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Assessing Retrofit Single-Ply Roof Systems Installed Over Existing Metal Panel Roof Systems

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Abstract

Metal buildings with metal panel roof systems are commonly used across the United States, and a retrofit single-ply roof system is frequently installed after the metal roof is no longer providing useful service. Research has been conducted to experimentally and analytically investigate the performance of metal panel roofs retrofitted using single-ply roof systems. Various large-scale assemblies were subjected to an industry-recognized uplift resistance test to determine uplift resistance and mode(s) of failure. Variations in fastener schedules and type were also evaluated using finite element analysis (FEA) models that were developed and calibrated by experimental testing. Of specific concern are differences in uplift resistance of retrofit single-ply roof systems because of variations in attachment, including fastener types, schedules, and spacing of existing structural members.

The research paper and presentation will discuss the research parameters, the outcome of the physical testing, and the results of the FEA modeling of different attachment scenarios. Best-practice design and installation recommendations will be provided.

Speaker

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Assessing Retrofit Single-Ply Roof Systems Installed Over Existing Metal Panel Roof Systems

INTRODUCTION

Metal buildings with metal panel roof systems are commonly used across the United States, and a retrofit single-ply roof system is often installed on top of the metal panel roof after it has been determined to no longer provide useful service. This paper will discuss the current status of metal panel roof systems in terms of market share, as well as review and catalogue current industry practices for retrofit single-ply roof systems.

Different fastening approaches, which result in different load paths for wind resistance, were analyzed with regard to their wind uplift resistance effectiveness. Based on the analysis, installation guidelines (including the design parameters) for fastening of retrofit single-ply roof systems are presented here for best-practice wind uplift resistance. Embedded in the analysis and design of a retrofit single-ply roof system are two critical assumptions that are presented and analyzed. Finally, a discussion of in-progress physical testing and modeling work is provided and will be presented in detail in the near future.

For this paper, a metal panel roof system is defined as an assembly of structural metal roof panels with concealed clips at panel seams that are attached to purlins with consistent spacing. These types of panels have a major vertical element at the panel-to-panel interface and may or may not have lesser vertical elements (i.e., stiffener ribs) within a panel that provide strength to carry dead and live loads, including wind uplift. These types of panels are commonly installed with ¼:12 to 2:12 slope.

CURRENT STATUS OF METAL BUILDINGS AND METAL ROOFS

Market Share

The Metal Building Manufacturers Association (MBMA) provides data on the overall size and market share of the metal building industry. The most recent data published by MBMA are from 2013 and 2014. The 2013 market share crosses many building types, including commercial (34%), manufacturing (30%), community (14%), miscellaneous (14%), and agricultural (8%). The MBMA member sales were $2.452 trillion in 2014, up from $2.173 trillion in 2013. MBMA's comparison to F.W. Dodge data shows MBMA members have 51.7% of the total non-residential market for new low-rise building construction. See *Figure 1*. This accounts for a total of 283 million sq. ft. that MBMA members constructed in 2013 alone.[1] Compounding the installations over the past 20 years suggests that there is a large quantity of buildings with structural metal panel roof systems in the United States.

Current Retrofit Single-Ply Roof System Practice

There are three general ways to re-cover an existing metal panel roof system:

- Metal roof panels
- Single-ply roof systems
- Roof coatings
- Spray polyurethane foam

The focus of this research is single-ply roof systems used to re-cover existing metal panel roof systems.

A review of installation guidelines from current roofing manufacturers reveals that all single-ply membranes—such as EPDM,

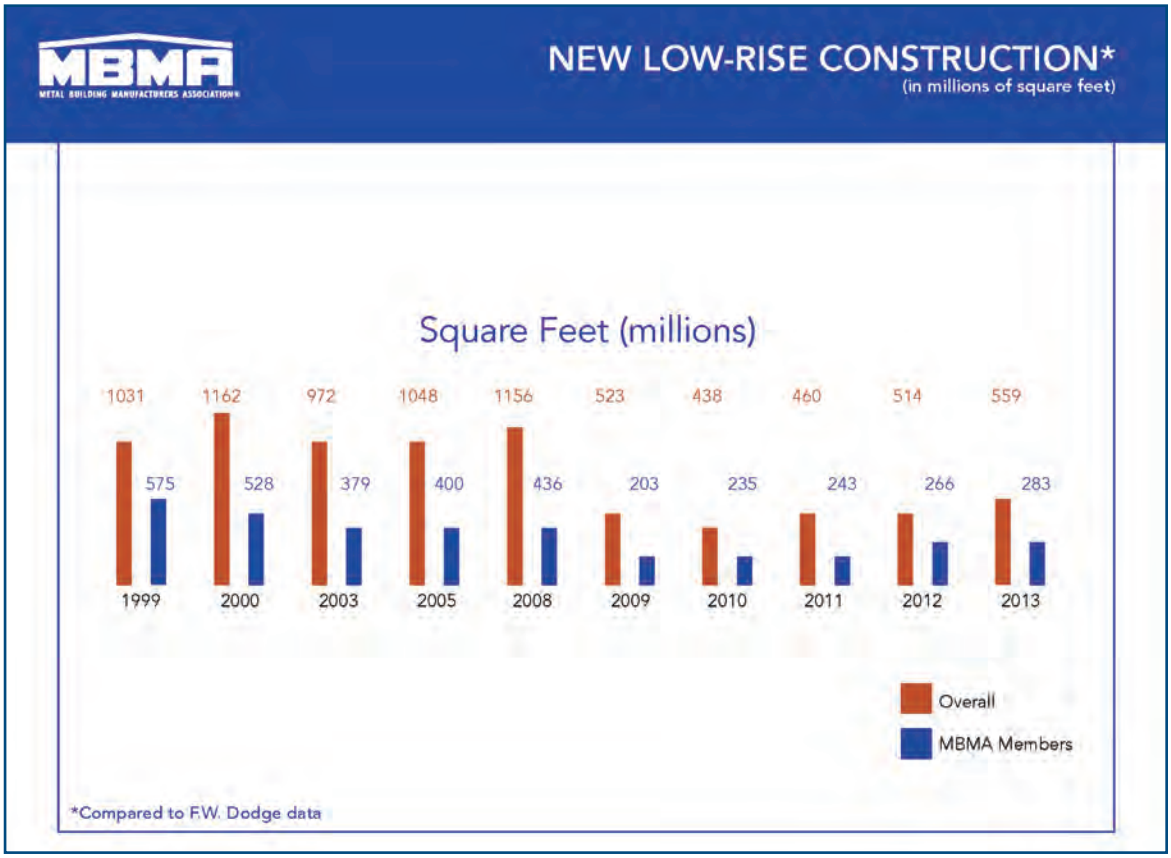

Figure 1 – MBMA new low-rise construction data compared to F.W. Dodge data.

PVC, and TPO—are used to retrofit single-ply roof systems. Most commonly, membranes are shown or recommended through guide specifications to be mechanically attached into the roof sub-structure (i.e., the purlins) and not into the existing metal roof panels only. In some cases, membranes can be secured to membrane strips that are mechanically attached to the purlins.

Mechanical fasteners used with a retrofit membrane can be installed into every purlin or every other purlin, and the fastener spacing within a row is based on the required wind uplift resistance for the specific project. However, not all manufacturers provide guidelines relating to purlin fastening, nor do all manufacturers provide minimum requirements for fastener pullout values from a purlin. This leaves a gap in assisting the roofing industry with appropriate installation specifics for wind uplift resistance.

Mechanical attachment into purlins can be accomplished with two methods:

- A purlin fastener and seam plate that secures the membrane from within a seam or is covered with a stripping ply
- A purlin fastener and specialty coated plate that is heat-induction welded to the underside of the sheet

At least one manufacturer allows an adhered membrane over mechanically attached insulation into existing metal panels. Fastener density of the attached insulation is based on pullout values of the fasteners into the metal roof panels. It is worth noting that metal roof panel thickness is typically much less than the thickness of steel roof decks; therefore, pullout resistance is less, and more fasteners are needed relative to attaching into a traditional roof deck.

ATTACHMENT CONCERNS

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

While some may equate a structural metal roof panel to a traditional steel roof deck, in fact, these products can be significantly different. The yield strength of the steel can vary, the thickness of the metals can vary (e.g., 24 gauge or thinner for metal roof panels versus 22 gauge or thicker for steel decks), and the geometry differs between the two (e.g., steel decks have deep, closely spaced ribs relative to metal roof panels).

Additionally, the overall structural capacity of a steel deck attached to steel joists and trusses very likely has more inherent capacity than a metal building. As noted in a 2017 article written by 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) so structural modifications are not needed or are kept to a minimum to carry the new, additional roofing materials.[2]

Given the inherent differences, the roofing industry should not treat a metal panel roof system as an equivalent to a traditional steel deck.

ADDITIONAL CONCERNS

MBMA's white paper[3] presents a number of issues that should be considered when installing a retrofit single-ply roof system over an existing metal panel roof on a metal building. The issues included in MBMA's white paper are as follows:

- Building code requirements
- Existing support structure
- Secondary structural member deflection
- Existing metal roof properties
- Ponding water
- Retrofit roof fastening
- Drag load
- Fire rating

Building on MBMA's white paper information, this paper focuses on wind uplift resistance of retrofit single-ply roof systems over metal panel roofs on metal buildings.

WIND UPLIFT

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. Some metal roof panels are attached with exposed fasteners in lieu of concealed clips. The load on the purlins is transferred to the main structural members

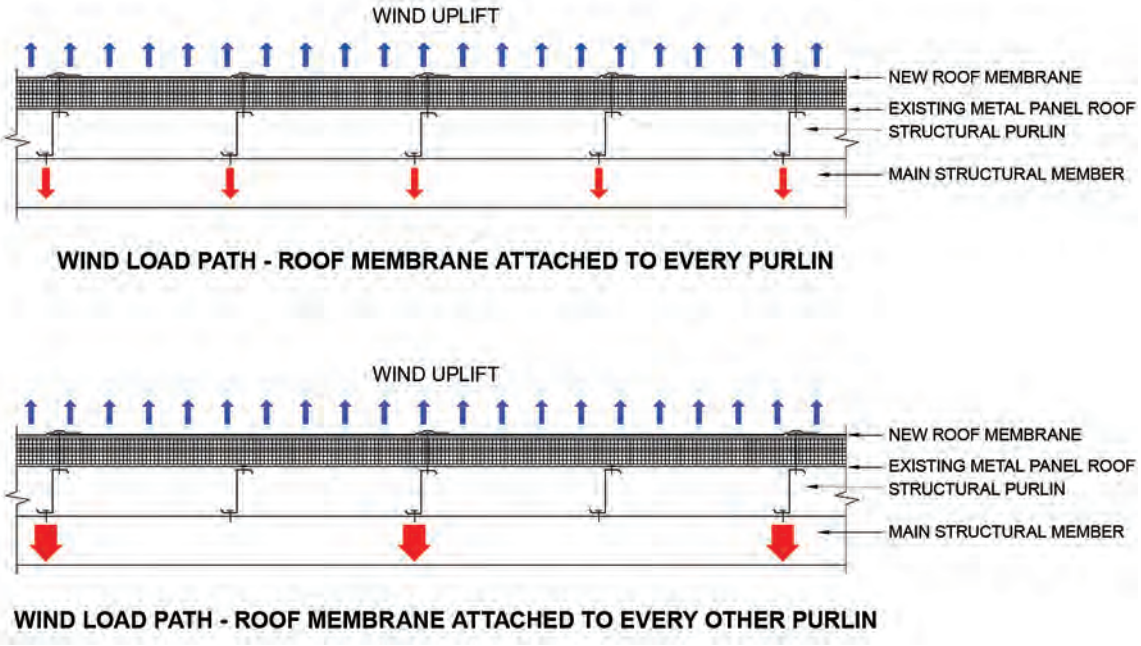

Figure 2 – Illustration of wind-resistance load paths.

Max. Purlin & Fastener Row Spacing	Purlin Type	Min. Pull-out Value, lbs/fastener	Max. Fastener Spacing Field of Roof	Max. Fastener Spacing Perimeter Zone	Max. Fastener Spacing Corner Zone
Up to 5 ft. (1.52 m) [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. (3.05 m) [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.

Figure 3 – Mechanical attachment best practice guidelines for purlin fasteners and seam plates.

Max. Purlin & Fastener Row Spacing	Purlin Type	Min. Pull-out Value, lbs/fastener	Max. Fastener Spacing Field of Roof	Max. Fastener Spacing Perimeter Zone	Max. Fastener Spacing Corner Zone
Up to 5 ft. (1.52 m) [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.

Figure 4 – Mechanical attachment best practice guidelines for inductively heated fasteners and plates.

through fasteners that attach the purlin to the main structural members. A metal building is designed to use the capacity of every purlin for wind uplift resistance, and the initial design load path for a metal building is maintained when a retrofit single-ply roof system is mechanically attached to every purlin. However, when a retrofit single-ply roof system is mechanically attached to every other purlin, the load path is altered considerably. *Figure 2* shows the difference between the load paths for an "every-purlin" and an "every-other-purlin" retrofit single-ply roof system installation.

Altering the load path to this extent raises the question about the effect on the existing metal building's capacity to resist wind uplift.

BEST PRACTICE RECOMMENDATIONS

Best-practice guidelines for retrofit single-ply roof systems over existing structural metal panel roofs include calculating wind uplift loads acting on a building and limiting the use of retrofit single-ply roof systems to applications where wind resistance of the installed retrofit exceeds the wind uplift loads acting on the building.

There are three general ways to mechanically attach a retrofit single-ply roof system over an existing metal panel roof system:

1. Purlin fasteners and seam plates into every purlin at various fastener spacing
2. Purlin fasteners and seam plates into every other purlin at various fastener spacing
3. Inductively heated fasteners and plates into every purlin at various fastener spacing

DESIGN PARAMETERS FOR CALCULATIONS OF WIND UPLIFT RESISTANCE

The best-practice recommendations for fastener spacing are listed in *Figures 3* and *4*. The recommendations in these figures are based on calculations using the Allowable Stress Design method from the 2010 edition of ASCE 7, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures," and are based on the following design parameters. (Altering these design parameters may alter the best practice recommendations.)

- Maximum building height = 40 ft.
- Basic wind speed = 120 mph
- Exposure Category = Exposure C
- Building Risk Category = Risk Category II
- Enclosure Classification = Enclosed
- Maximum roof slope = 2:12
- Factor of safety of 2.0 was applied to the design wind loads

The resulting design uplift loads for each roof zone are shown in *Figure 5*.

The design wind loads on older metal buildings may be less than the design wind loads that are being used today. Hence, in the process of re-covering 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.

Roof Zone	Design Uplift, psf
Field of Roof	62
Perimeter	97
Corner	133

Figure 5 – The resulting design uplift loads for each roof zone.

The required fastener spacing for each row of fasteners is based on a minimum pullout capacity and purlin gauge. See *Figures 3* and *4*.

CRITICAL ASSUMPTIONS AND EXAMINATION

Critical Assumptions

When installing fasteners into purlins, two critical assumptions are made. They are as follows:

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 assumption No. 1, when installing fasteners into every purlin, the overall load path is not significantly changed, and it is rational to believe the retrofit single-ply roof system 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 generally will not be rational to believe 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 assumption No. 2, new purlin bracing can be used to prevent excessive rotation or deformation of the purlin. However, 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 retrofit single-ply roof system is attached to every purlin. Therefore, the existing metal panels should continue to prevent excessive purlin rotation or deformation. If the purlins resisted rotation because of, for example, the 24-in. on-center panel clips that are fastened to the purlins, the purlins should remain resistant to rotation or deformation unless the existing system is altered in some way that allows purlin rotation or deformation. The addition of the retrofit single-ply roof system fasteners does not provide any significant resistance to purlin rotation because the membrane and insulation do not provide racking resistance/stiffness. However, when fasteners are attacehd to every other purlin, it is unknown if the purlins will be subject to excessive rotation or deformation under wind uplift conditions.

Upcoming Examination of Critical Assumption No. 1

In order to assess the potential concern with the change in load path relative to wind uplift resistance, a research project was initiated in early 2018 with the Missouri University of Science and Technology (MST). The research project is examining the wind uplift resistance of retrofit single-ply roof systems installed over existing structural metal panel roof systems on metal buildings.

Literature Review

An extensive literature review was conducted to determine the different testing techniques generally used for roof systems and structural metal roofs, specifically. A literature review was also performed to examine finite element analysis models of roof systems and how to use finite element analysis to model wind pressures. From this assessment, the design of test specimens and finite element analysis models will be finalized.

Experimental Work

Small-scale testing of membrane fastener-to-purlin and panel-to-clip connections will be performed to validate components of the finite element analysis model.

Full-scale testing of retrofit single-ply roof systems over structural metal panel roofs over purlins and main structural members will be conducted using the ASTM E1592 test method.[4] The test specimens will represent full-scale specimens and include all details required for actual construction of a roof system. Therefore, the tests will determine the performance of all typical parts of a retrofit single-ply roof system.

Physical Testing

Physical testing will be conducted using the Butler MR-24 panel attached with Butler concealed clips and fasteners into 16-gauge Z purlins, 8 in. deep, and 5 ft. o.c.

The retrofit single-ply roof system includes a 60-mil-thick TPO mechanically attached with Drill-Tec™ purlin fasteners and 2 ⅜-in. diameter barbed seam plates at varying fastener spacings over polyisocyanurate infill board (flute filler insulation) and standard-sized polyisocyanurate boards above the tops of the metal roof panel seams. Supplementary fasteners are used to hold insulation in place.

CONCLUSIONS

Given the current market share and an accumulating existing stock of metal buildings with metal roof panels, the need to properly re-cover or refurbish structural metal panel roof systems is essential. Review and analysis of retrofit single-ply roof systems—this paper's focus—resulted in a number of conclusions. They are as follows:

- There is a significant opportunity to install retrofit single-ply roof systems on existing metal panel roofs.
- All single-ply membrane types are used for retrofit single-ply roof systems in various configurations, with the predominant method of fastening into the purlin, thereby avoiding attachment to the existing metal roof panels.
- Metal roof panels are not structurally equivalent to traditional steel decks.
- Fastening into every purlin provides a similar wind uplift resistance load path versus fastening into every other purlin, which significantly changes the wind uplift resistance load path.
- The rotation or deformation of existing purlins should not be a concern when installing a retrofit single-ply roof system with fastener attachment into every purlin. The potential for excessive rotation or deformation when fastener attachment is into every other purlin is unknown without further analysis or study.
- Additional physical testing is needed and is in progress to support or refute current assumptions about purlins and wind uplift resistance when designing retrofit single-ply roof systems.

FOOTNOTES

1 "Metal Building Continues to Increase in Market Share." Industry Trends, 2014. *MBMA Business Review*. 2014 and 2013 data. http://www.mbma.com/Industry_Trends.html.

2 W. Lee Shoemaker, Vincent E. Sagan, and Dale Nelson. "Metal to the Metal." *Professional Roofing*. October 2017.

3 Brian Gardiner. "Comparison of Retrofit Systems Over Existing Metal Roofs." White paper for BMG Enterprises, LLC. April 3, 2017.

4 ASTM International. ASTM E1592-05 (Reapproved 2017), *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Differences*. West Conshohocken, PA.