for one (1) hour without ultimate failure.