Testing and Approval of Contractor-fabricated Metal Panel Roof Systems

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Uplift resistance; metal panel roof systems; UL 580; UL 1897; aluminum; copper; Galvalume; galvanized steel; stainless steel; terne-coated stainless steel; terne-coated carbon steel.

Abstract

Building code requirements mandate minimum uplift resistance for roof assemblies. The building codes list approved test methods that determine uplift resistance of roof assemblies (for those roof assemblies that cannot have uplift resistance determined analytically). Underwriters Laboratories (UL) test method UL 580, "Tests for Wind Uplift Resistance of Roof Assemblies," is currently referenced in building codes as an approved method to determine uplift resistance of roof assemblies.

Theoretical analyses of contractor-fabricated aluminum, Galvalume,™ galvanized steel, terne-coated stainless steel and terne-coated carbon steel roof panels were performed to determine uplift resistance in accordance with standard design practice. Because the uplift resistance of copper panel roof systems cannot be determined analytically, NRCA embarked on a testing program of contractor-fabricated copper panel roof systems. All metal panels are flat pan with double-lock standing seams.

Analysis was performed by ENCON® Consultants and testing was performed at the Hurricane Testing Laboratory in West Palm Beach, Fla. NRCA now has a copper panel roof system listing in the UL *Roofing Materials & Systems Directory*.

The analysis, testing, approval information and purpose will be discussed in this paper.

Authors Biography

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Introduction

Contractor-fabricated architectural metal panel roof systems have been used successfully in the United States for years. However, there has been increased scrutiny recently about some of these roof systems' uplift-resistance capabilities.

Building code requirements mandate minimum uplift resistance for roof assemblies. The model building codes list approved test methods that determine uplift resistance of roof assemblies (for those roof assemblies that cannot have uplift resistance determined analytically). Underwriters Laboratories (UL) test method UL 580, "Tests for Wind Uplift Resistance of Roof Assemblies," is currently referenced in building codes as an approved test method to determine uplift resistance of roof assemblies and is the most common method used.

In this work, theoretical analyses of contractor-fabricated aluminum, Galvalume,™ galvanized steel, terne-coated stainless steel and terne-coated carbon steel roof panels were performed to determine uplift resistance in accordance with standard design practice. Engineering rationale exists for steel and aluminum; each has an analytical design methodology that is industry-accepted. There is no industry-accepted analytical design methodology for copper; therefore, the uplift resistance of copper panel roof systems must be determined through physical testing.

For most roofing products used in the United States, roofing contractors rely on product manufacturers to perform any testing and provide the necessary documentation for product compliance with building codes. However, because there are no product manufacturers for contractor-fabricated architectural metal panel roof systems, the responsibility for providing the product's code compliance information most typically resides with the contractor who fabricates and installs the metal panels.

Because of this, NRCA embarked on a testing program of contractor-fabricated copper panel roof systems. All metal panels in this study are flat pan with double lock standing seams. NRCA retained and analyses were performed by ENCON® Consultants and testing was performed at the Hurricane Testing Laboratory in West Palm Beach, Fla.

NRCA has a copper panel roof system listing in the UL *Roofing Materials & Systems Directory* and now has a process by which NRCA member contractors can obtain a sublisting for their copper panel roof assemblies.

Explanation of Analytical Study

The uplift load capacity of these standing-seam roof systems depends on a number of factors, such as panel material, panel configuration, number of spans and span length (i.e., clip spacing), sidelap seam configuration, clip strength and attachment, and other related factors. The uplift capacity of a roof system is limited by its “weakest link,” or the initial failure mode, of a roof system. The primary objective of the analytical study and small-scale bench test studies is to establish the roof system’s weakest link. Then the weakest link allowable load capacity was assessed and used to determine the roof system’s resistance to uplift load.

A practical analysis of the roof system suggests that one of the following possible modes of failure will constitute the roof system’s weakest link:

- Failure of the panel sidelap as a beam between clips. (Failure mode 1)
- Disengagement of the clip from the seamed panel sidelap assembly. (Failure mode 2)
- Crushing of the top of the male corrugation under the clip as uplift load is applied. (Failure mode 3)
- Clip deformation or the clip base pulling over the head of the fastener. (Failure mode 4)
- Clip fastener pull-out from the substrate. (Failure mode 5)
- Unfurling and unzipping of the sidelap seam as cross-directional deformation of the panel flat occurs. (Failure mode 6)
- Fatigue failure of rib. (Failure mode 7)

Small-scale Tests of the Panel/Clip and Clip/Fasteners Assemblies

One way to establish the weakest link (the initial failure mode) is by conducting small-scale tests of the clip assembled in the various panel sidelaps. The results of the small-scale clip tests with the clip seamed into the various panel sidelaps can be used to evaluate failure modes 2, 3, 4 and 5.

Small-scale tests were conducted to establish the uplift resistance of a 24-gauge (0.024 inch [0.61 mm] thick) stainless-steel clip when the clip is seamed into the different panel systems. Reference Table 1 for the panel system types. During the testing of the different systems, failure included yielding of the panel, crushing of the male rib and pull-over failure of the panel clip base.

The uplift resistance of the clip/fastener assembly when attached to 15/32-inch (11.9-mm) and 23/32-inch (18.3-mm) thick plywood sheeting was tested. Failure modes observed in these tests included pull-out failure of the fastener (failure mode 5) and pull-over failure of the clip base (failure mode 4).

The small-scale clip tests with the clip inserted in the various panel sidelaps suggest that with at least some of the materials under consideration, the panel clip assembly will be the weakest link. For example, some failures are the result of the following.

- male sidelap crushing under the clip
- failure of the clip by pulling the clip base over the head of the screw
- the screws pulling out from the substrate material

Theoretical Calculations

Determination of the weakest link in the roof system also included determining the beam strength of the panel corrugation between clips for a three-span condition. Section properties for each panel were calculated in accordance with the appropriate design manual for a given material type and yield stress. The allowable moment was then calculated for two conditions. A summary of the allowable moments for the various systems is shown in Table 1.

Table 1. Material and Section Properties

Material	Yield Stress Ksi (MPa)	Rib Height Inch (mm)	Panel Width Inch (mm)	Thickness Inch (mm)	Allowable Moment in. kips/ft (KNm/m)	
					Top in Compression	Bottom in Compression
Aluminum ASTM B209 (1)	19 (131)	1.50 (38)	16 (406)	0.032 (0.81)	0.817 (302.8)	0.544 (201.6)
Aluminum ASTM B209 (1)	19 (131)	1.50 (38)	20 (508)	0.032 (0.81)	0.653 (242.0)	0.351 (130.1)
Galvalume ASTM A792 (2)	50 (348)	1.50 (38)	16 (406)	0.024 (0.61)	1.478 (547.8)	1.249 (463.0)
Galvalume ASTM A792 (2)	50 (348)	1.50 (38)	20 (508)	0.024 (0.61)	1.169 (433.3)	0.996 (369.2)
Galvalume ASTM A792 (2)	50 (348)	1.00 (25)	17 (432)	0.024 (0.61)	0.754 (279.5)	0.670 (248.3)
Galvalume ASTM A792 (2)	50 (348)	1.00 (25)	21 (533)	0.024 (0.61)	0.610 (226.1)	0.543 (201.3)
Galvanized Steel ASTM A653 (2)	37 (255)	1.50 (38)	16 (406)	0.024 (0.61)	1.136 (421.1)	0.948 (351.4)
Galvanized Steel ASTM A653 (2)	37 (255)	1.50 (38)	20 (508)	0.024 (0.61)	0.915 (339.2)	0.759 (281.3)
Galvanized Steel ASTM A653 (2)	37 (255)	1.00 (25)	17 (432)	0.024 (0.61)	0.583 (216.1)	0.509 (188.7)
Galvanized Steel ASTM A653 (2)	37 (255)	1.00 (25)	21 (533)	0.024 (0.61)	0.474 (175.7)	0.412 (152.7)
Terne-coated Stainless Steel (3)	30 (207)	1.50 (38)	16 (406)	0.015 (0.38)	0.476 (176.4)	0.387 (143.4)
Terne-coated Stainless Steel (3)	30 (207)	1.00 (25)	17 (432)	0.015 (0.38)	0.268 (99.3)	0.209 (77.5)
Terne-coated Carbon Steel A308(2)	33 (228)	1.00 (25)	21 (533)	0.015 (0.38)	0.237 (87.8)	0.206 (76.3)
Terne-coated Carbon Steel A308(2)	33 (228)	1.00 (25)	17 (432)	0.012 (0.30)	0.207 (76.7)	0.182 (67.5)

Notes:

1. Theoretical section properties are calculated in accordance with “Specification of Aluminum Design Manual” produced by Aluminum Association Inc., Sixth Edition, 1994.
2. Theoretical section properties are calculated in accordance with AISI "Specification for the Design of Cold-Formed Steel Structural Members," 1996 Edition.

3. Theoretical section properties are calculated in accordance with ANSI/ASCE-8-90 "Specification for the Design of Cold-Formed Stainless Steel Structural Members," 1990 Edition.
    a. When the top of the panel is in compression.
    b. When the bottom of the panel is in compression.

Full-scale testing of panels with double-locked seams has shown that the clip is normally well restrained in such seams and crushing of the male rib of the panel is the most common failure mode.

The theoretical calculations establish that the weakest link in the aforementioned schedule of possible failure modes under actual wind load will not be panel sidelap beam failure between clips.

Yield strength tests of the panel at its point of maximum moment were conducted to determine the failure of the panel sidelap as a beam between clips. From this, it was concluded that the panel sidelap beam that spans between clips is not the weakest link for clip spacing less than or equal to 2 feet, 6 inches (762 mm).

Allowable Load Calculation

The allowable uplift load that can be carried by each panel system was calculated for clips installed to 15/32-inch- (11.9-mm-) and 23/32-inch- (18.3-mm-) thick plywood. The clip spacing or panel span varied from 1 foot (305 mm) to 2 feet, 6 inch (762 mm). The allowable uplift loads are based on the following criteria and factors of safety:

1. Allowable loads calculated from theoretical allowable moments are based on three or more equal spans. The theoretical allowable moments are calculated in accordance with the following specifications:
    a. Aluminum Alloys: “Specification of Aluminum Design Manual” produced by Aluminum Association Inc., Sixth Edition, 1994.
    b. Galvalume, Galvanized and Terne-coated Steel: AISI "Specification for the Design of Cold-Formed Steel Structural Members," 1996 Edition.
    c. Terne-coated Stainless Steel: ANSI/ASCE-8-90 "Specification for the Design of Cold-Formed Stainless Steel Structural Members," 1990 Edition.

2. Allowable loads were calculated from panel yield loads measured during the small-scale tests. A factor of safety of 1.67 for aluminum, steel and terne metal panels and a factor of safety of 1.85 for stainless steel (obtained from the aforementioned specifications) were used to establish the allowable loads.

3. Allowable loads were also calculated from the panel/clip assembly small-scale tests. These uplift loads were calculated by dividing the panel clip load by the tributary area for a given panel span and panel width using a factor of safety of 2.5, which was obtained from the aforementioned specifications.

4. Allowable loads were also calculated from the clip/fastener assembly tests when attached to either 15/32-inch- (11.9-mm-) and 23/32-inch- (18.3-mm-) thick plywood. These wind-uplift loads were calculated by dividing the clip fastener load by the tributary area for a given panel span and panel width using a factor of safety of 2.5, which was obtained from the aforementioned specifications.

The allowable uplift loads for the metal panels with clips installed in 15/32-inch- (11.9-mm-) thick plywood for the various spans are provided in the conclusion.

Discussion

The small-scale bench-type tests of the clip performed in this work do not completely simulate the actual field conditions that will be encountered by the clip under full-scale wind-uplift load conditions. There is the possibility that under actual load conditions, with at least some of the materials, there may be some interaction between the various elements that will cause a premature failure or a failure at a lower load than this analysis has identified. And there is the possibility that under actual load conditions, the failure load may be higher than this analysis had identified.

Another factor that may cause the loads, as established in the allowable load tables, to vary from the loads actually obtained under simulated wind load conditions relates to the potential inclusion of an airtight barrier on the substrate. The loads established in the allowable load tables do not consider the fact that in the field, the panels will be installed over plywood and the plywood substrate and/or other component may form an airtight barrier. If this occurs, at least some of the uplift load will be resisted by the plywood substrate. The load on the metal roof system will be reflected onto the plywood, therefore, the uplift capacity of the roof system will be greater than the established allowable load on the panel and its attachment. From an engineering perspective, this would be beneficial to the overall uplift resistance capability, thus making the calculated loads conservative.

Explanation of UL 580 Test Method

The UL 580, “Tests for Uplift Resistance of Roof Assemblies,” test method subjects a 10-foot by 10-foot (3.05-m by 3.05-m) roof assembly sample to various static and oscillating pressures; these are intended to represent the uplift forces imposed on a roof assembly exposed to high winds.

The test is divided into four levels with increasing pressures, which correlate to the Class 15, 30, 60 and 90 classifications. Roof assemblies passing this test are assigned classifications of Class 15, 30, 60 or 90.

Each individual classification is divided into five phases. The first phase is static negative pressure for five minutes. The second phase is static negative and positive pressure for five minutes. The third phase is oscillating negative pressure and static positive pressure for 60 minutes. The fourth phase is static negative pressure for five minutes, and the fifth phase is static negative and positive pressure for five minutes. See Figure 1 for test pressures.

The maximum total pressure applied to the roof assembly test specimen for Class 15 is 22.9 psf (1.1 kPa); Class 30 is 45.0 psf (2.16 kPa); Class 60 is 75.0 psf (3.60 kPa); and Class 90 is 105 psf (5.04 kPa).

A roof assembly receiving a Class 90 rating has endured four hours of static and oscillating pressures without failure. To receive a Class 90 rating, it is not required that the Class 15 level be used. However, the Class 30 and 60 levels are required. The UL 580 testing protocol performed for NRCA did not include the Class 15 level.

Explanation of UL 1897 Test Method

The UL 1897, "Uplift Tests for Roof Covering Systems," test method subjects a 10-foot by 10-foot (3.05-m by 3.05-m) roof assembly sample to various static pressures. These pressures are intended to represent the uplift forces imposed on a roof assembly exposed to high winds.

The test consists of multiple phases of 15 psf (0.72 kPa) increments, beginning at 15 psf (0.72 kPa). Roof assemblies passing this test are assigned classifications of Class 15, 30, 45, 60, 75, 90, 105, etc.

Each phase consists of static negative pressure held for one minute. If the roof assembly sample passes, the pressure is increased to the next increment and then held for one minute. The roof assembly rating is the maximum static negative pressure sustained for one minute without failure.

Explanation of UL 580 and UL 1897 Test Results

NRCA's intent was to achieve a UL 90 classification with the least-conservative copper panel roof assembly that is commonly installed and would pass. This would facilitate a UL 90 classification of more conservative panel assemblies based on future engineering analyses. Achieving a UL 90 classification with the most liberal panel assembly provides the opportunity for the largest number of possible copper panel roof assemblies to be evaluated (via an engineering analysis) and qualify to have a UL 90 classification.

NRCA believed that a double-lock seam was the most appropriate seam to test. It is generally considered to be the most weatherproof seam (i.e., the most air and water infiltration resistant). The double lock seam was assumed to be the strongest seam type available. Also, it was initially presumed that a taller double lock seam (1 1/2 inches vs. 1 inch [38.1 mm vs. 25.4 mm]) would provide greater uplift resistance.

NRCA also decided to initially test the least conservative clips and clip spacing (i.e., wide). It was decided to begin with a two-piece, 28-gauge (0.015-inch- [0.38-mm-] thick) stainless-steel clip at 24 inches (610 mm) on center.

Testing Part One

The initial UL 580 test was performed in May 2000 on 21-inch- (533-mm-) wide, 16-ounce/square foot (0.0216-inch- [0.56-mm-] thick) copper panels meeting ASTM B370, with 1-inch- (25-mm-) tall double-lock standing seams with 28-gauge (0.015-inch- [0.38-mm-] thick), two-piece stainless steel expansion clips at 24 inches (610 mm) on center. The roof assembly failed the test during phase 3 (the 60-minute phase) of the UL 60 classification level due to buckling of the panel seams and subsequent buckling of the panels. Therefore, this copper panel assembly achieved a UL 30 rating. Because the test results did not satisfy NRCA's objective, NRCA is not pursuing a UL listing of this tested configuration.

Based on the analysis of the failed assembly, the clips themselves did not appear to be part of the failure mode (i.e., the clips did not appear to be significantly deformed during the test). However, due to the buckled seam, it was believed that the clip spacing was too wide, allowing for substantial seam deflection. The seam deflection led to the buckling of the panels, which constituted the failure of the roof assembly.

Because the failure mode was initiated by a buckled seam, it was predicted that a taller seam would provide more uplift resistance. This prediction follows engineering logic that deeper beams (i.e., taller seams) provide greater resistance to deflection under similar loads. The clip spacing was also reduced to provide another more conservative parameter to the assembly.

Testing Part Two

The second UL 580 test was performed in April 2001 on 20-inch- (508-mm-) wide, 16-ounce/square foot (0.0216-inch- [0.56-mm-] thick) copper panels meeting ASTM B370, with 1 1/2-inch- (38-mm-) tall, double-lock standing seams with 28-gauge (0.015-inch- [0.38-mm-] thick), one-piece stainless-steel clips at 18 inches (457 mm) on center. The roof assembly failed the test during phase 2 (the five minute phase) of the UL 60 classification level due to buckling of the panel seams. Therefore, this copper panel assembly achieved a UL 30 rating. Because the test results did not satisfy NRCA's objective, NRCA is not pursuing a UL listing of this tested configuration.

Based on the analysis of the failed assembly and comparison to the failure mode of the initial test, it was apparent the seam height (1 1/2 inches [38 mm]) was the cause of the buckled panel seams. This panel assembly (20/1.5/18) did not perform as well as the initial assembly tested (21/1/24). This panel had a narrower panel ribs and closer clip spacing than the panel used in the initial test. Therefore, the conclusion was reached that the taller panel seams were the cause of the failure. And because neither of the panel assemblies passed the UL 60 classification, it was determined that another parameter of the test assembly needed to be more conservative. It was determined to test narrower panels, use a 1-inch- (25-mm-) tall seam and retain the 18-inch on center clip spacing.

The third UL 580 test was performed in April 2001 on 17-inch- (432-mm-) wide, 16-ounce/square foot (0.0216-inch- [0.56-mm-] thick) copper panels meeting ASTM B370, with 1-inch- (25-mm-) tall, double-lock standing seams with 28-gauge (0.015-inch- [0.38-mm-] thick), one-piece stainless-steel clips at 18 inches (457 mm) on center. The roof assembly passed the UL 90 classification cycle.

Note that "passing" implies that the roof assembly is functional and weatherproof, not that the roof assembly would remain aesthetically acceptable to the owner. With more than 2 inches (51 mm) of permanent deflection at the center of the middle panels, it is unlikely that any owner would allow this roof system to remain in place. However, the roof assembly will serve its primary purpose--it will keep water out of a building by remaining in place and providing reliable weatherproofing.

Comparison of test methods

NRCA decided to test its UL 90-rated metal panel roof assembly by an alternate test method, the UL 1897 test method, to see the influence the test method has on the ultimate failure load (i.e., the resultant classification). The test methods' durations differ significantly. To achieve a UL 90 classification from the UL 580 test method, a roof assembly must endure four hours of testing. Comparatively, to achieve a UL 90 classification from the UL 1897 test, a roof assembly must endure approximately 12 minutes of testing. (The 12-minute time is the additive time of the six one-minute phases and the approximate time to increase the pressure before beginning each phase.)

The UL 1897 test was performed in November 2001 on 17-inch- (432-mm) wide, 16 ounce/square foot (0.0216-inch- [0.56-mm-] thick) copper panels meeting ASTM B370, with 1-inch (25-mm) tall, double-lock standing seams with 28-gauge (0.015-inch- [0.38-mm-] thick), one-piece stainless-steel clips at 18 inches (457 mm) on center. This is the same assembly that achieved a UL 90 classification by the UL 580 test method. However, the roof assembly achieved a UL 165 classification from the UL 1897 test method.

It is apparent the different duration of the test methods has a significant effect on the result. Without further testing, it is unknown whether the UL 1897 test method will consistently result in nearly double the Classification of the UL 580 test method, similar to the results seen here.

Conclusions

Analytical Analysis of Metal Panels

The allowable uplift loads for the metal roof system panels are provided in Table 2. This includes the use of 24-gauge (0.024-inch- [0.61-mm-] thick) stainless-steel clips installed in 15/32-inch- (11.9-mm-) thick plywood for the various spans.

Table 2: Allowable Uplift Loads When Attached In 15/32" (11.9 mm) Plywood

Material	Yield Strength Ksi (MPa)	Rib Height Inch (mm)	Panel Width Inch (mm)	Thickness Inch (mm)	Allowable Uplift Load psf (KPa)			
					Panel Span ft (mm)			
					1.00 (305)	1.50 (457)	2.00 (610)	2.50 (762)
Aluminum ASTM B209	19 (131)	1.50 (38)	16 (406)	0.032 (0.81)	161.7 (7.74)	107.8 (5.16)	80.8 (3.87)	64.7 (3.10)
Aluminum ASTM B209	19 (131)	1.50 (38)	20 (508)	0.032 (0.81)	129.3 (6.19)	86.2 (4.13)	64.7 (3.10)	51.7 (2.48)
Galvalume ASTM A792	50 (348)	1.50 (38)	16 (406)	0.024 (0.61)	211.7 (10.1)	141.1 (6.76)	105.8 (5.07)	84.7 (4.06)
Galvalume ASTM A792	50 (348)	1.50 (38)	20 (508)	0.024 (0.61)	169.4 (8.11)	112.9 (5.41)	84.7 (4.06)	67.7 (3.24)
Galvalume ASTM A792	50 (348)	1.00 (25)	17 (432)	0.024 (0.61)	199.2 (9.54)	132.8 (6.36)	99.6 (4.77)	79.7 (3.82)
Galvalume ASTM A792	50 (348)	1.00 (25)	21 (533)	0.024 (0.61)	161.3 (7.72)	107.5 (5.15)	80.6 (3.86)	64.5 (3.09)
Galvanized Steel ASTM A653	37 (255)	1.50 (38)	16 (406)	0.024 (0.61)	211.7 (10.1)	141.1 (6.76)	105.8 (5.07)	84.7 (4.06)
Galvanized Steel ASTM A653	37 (255)	1.50 (38)	20 (508)	0.024 (0.61)	169.4 (8.11)	112.9 (5.41)	84.7 (4.06)	67.7 (3.24)
Galvanized Steel ASTM A653	37 (255)	1.00 (25)	17 (432)	0.024 (0.61)	199.2 (9.54)	132.8 (6.36)	99.6 (4.77)	79.7 (3.82)
Galvanized Steel ASTM A653	37 (255)	1.00 (25)	21 (533)	0.024 (0.61)	161.3 (7.72)	107.5 (5.15)	80.6 (3.86)	64.5 (3.09)
Terne-coated Stainless Steel	30 (207)	1.50 (38)	16 (406)	0.015 (0.38)	126.2 (6.04)	84.2 (4.03)	63.1 (3.02)	50.5 (2.42)
Terne-coated Stainless Steel	30 (207)	1.00 (25)	17 (432)	0.015 (0.38)	128.7 (6.16)	85.8 (4.11)	54.5 (2.61)	34.9 (1.67)
Terne-coated Carbon Steel ASTM A308	33 (228)	1.00 (25)	21 (533)	0.015 (0.38)	102.6 (4.91)	64.8 (3.10)	49.4 (2.37)	49.4 (2.37)
Terne-coated Carbon Steel ASTM A308	33 (228)	1.00 (25)	17 (432)	0.012 (0.30)	85.1 (4.07)	56.8 (2.72)	42.6 (2.04)	27.7 (1.33)

Note: The structural capacity of plywood is not considered and must be examined independently.

Copper Panel Roof Assembly

The conclusions drawn from the testing of the copper panel roof systems are based on visual observations made during the testing. It is apparent that additional work could be done to further verify these conclusions. However, the information gained during this testing is invaluable and should be considered if further tests are performed. The conclusions are as follows:

- Clip spacing is more critical to uplift resistance than the width of the panel. Buckling of the panels' seams initiated the buckling of the panels. Buckling of the panels was the failure mode in this study.

- Seam height affects the uplift resistance of the panel assembly. Shorter seams provide greater resistance to buckling--1 inch versus 1 1/2 inches (25 mm versus 38 mm) in this study. The taller seams, during loading conditions, begin to spread apart when the flat portions of the panels begin to deflect upward. The deflection of the pan pulls the bottom portion of the seams away from vertical. After the panels deflect significantly, the individual sides of the seams are pulled apart, resulting in a triangular-shaped seam. This seam distortion changes the physical properties of the double-lock seam. It was observed that the strength of the seam is greatly reduced in this position.

- Test parameters affect the resultant uplift-resistance classification. Specifically, the test duration significantly affects the test results. Identical roof assembly samples were tested under two vastly different test protocols, and the test method with the greatest duration resulted in the lowest uplift-resistance capacity rating (i.e., classification).

  It is unknown from these tests if oscillation affects the test results more, less or indifferently than the duration. It is the authors' belief that the oscillation within the 60-minute phase fatigues the copper panel clips and seams to some degree. Further study is warranted to determine if removal of the oscillation portion within the 60-minute phase of each level would affect the test results.

NRCA's UL listing, No. 575, is shown in the UL *Roofing Materials & Systems Directory.* UL Construction No. 575 provides an Uplift Class 90. NRCA's listing incorporates a copper panel roof system with 17-inch- (432-mm-) wide, 16-ounce/square foot (0.0216-inch- [0.56-mm-] thick) copper panels meeting ASTM B370, with 1-inch- (25-mm-) tall, double-lock standing seams with 28-gauge (0.015-inch- [0.38-mm-] thick), one-piece stainless-steel clips at 18 inches (457 mm) on center. This system is required to be installed over any UL Classified base or ply sheet over a minimum 19/32-inch (15.1-mm) thick, Grade C-D plywood. Additional requirements are described in the listing.

Figure 1: UL 580 Test Method Pressures

Test Phase	Time Duration, Minutes	Negative Pressure		Positive Pressure	
		Pounds Per Square Foot (kPa)	Inches of Water (mm)	Pounds Per Square Foot (kPa)	Inches of Water (mm)
Class 15					
1	5	9.4 (0.45)	1.8 (46)	0.0 (0.0)	0.0 (0)
2	5	9.4 (0.45)	1.8 (46)	5.2 (0.25)	1.0 (25)
3	60	5.7-16.2 (0.27-0.78)*	1.1-3.1 (28-79)	5.2 (0.25)	1.0 (25)
4	5	14.6 (0.70)	2.8 (71)	0.0 (0.0)	0.0 (0)
5	5	14.6 (0.70)	2.8 (71)	8.3 (0.40)	1.6 (41)
Class 30					
1	5	16.2 (0.79)	3.1 (79)	0.0 (0.00)	0.0 (0)
2	5	16.2 (0.79)	3.1 (79)	13.8 (0.66)	2.7 (69)
3	60	8.1-27.7 (0.39-1.33)*	1.5-5.3 (38-135)	13.8 (0.66)	2.7 (69)
4	5	24.2 (1.16)	4.7 (119)	0.0 (0.00)	0.0 (0)
5	5	24.2 (1.16)	4.7 (119)	20.8 (1.00)	4.0 (102)
Class 60					
1	5	32.2 (1.55)	6.2 (157)	0.0 (0.00)	0.0 (0)
2	5	32.2 (1.55)	6.2 (157)	27.7 (1.33)	5.3 (135)
3	60	16.2-55.4 (0.79-2.66)*	3.1-10.7 (79-272)	27.7 (1.33)	5.3 (135)
		40.4 (1.94)	7.8 (198)		
4	5	40.4 (1.94)	7.8 (198)	0.0 (0.00)	0.0 (0)
5	5			34.6 (1.66)	6.7 (170)
Class 90					
1	5	48.5 (2.33)	9.3 (236)	0.0 (0.00)	0.0 (0)
2	5	48.5 (2.33)	9.3 (236)	41.5 (1.99)	8.0 (203)
3	60	24.2-48.5 (1.16-2.33)*	4.7-9.3 (119-236)	41.5 (1.99)	8.0 (203)
		56.5 (2.71)	10.9 (277)		
4	5	56.5 (2.71)	10.9 (277)	0.0 (0.00)	0.0 (0)
5	5			48.5 (2.33)	9.3 (236)

*--The oscillation frequency is to be 10 +/- 2 seconds per cycle.