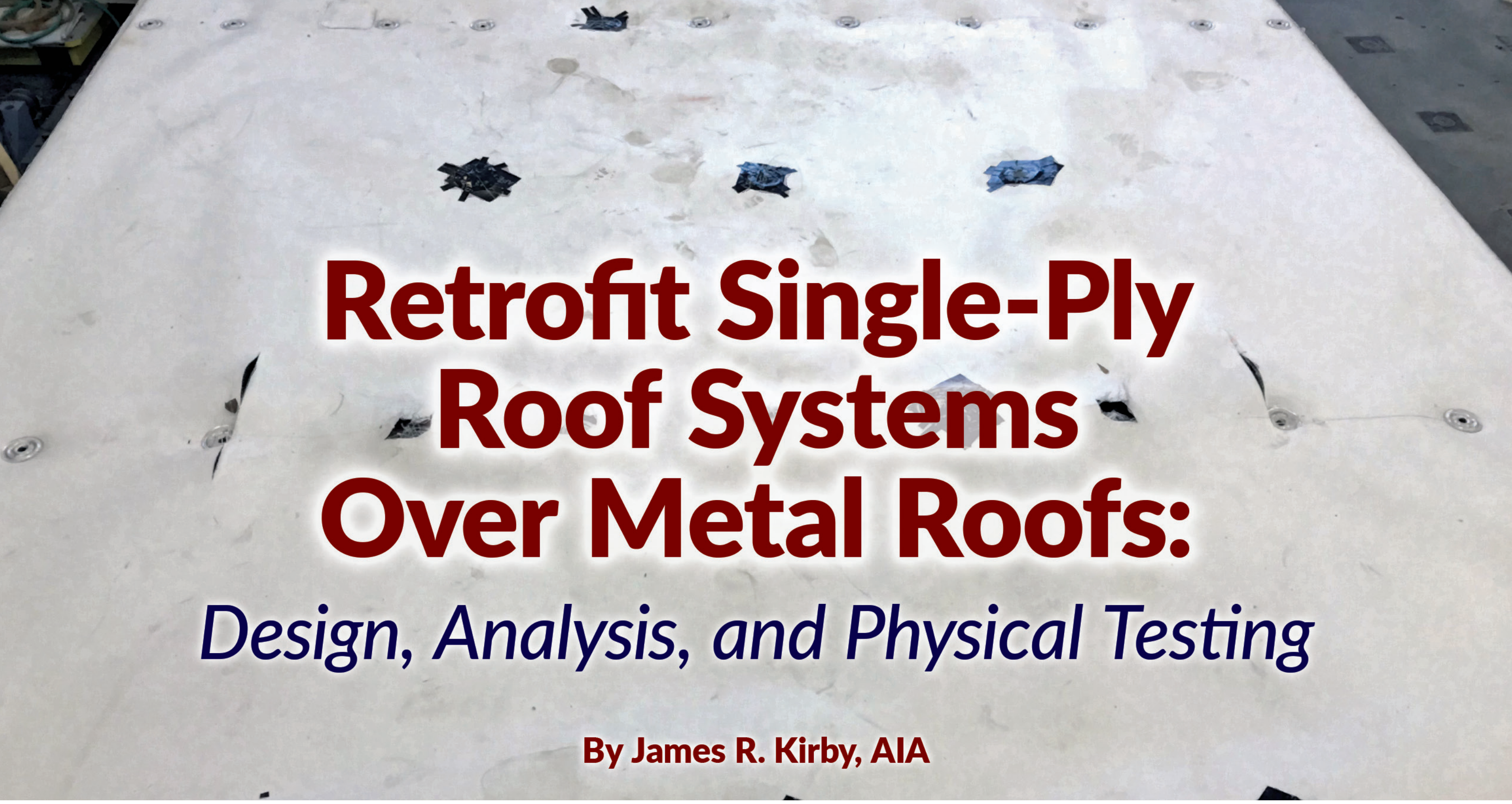


Retrofit Single-Ply Roof Systems Over Metal Roofs:

Design, Analysis, and Physical Testing

By James R. Kirby, AIA

Metal buildings with metal panel roof systems are commonly used across the United States, and a retrofit single-ply roof system (RSPRS) is often installed on top of the metal panel roof after it has been determined that it no longer provides useful service.

Before discussing retrofit single-ply installations, it is necessary to mention that there are four general ways to reroof an existing metal panel roof system:

- *Metal roof panels* can replace the existing metal panels, or metal roof panels can be installed as a re-cover roof system.
- *Single-ply roof systems* can be installed as a re-cover roof system.
- *Roof coatings* can be applied to the existing metal roof.
- *Spray polyurethane foam (SPF)* and coating can be installed over the existing metal roof.

The focus of this article is the use of single-ply roof systems as re-covers over existing metal panel roofs.

ATTACHMENT OPTIONS

The method of attachment for an RSPRS over an existing metal panel roof is of utmost importance for the long-term success of the overall system and for the wind uplift resistance of the single-ply system.

An RSPRS over a metal roof can be installed in a number of ways:

- The membrane can be adhered to insulation boards that are adhered to the metal roof panels. This is problematic for long-term performance because the metal panels will deflect and create shear within the adhesive layer that is attaching the metal panels to the insulation boards that are part of the RSPRS. Over time, this can cause the adhesive to fail and, therefore, the single-ply roof would no longer be attached to the metal panel roof, reducing the uplift capacity of the retrofit roof system.
- The membrane can be adhered to insulation boards that are mechanically attached to the metal roof panels. This can be problematic because the metal roof panels are not structurally equivalent to a steel deck. This topic will be discussed further in the following section.
- The membrane can be mechanically attached into the substructure (that is, the purlins) through the insulation layers. This is considered to be best practice for wind design.

Concerns With Adhering a Membrane to Mechanically Attached Insulation

While it is possible to use an adhered membrane over insulation that is mechanically attached to existing metal panels, this is not best practice. The primary issue is that a metal roof panel is not structurally equivalent to a traditional steel roof deck. The yield strength of the steel can vary, the thickness of the metals can vary, and the geometry differs between a steel deck and a metal roof panel.[1]

As noted in a 2017 article written by the Metal Building Manufacturers' Association's (MBMA's) director of research and engineering,

> "Many conventional roof systems have inherent excess capacity because their structural systems are not amenable to optimization. However, metal roof and metal building systems can be highly optimized for design load requirements to use material more efficiently. Because of this, the materials used during a re-cover installation must be lightweight (less than 3 pounds per square foot [144 Pa]) so structural modifications are not needed or are kept to a minimum to carry the new, additional roofing materials."[2]

Therefore, the roofing industry should not treat a metal panel roof system as an equivalent to a traditional steel deck. This confirms that adhering a single-ply membrane to insulation boards that are mechanically attached to metal roof panels is not best practice for long-term performance.

Mechanical Attachment of Retrofit Single-Ply Roof Systems

Best practice—for longevity and wind resistance—is to mechanically attach a retrofit system into the existing structural purlins. There are three general ways to mechanically attach an RSPRS over an existing metal panel roof system:

- Purlin fasteners and seam plates into *every* purlin at various fastener spacing
- Purlin fasteners and seam plates into *every other* purlin at various fastener spacing
- Purlin fasteners and induction-welded plates into *every* purlin at various fastener spacing

Purlin fasteners and seam plates can be installed within a seam (for example, a traditional mechanically attached roof) or through the membrane weatherproofed with a stripping ply. Purlin fasteners and heat-induction-welded plates can be installed prior to the membrane installation and are induction welded from the topside of the membrane after it is in place.

For any of the fastening methods, the fastener spacing within a row is based on the required wind uplift resistance for the specific project and pullout strength of the fastener/purlin combination.

EXAMPLE CALCULATION OF WIND UPLIFT RESISTANCE

Let's take a look at example calculations for one set of conditions using the following design parameters.

- Building height = 40 ft. (12.2 m)
- Basic wind speed = 120 mph (193 km/h)
- Exposure category = Exposure C
- Building risk category = Risk category II
- Enclosure classification = Enclosed
- roof slope = 2:12
- Factor of safety of 2.0 is applied to the design wind loads

The calculations are based on using the Allowable Stress Design method from the 2010 edition of ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. It's important to note that different versions of ASCE 7 (for example, 2005 or 2016) may be applicable to a project, depending on the location and building code in effect.

The resulting design uplift loads for each roof zone are:

- Field: 62 lb./ft.^{2} (3.0 kPa)
- Perimeter: 97 lb./ft.^{2} (4.6 kPa)
- Corner: 133 lb./ft.^{2} (6.4 kPa)

The required fastener spacing for each row of fasteners is based on a minimum pullout capacity and purlin gauge.[3] See *Tables 1* and *2*.

The design wind loads on older metal buildings may be less than the design wind loads used today. Therefore, when recovering an older building, purlins may need to be added in the corners and along the perimeters to provide additional locations for fasteners to be installed in order to resist an increased design wind load.

CONCERNS ABOUT WIND UPLIFT LOAD PATH

The load path for wind uplift resistance for metal panel roofs on metal buildings is from the roof panels to the purlins through the concealed clips that attach the panel to the purlin. The load on the purlins is transferred to the main structural members through fasteners.

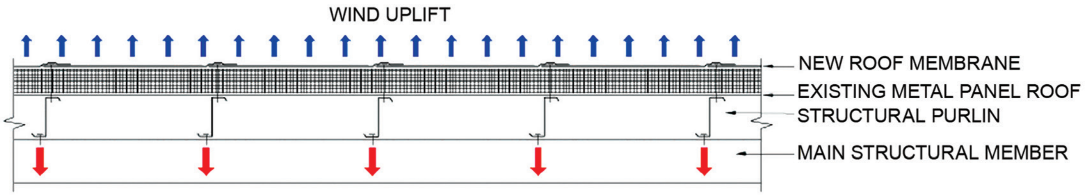
A metal building is designed to use the capacity of every purlin for wind uplift resistance, and the original load path for a metal building is maintained when an RSPRS is mechanically attached to every purlin. However, when an RSPRS is mechanically attached to every other purlin, the load path

Maximum Purlin and Fastener Row Spacing	Purlin Type	Minimum Pullout Value, lbf/Fastener	Maximum Fastener Spacing Field of Roof	Maximum Fastener Spacing Perimeter Zone	Maximum Fastener Spacing Corner Zone
Up to 5 ft. [every purlin]	Min. 16 ga.	800	12 in. o.c.	10 in. o.c.	8 in. o.c.
	Min. 14 ga.	1000	18 in. o.c.	12 in. o.c.	9 in. o.c.
	Min. 12 ga.	1000	18 in. o.c.	12 in. o.c.	9 in. o.c.
Up to 10 ft. [every other purlin]	Min. 16 ga.	800	6 in. o.c.	10 in. o.c.	8 in. o.c.
	Min. 14 ga.	1000	9 in. o.c.	12 in. o.c.	9 in. o.c.
	Min. 12 ga.	1000	9 in. o.c.	12 in. o.c.	9 in. o.c.

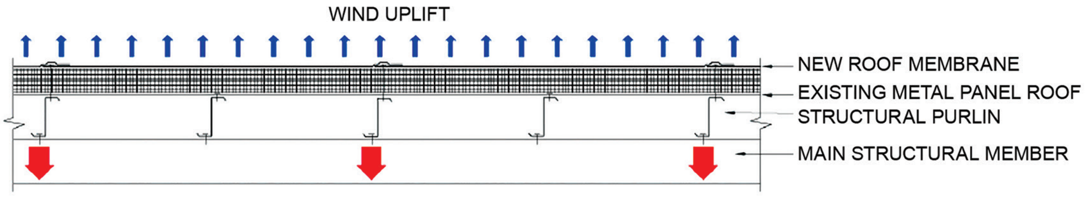
Table 1 – Mechanical attachment best-practice guidelines for purlin fasteners and seam plates. Note: ga. = gauge; min. = minimum; o.c. = on center. 1 ft. = 0.3048 m; 1 in. = 25.4 mm; 1 lbf = 4.45 N.

Maximum Purlin and Fastener Row Spacing	Purlin Type	Minimum Pullout Value, lbf/Fastener	Maximum Fastener Spacing Field of Roof	Maximum Fastener Spacing Perimeter Zone	Maximum Fastener Spacing Corner Zone
Up to 5 ft. [every purlin]	Min. 16 ga.	800	24 in. o.c.	10 in. o.c.	8 in. o.c.
	Min. 14 ga.	1000	24 in. o.c.	12 in. o.c.	9 in. o.c.
	Min. 12 ga.	1000	24 in. o.c.	12 in. o.c.	9 in. o.c.

Table 2 – Mechanical attachment best-practice guidelines for induction-welded fasteners and plates. Note: ga. = gauge; min. = minimum; o.c. = on center. 1 ft. = 0.3048 m; 1 in. = 25.4 mm; 1 lbf = 4.45 N.



WIND LOAD PATH - ROOF MEMBRANE ATTACHED TO EVERY PURLIN



WIND LOAD PATH - ROOF MEMBRANE ATTACHED TO EVERY OTHER PURLIN

Figure 1 – Illustration of wind resistance load paths.

is altered considerably. *Figure 1* shows the difference between the load paths for an “every purlin” and an “every other purlin” RSPRS installation.

Critical Assumptions

When installing fasteners into purlins, two critical assumptions are made:

1. The wind uplift loads that are transferred to the purlins are not overloading the uplift capacity of the purlin-to-frame attachment.
2. The wind uplift loads that are transferred to the purlins are not going to create excessive rotation or deformation of the purlin, and therefore reduce its uplift capacity.

Regarding the first critical assumption, when installing fasteners into every purlin, the overall load path is not significantly changed, and it is rational to believe the RSPRS is not overloading the purlin-to-frame attachment. However, when installing fasteners into *every other* purlin, the overall load path is changed (only every other purlin is part of the load path for wind uplift resistance). It may not be appropriate to assume the original design of the connection from the purlin to the main structural member has the capacity to resist this increase in wind uplift loads, given the new load path.

Regarding the second critical assumption, new purlin bracing can be used to prevent excessive rotation or deformation of the purlin. It should be recognized that the existing metal panels remain attached to the existing purlins, and if the overall metal building/system was originally designed to resist purlin rotation, that should remain unchanged if the RSPRS is attached to *every* purlin. However, when fastener attachment occurs in *every other* purlin, it is unknown whether the purlins will be subject to excessive rotation or deformation under wind uplift conditions.

When attachment is *every other* purlin, the aforementioned assumptions should be analyzed by a design professional for the specific project conditions.

PHYSICAL TESTING

There have been no publicly available validation studies or data supporting any particular approach to installation of RSPRSs. Non-validated attachment methods could result in failures during wind events. Therefore, the objective of our physical testing program was to determine the wind uplift resistance of RSPRSs fastened directly into purlins. A variety of fastening patterns and fastener densities were tested in order to provide a better understanding of the effect of wind loads on these systems. The physical testing was performed at the Civil, Architectural, and Environmental Engineering Department of the Missouri University of Science and Technology (MS&T).[4]

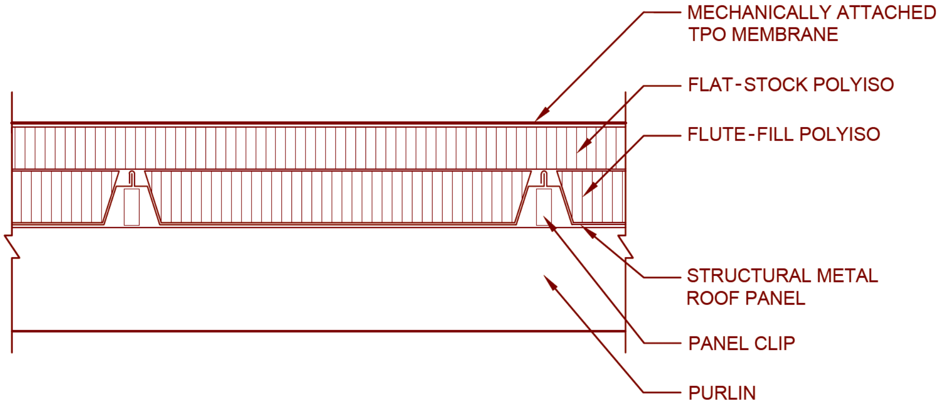
Test Roof Construction

Four full-scale test roofs were constructed and tested in a 10-ft.-wide by 20-ft.-long (3.0-m by 6.1-m) chamber. The test roofs were installed by Missouri Builder Services[5] with oversight by the author. After the test roofs were constructed, the MS&T research team instrumented the assemblies for data collection. *Figure 2* shows the as-built test chamber.

The four test roofs consisted of 24-in.-wide (610-mm), 24-gauge structural metal roof panels attached to 16-gauge Z-purlins

Figure 2 – A photograph of the as-built test chamber.

Figure 3 – Cross section of the RSPRS over a structural metal panel roof system.



with concealed expansion clips and purlin screws. The purlins were connected to and supported by horizontal steel channels; the purlin/channel construction was supported by four vertical steel columns. To complete the test specimen, flute-fill polyisocyanurate insulation, flat-stock polyisocyanurate insulation, and a mechanically attached 60-mil TPO membrane were installed. *Figure 3* shows a cross section of the completed RSPRS over the structural metal panel roof system.

Fastening Patterns

For Tests 1, 2, and 3, purlin fasteners and $2\,^{3}/_{8}$-in. (60-mm) barbed fastener plates were used to secure the membrane, simulating a "strapped" installation. The fasteners and plates were not stripped in. For Test 4, purlin fasteners and 3-in.- (76-mm-) wide induction-welded fastener plates were used. The physical testing was performed in accordance with the loading requirements for ASTM E1592.[6]

The purlins in all tests were attached to C-channels. This did not allow for data collection at a typical purlin-to-mainframe connection. When an RSPRS is mechanically attached to every other purlin, the load path is altered significantly. This raises a question about the effect on the wind uplift capacity of the existing metal building when the load path is altered. Therefore, it is recommended to engage a structural engineer when altering the load path of an existing structure.

Results and Discussion

Test 1

The fastening pattern for Test 1 was 5 ft. (1.5 m) on center between the fastener rows and 12-in. (300-mm) fastener spacing within the row. Test 1 failed when the membrane ruptured simultaneously at seven fastener locations in the center purlin. The system successfully completed 160.1 lb./ft.^{2} (7.7 kPa) and then failed as the pressure was being increased to 174.5 lb./ft.^{2} (8.4 kPa); the failure occurred at 162.7 lb./ft.^{2} (7.8 kPa). The membrane pulled over the five center fastener plate locations in an essentially circular pattern along the outer edges of the fastener plates. The outer two failure locations resulted in L-shaped tearing of the membrane, which was attributed to the boundary conditions of the test chamber.

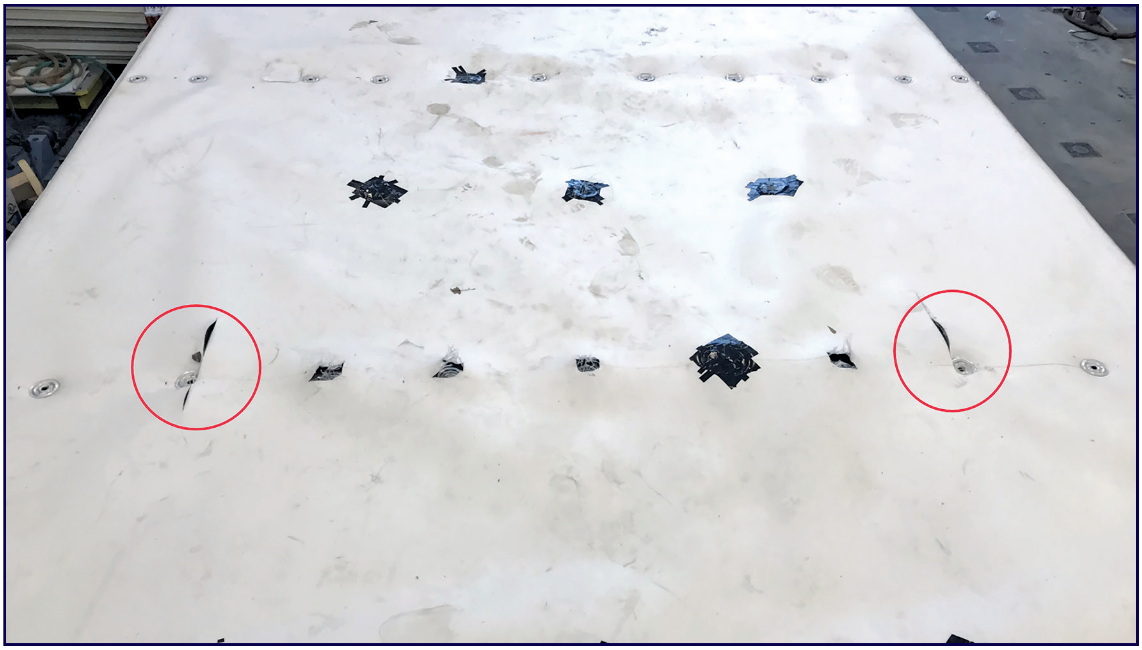


Figure 4 – The outcome of Test 1. The membrane ruptured at seven fasteners in the center purlin. The outer two fastener locations where the membrane tore in an "L" shape are identified in the photo by red circles.

The fastener plates were deformed upward. There were many locations of permanent upward membrane deformation. *Figure 4* shows the outcome of Test 1.

The permanent upward membrane deformation was evident along the edges of the rows of fasteners, as can be seen in the upper row of fasteners in *Figure 4*. There was very little permanent upward membrane deformation between fasteners within a row. This pattern of deformation leads to the belief that the load within the membrane is being transferred from fastener row to fastener row, and not significantly from fastener to fastener within a row.

Test 2

The fastening pattern for Test 2 was 5 ft. (1.5 m) on center between the fastener rows and 24-in. (600-mm) fastener spacing within the row. Test 2 failed when the membrane ruptured simultaneously at the three central fastener locations in the northern quarter-point row of fasteners. The system successfully completed 116.9 lb./ft.^{2} (5.6 kPa) and then failed as the pressure was being increased to 124.1 lb./ft.^{2} (6.0 kPa); the failure occurred at 119.5 lb./ft.^{2} (5.7 kPa). The membrane pulled over the three center fastener plate locations within the row. The center rupture was circular at the fastener plate. The outer two ruptures were D-shaped; the straight-line edges were attributed to the boundary conditions of the test chamber.

The tributary area for each fastener for Test 2 was double that of Test 1. This led to the assumption that the ultimate load for Test 2 would be one half of that from Test 1, or 81.4 lb./ft.^{2} (3.9 kPa). However, the ultimate load was 119.5 lb./ft.^{2} (5.7 kPa), which is approximately 73% of that from Test 1. This is believed to indicate that the membrane transitioned from one-way loading to a more efficient two-way loading, as shown in *Figure 5*.

The load path was not only distributed across the 5-ft. (1.5-m) purlin-to-purlin span (as was the case in Test 1), but was also distributed between fasteners within a row. The uplift loads were pulling on the fastener and fastener plates from all sides (two-way loading) instead of just two sides (one-way loading). During the test, the membrane deflected up approximately 4 in. (100 mm) between fasteners within a row. The loads were more equally distributed within the membrane and around the fastener plate, and therefore, the load per fastener increased from 813.5 lb. (3.62 kN) for Test 1 to 1195 lb. (5.32 kN) for Test 2.

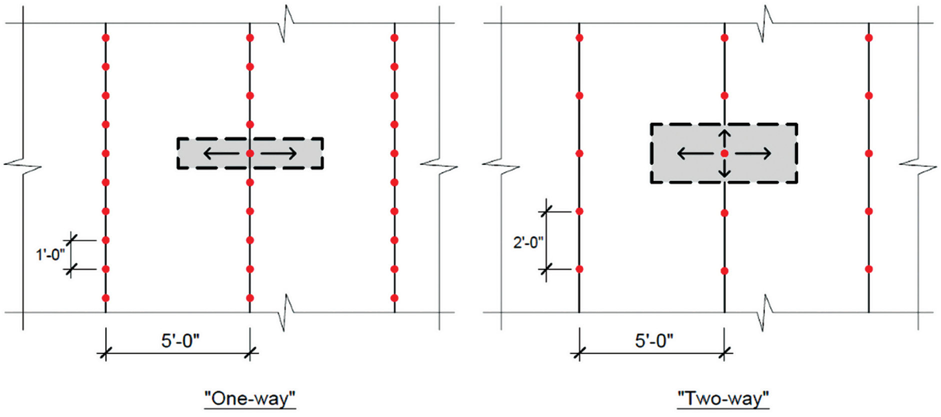


Figure 5 – Graphical representation of one-way and two-way loading.

The membrane resisted the uplift loads in two generalized directions: between fastener rows and between fasteners within a row, which aligns with the machine-direction (MD) and cross-machine-direction (XMD) reinforcement yarns within the membrane, respectively. The membrane had permanent upward deformation between rows and between fasteners within a row because of this two-directional loading. The permanent upward membrane deformation was circular around fasteners, as seen in *Figure 6*.

Test 3

The fastening pattern for Test 3 was 5 ft. (1.5 m) on center between the fastener rows and 36-in. (910-mm) fastener spacing within the row; fasteners were staggered row to row. Test 3 failed when the membrane ruptured at a single fastener location in the southern quarter-point row of fasteners. The system successfully completed 59.3 lb./ft.^{2} (2.9 kPa) and then failed as the pressure was being increased to 66.5 lb./ft.^{2} (3.2 kPa); the failure occurred at 61.9 lb./ft.^{2} (3.0 kPa). The membrane pulled over the center-most fastener plate within the row.

Figure 7 shows a close-up of the failure location for Test 3. The failure was D-shaped, similar to failure locations in Test 2. The flat edge was on the boundary

Figure 6 – A photograph showing circular permanent upward membrane deformation due to two-directional loading in Test 2.

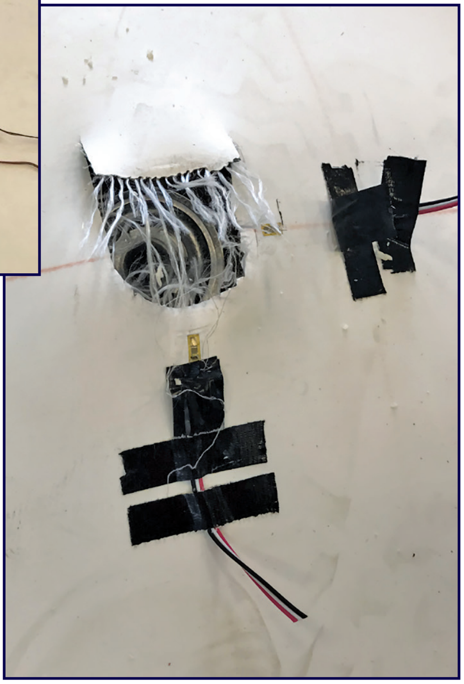


Figure 7 – A photograph of the failure location for Test 3.

edge of the test roofs; the rounded edge is towards the center of the test roof.

Similar to Test 2, there was circular upward permanent membrane deformation at fastener locations for Test 3 as shown in *Figure 6*. This shows that the membrane is being loaded in the MD and XMD. This is due to the relatively wide spacing of the in-row fasteners (2 ft. and 3 ft. [0.6 m and 0.9 m]) relative to Test 1 (1 ft. [0.3 m]).

The tributary area for each fastener for Test 3 was 50% greater than that for Test 2. This led to the assumption that the ultimate load would be two-thirds of Test 2, or about 79.7 lb./ft.^{2} (3.8 kPa). However, the ultimate load was 61.9 lb./ft.^{2} (3.0 kPa), which is approximately 52% of that from Test 2.

Comparing Test 3 to Test 1, traditional assumptions based on tributary area would lead to an expected ultimate load for Test 3 to be 33% of Test 1. The ultimate load from Test 1 was 162.7 lb./ft.^{2} (7.8 kPa), so the expected ultimate load for Test 3 was 54.2 lb./ft.^{2} (2.6 kPa). The actual ultimate load for Test 3 was 61.9 lb./ft.^{2} (3.0 kPa), which is larger than expected at approximately 38% of that from Test 1 (yet within a range acceptable as equivalent).

While two-direction membrane loading appears to increase the expected ultimate load of a roof system relative to the traditional linear expectation of failure load, it appears there is a limit to this increase. For this series of tests, the limit seems to be 5 ft. (1.5 m) on center between the four fastener rows with 24-in. (600-mm) fastener spacing within each row.

Test 4

The fastening pattern for Test 4 was 5 ft. (1.5 m) on center between the fastener rows and 24-in. (600-mm) fastener spacing within the row; fasteners were staggered row to row and induction welded. Test 4 failed in two locations—a fastener plate pulled over the fastener head and the membrane separated at the reinforcement layer at the adjacent welded fastener plate. The system successfully completed 59.3 lb./ft.^{2} (2.9 kPa) and then failed as the pressure was being increased to 66.5 lb./ft.^{2} (3.2 kPa); the failure occurred at 64.8 lb./ft.^{2} (3.1 kPa). The failures occurred in the southern quarter-point row of fasteners.

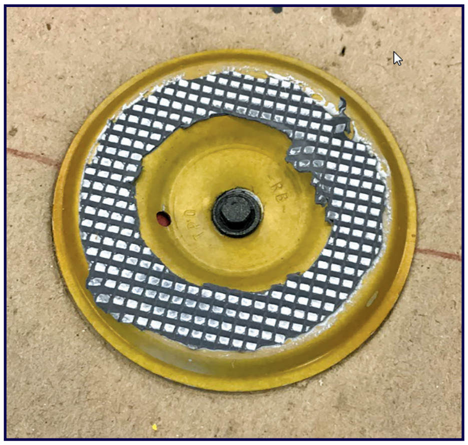


Figure 8 – The top of an induction weld fastener plate showing membrane delamination (cap-to-core separation).

Test 4 used induction-welded fasteners, which means the fastener plates were under the membrane. Therefore, the membrane was cut in order to evaluate each failure.

Based on audible observation at the time of failure, the two failures occurred "simultaneously." It was difficult to determine from visual examination which occurred first: the fastener plate pulling over the fastener head or the delamination of the membrane at the fastener plate.

Test 4 and Test 2 have the same tributary area per fastener location—10 ft.^{2} (6450 mm^2). However, Test 2 achieved a 119.5 lb./ft.^{2} (5.7 kPa) ultimate load, and Test 4 achieved a 64.8 lb./ft.^{2} (3.1 kPa) ultimate load. All components were identical for both test roofs except for the fastener/plate combination, and Test 4's fasteners were staggered row to row.

The above-membrane fastener (for example, an in-seam fastener) is $2\,^3/_8$ in. (60 mm) in diameter. An induction-welded fastener plate is 3 in. (76 mm) in diameter and is constructed such that a raised 'ring' surface adheres to the membrane, not the entire fastener plate, as seen in *Figure 8.*

The area of a 2⅜-in.- (60-mm-)diameter, above-membrane fastener plate is approximately 4.4 in.^{2} (2,840 mm^2). The area of the attachment surface for an induction-welded fastener plate is approximately 3.3 in.^{2} (2,130 mm^2). Therefore, an induction-welded fastener plate has approximately 75% of the surface area of a traditional mechanically attached fastener plate to restrain the membrane.

Individual fastener load for Test 2 (with the same tributary area as Test 4) was 1,195 lb. (5.32 kN). Direct extrapolation to the induction-welded fastener plate (at 75%) leads to the predicted value of the fastener load for Test 4 to be 896 lb. (3.99 kN). This prediction assumes the reinforcement is the weak link, but the test clearly shows the cap-to-core connection (adhesion) is the weak link, and it therefore makes sense that the failure load per fastener for Test 4 was less than 896 lb. (3.99 kN); in fact, it was 648 lb. (2.88 kN) per fastener.

The analysis of these two different types of fastening methods and failure modes supports the result that Test 4 has lower wind uplift resistance than Test 2, even though the tributary area for each fastener is the same for Tests 2 and 4. The effect of the staggered pattern is unknown without additional testing.

Test Results Summary

Table 3 shows the ultimate loads achieved, fastening pattern, tributary area, and load per fastener, as well as fastening method.

CONCLUSIONS AND RECOMMENDATIONS

Given the accumulating stock of metal buildings with metal roof panels, the need to properly re-cover or refurbish structural metal panel roof systems is essential. When an RSPRS is used, it is appropriate to attach into every purlin in order to maintain the original load path for wind resistance. When attaching into every other purlin, it is important to examine whether the purlin-to-mainframe connection might become overloaded when resisting wind loads.

Review and analysis of the four full-scale physical tests of RSPRSs installed over structural metal panel roof systems resulted in a number of conclusions. They are as follows:

- Uplift resistance of an RSPRS and individual fastener loads in an RSPRS are based on the membrane's reinforcement strength and one-directional versus two-directional loading of reinforcement.
- Reducing the overall fastener density increases the tributary area

Test Roof No.	Ultimate Load†, lb./ft.^{2}	Fastening Pattern	Tributary Area Per Fastener, ft.^{2}	Load Per Fastener, lbf	Fastening Method
1	162.7 (160.1)	5 ft o.c. x 12 in.	5	813.5 (800)	Above membrane
2	119.5 (116.9)	5 ft o.c. x 24 in.	10	1195 (1160)	Above membrane
3	61.9 (59.3)	5 ft o.c. x 36 in. staggered	15	928.5 (890)	Above membrane
4	64.8 (59.3)	5 ft o.c. x 24 in. staggered	10	648 (593)	Induction welded

Note †: Actual load recorded at time of failure is shown. The highest E1592 "step" successfully passed is shown parenthetically.

Table 3 – The ultimate loads, tributary area, and load per fastener for each test roof. Note: o.c. = on center. 1 ft. = 0.3048 m; 1 in. = 25.4 mm; 1 lbf = 4.45 N; 1 lb./ft.^{2} = 0.048 kPa.

for each fastener. As expected, the ultimate load is reduced with larger tributary areas.

- Two-directional membrane loading increases the expected ultimate load of a roof system relative to linear extrapolation based on fastener tributary area. However, it appears there is a limit to this expected increase. For this series of tests, the ultimate load exceeded expectations for the Test 2 fastening pattern, but the ultimate load was more in line with traditional linearly extrapolated expectations for the Test 3 fastening pattern.
  - This work emphasizes the limitations of extrapolation and validates the use of physical testing to determine uplift resistance of roof systems.
- Permanent deformation of the membrane was observed in all four physical tests at the end of testing and was not seen to be a watertightness issue. The test procedure performed did not determine at what pressure during the test cycling the membrane deformation began. This observation may provide an explanation for "wrinkles" observed in mechanically attached membranes that have experienced high wind events.

This article was adapted and contains the information from previous IIBEC papers from 2019[7] and 2020.[8]

FOOTNOTES

1. "Building Science FAQ, Episode 5—What is the difference between a metal roof and a metal deck?" www.GAF.com.
2. Shoemaker, W. Lee, PhD, PE; Vincent E. Sagan, PE; and Dale Nelson. 2017. "Metal to the Metal." *Professional Roofing.* (October).
3. "EverGuard® TPO/PVC Mechanically Attached and Drill-Tec™ Rhinobond® Retrofit Roofing Systems Over Metal Roof." www.GAF.com.
4. The Missouri University of Science and Technology's Civil, Architectural and Environmental Engineering Department is chaired by Joel Burken, PhD, PE, BCEE, F.AEESP. The work was directed by Mohamed ElGawady, PhD, professor and Benavides Faculty Scholar, with the assistance of PhD candidates. The lead PhD candidate was Yasser Darwish.
5. Missouri Builders Service, Inc., Post Office Box 104205, 3807 Route CC, Jefferson City, MO 65110. Phone: 573-636-7733. Web: www.missouribuilders.net.
6. ASTM E1592-05. 2017. *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference.* ASTM International. West Conshohocken, PA.
7. Kirby, James R., AIA; and Jennifer Keegan, AAIA. 2019. "Assessing Wind Resistance of Retrofit Single-Ply Roof Systems Installed over Existing Metal Panel Roof Systems." *Proceedings of the RCI International Convention and Trade Show* (March).
8. Kirby, James R., AIA: and Mohamed ElGawady, PhD. 2020. "Physical Testing for Wind Resistance of Retrofit Single-Ply Roof Systems Over Structural Metal Panel Roof Systems." *Proceedings of the IIBEC Virtual International Convention and Trade Show.* (June).

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Europe's Largest Green Façade Completed in Düsseldorf

Nearly 30,000 hornbeam hedges form the "cladding" for Kö-Bogen II, a new building in Gustaf-Gründgens-Platz (plaza), Düsseldorf, Germany. Ingenhoven Architects, the project's designer, said they didn't want the new structure to compete with the existing buildings in the plaza, so it had to be completely different.

Beneath the greenery lies 450,000 sq. ft. of office and retail space. The building itself is reinforced concrete. The shrubs are housed in metal panels, each 18 x 40 in., with access cages on rails to allow maintenance of the plants.

— Architectural Record