WIND TUNNEL TESTING OF EDGE METAL

ABSTRACT

Wind resistance of edge metal continues to be a concern during high-wind events. Edge metal at perimeters and corners is often determined to be the initial point of failure of roofing systems during wind events. The loss of edge-metal functionality can lead to progressive failure of a larger portion of the roof system, potentially allowing water infiltration and damage to or loss of assets in the interior.

As part of the Wind Hazard and Infrastructure Performance (WHIP) Center's research initiatives, GAF and Florida International University (FIU) performed full-scale wind-tunnel testing of edge metal at FIU's Wall of Wind. Four (4) full-scale wind-tunnel tests were performed using one (1) contractor-fabricated, 24-gauge L-shaped edge metal system with an 8-inch face, 4-inch horizontal flange, and a ¾-inch drip edge. Two (2) different 22-gauge cleat shapes were used—a standard 6-inch cleat and an 8-inch cleat with a 1-inch horizontal return. Four (4) different cleat-fastener locations were used—one low, one in the middle, and one high on the vertical surface, as well as one on the horizontal surface.

A discussion on the test parameters and outcomes of the different cleats and associated attachment locations will be provided. Best-practice design and installation recommendations will be given.

LEARNING OBJECTIVES

- Discuss and review the current code-mandated test methods (i.e., ANSI/SPRI/FM 4435 ES-1) for determining wind resistance of edge metal shapes.
- Demonstrate the failure modes of L-shaped edge metal relative to cleat engagement, cleat shapes, and fastener locations when subjected to wind tunnel testing.
- Compare test results of full-scale wind tunnel testing with an equivalent ES-1-tested L-shaped edge metal assembly.
- Evaluate test methods, loading methodologies, and wind directions related to the determination of edge-metal wind-resistance capacity.

SPEAKERS

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Wind resistance of a low-slope roof system's edge metal has improved over the past couple of decades.[1] However, there continues to be a concern during high-wind events. Edge metal at perimeters and corners is often determined to be the initial point of failure of roofing systems during wind events.[2] The loss of edge-metal functionality from high winds generally creates a breach in the building enclosure in regard to weatherproofing and water intrusion. A breached roof-to-wall interface can lead to localized failure of the roof, or a progressive failure of a larger portion of the roof system, potentially allowing water infiltration that may cause damage to or loss of assets in the interior.

As part of the Wind Hazard and Infrastructure Performance Center (WHIP-C), GAF and Florida International University (FIU) performed full-scale wind tunnel testing at FIU's Wall of Wind in February 2022. Four full-scale wind tunnel tests were performed using a contractor-fabricated, 24-gauge L-shaped edge metal system with an 8 in. (20.32 cm) face, 4 in. (10.16 cm) horizontal flange, and ¾ in. (1.9 cm) drip edge. Two different 22-gauge cleat shapes were used—a 6 in. (15 cm) cleat and an 8 in. cleat with a 1 in. (25.4cm) horizontal return. Four different cleat-fastener locations were used—one low, one in the middle, and one high on the vertical surface, and one on the horizontal surface.

This paper will discuss the test parameters and outcomes of testing that used different cleat types and attachment locations. Observations made during testing are discussed, as well as how those observations may be put into practice. Aerodynamic tests were performed to determine pressure coefficients, and failure assessment testing was performed to assess failure modes of various installations.

EXPERIMENTAL APPROACH

The overall research approach was to build multiple full-scale edge metal systems and test them in a wind tunnel on a turntable to learn how wind speed and wind direction affect edge metal's wind performance based on varying cleat-fastener locations. Wind pressures acting on the edge metal and roof system and the vibration of the edge metal were recorded and analyzed to assess performance. Testing to failure was also performed to understand failure mode and performance variations during testing.

Two test decks were constructed on site by J Quintero Roofing of Miami, Florida. Each test deck included a wood structure, a thermoplastic polyolefin (TPO) roof system, and two of four different edge metal systems. FIU personnel instrumented each test deck to record pressures related to the fascia system and roof system and to record wind-induced vibration of the fascia system. GAF provided guidance about roofing installation practices and assisted with the installation of certain components of the roof system installation and instrumentation setup.

Each test deck included two variations of the edge metal system, with two contiguous sides installed per configuration. The corner was central to each configuration (**Fig. 1**). Specifically, one test deck included edge metal configurations 1 and 2, and the other test deck included edge metal configurations 3 and 4. In total, four configurations were tested for this research. Additional testing specifics

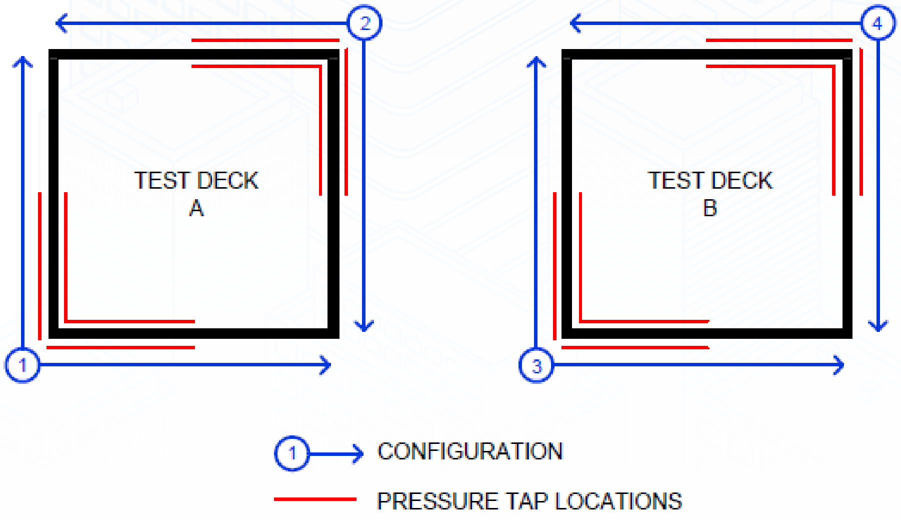

FIGURE 1: The overall layout of the 4 Configurations and pressure taps locations on the 2 test decks.

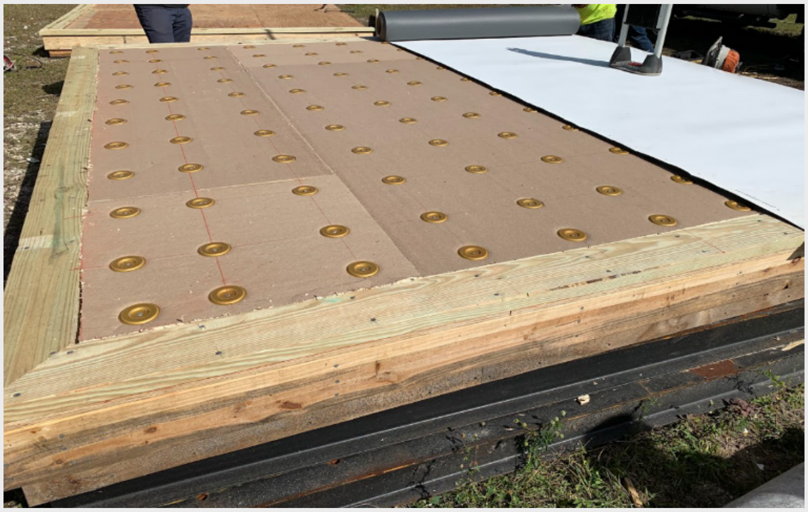

FIGURE 2. Photo showing the nailer, insulation, IW plates and fasteners, and a TPO sheet being installed on one of the 11ft x 11ft test decks.

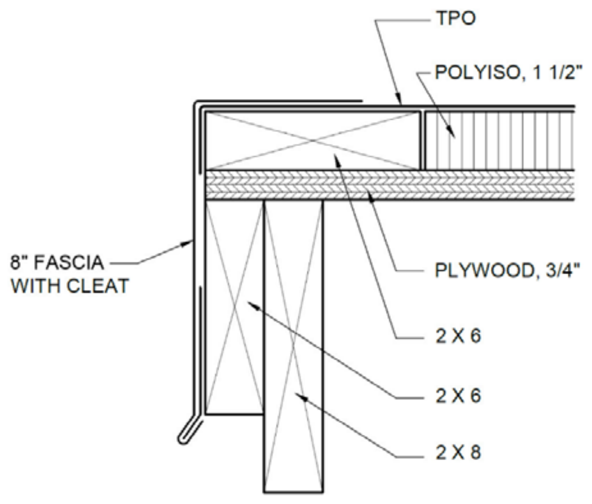

FIGURE 3. Graphic showing a section view of the construction of the two roof decks.

are explained in the "Physical Testing" section of this paper.

Importantly, the wind tunnel base that supports and secures the test decks is able to rotate 360 degrees. The ability to rotate allows for data collection across a 360-degree rotation. Wind tunnel testing that utilizes a rotatable turntable allows a fuller set of data collection, which, in turn, provides a fuller perspective on how edge metal systems may perform in the field during high winds.

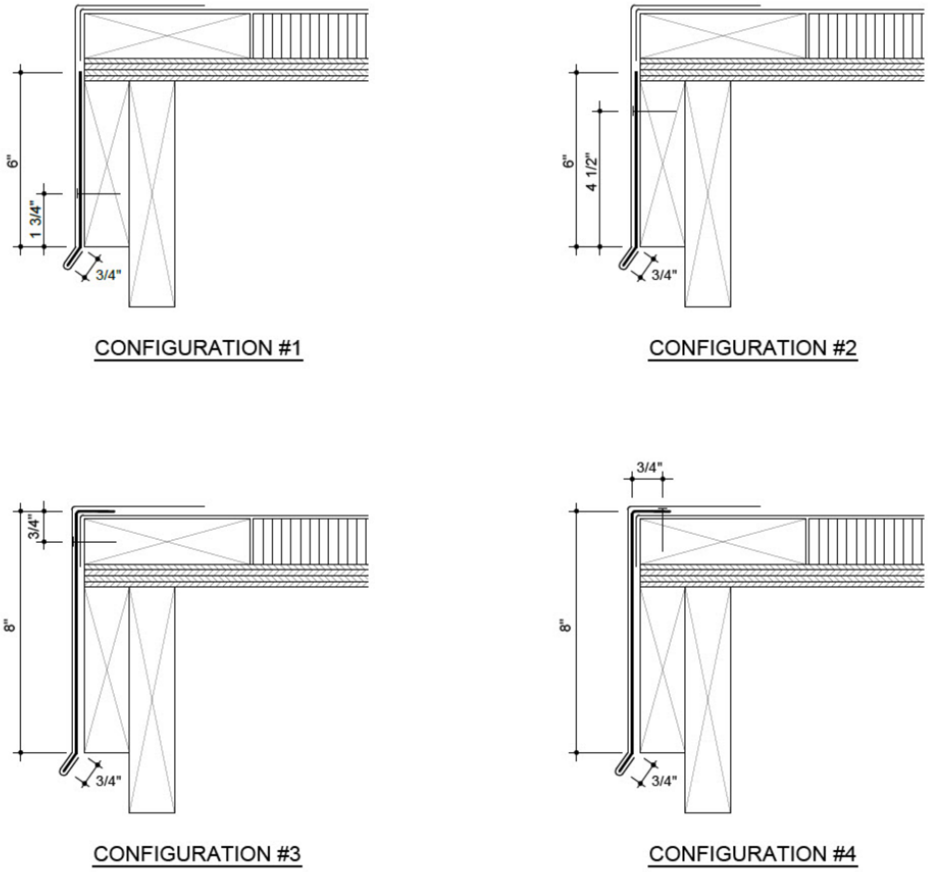

FIGURE 4. Graphics showing cleat types and cleat fastener locations for Configurations 1, 2, 3, and 4.

TEST APPARATUS AND TEST ROOFS

Two 11 × 11 ft (3.3 × 3.3 m) wood roof decks were constructed. Each consisted of ¾ in. (2 cm) plywood over traditional "2x" construction. The roof system consisted of an underlayment minimally fastened to the wood deck, a single layer of 1.5 in. (3.81 mm) thick polyisocyanurate foam insulation (polyiso), and a 60 mil TPO induction welded (IW) to "IW" plates. The fasteners and IW plates were installed at 1 ft (0.305 m) on center (o.c.) in both directions. A dense fastening pattern was used to help ensure the roof system itself would not fail during wind tunnel testing of the edge metal system. A 2x6 wood nailer was fastened along the perimeter edge for securement of the edge metal system and to create a perimeter for the polyiso (**Fig. 2**).

Full-scale wind tunnel tests were performed on four edge metal systems. All four configurations used a galvanized, 24 gauge, L-shaped edge metal fascia with a galvanized, 22-gauge cleat. The fascia had an 8 in. (20.32 cm) vertical face, a 4 in. (10 cm) horizontal flange, and a ¾ in. drip edge at the bottom that engaged the cleat. The cleat also had a ¾ in. drip edge (**Fig. 3**).

The four configurations varied based on the location of the fasteners for the cleat as well as cleat type (**Fig. 4**). It is important to note that the location of the fastener for the fascia metal was the same for all four configurations.

For configurations 1 and 2, a 6 in. (15 cm) cleat was used. In general, it is understood that when cleats are "nailed low," a short cleat is most commonly used, meaning the cleat does not have a horizontal flange at the upper edge. For configurations 3 and 4, an 8 in. (20cm) cleat with a 1 in. (25.4 mm) horizontal return was used.

For configuration 1, the cleat-fastener location was selected based on current industry approval listings for contractor-fabricated edge metal.

It should be noted that most building codes require edge metal systems to be tested to determine wind resistance using the appropriate test method(s) in ANSI/SPRI/FM 4435/ES-1.[3] Manufacturers and contractors (through the National Roofing Contractors Association [NRCA] ES-1 Program) provide many edge metal systems—both prefabricated and contractor-fabricated—that have been tested to determine their wind resistance.

The edge metal system used for this research (using an 8 in. [20 cm] face) intends to imitate a currently available, ES-1-tested edge metal system. The edge metal profile, ITS-30, is available from NRCA.[4] This is one of many contractor-fabricated edge metal and coping profiles tested according to ES-1. ITS-30, titled Embedded Edge (L-Type), has a tested resistance of 210 lb/ft2 (95kg) in the outward direction and the cleat fastener is 1¾ in. (4.4 cm) above the break line at the drip edge. Configuration 1 of this research used the same cleat-fastener location. For all four configurations, fastening of the horizontal flange of the fascia also imitated the ITS-30 nailing pattern.

Configurations 3 and 4 are installation locations where only a single 2x wood blocking is provided on top of a wall system. The cleat fastener location for configurations 3 and 4 means the system reacts to the wind differently than configurations 1 and 2 (which are "pinned" at each end). The roofing industry has long recommended that cleats be fastened as low/as close as possible to the drip edge, and to avoid fastening "high" on the cleat. In this research, intentionally placing cleat fasteners high on the cleat provides information about these types of installations.

Of the four configurations installed, three had fasteners in the vertical face and one in the horizontal. More specifically:

- **Configuration 1:** The cleat was nailed 1¾ in. (4.4 cm) above the drip edge at 6 in. (15 cm) o.c. into the wood substrate (to imitate/mimic ITS-30).
- **Configuration 2:** The cleat was nailed 4½ in. (11 cm) above the drip edge at 6 in. o.c. into the wood substrate (3½ in. [8.8 cm] down from the top of the wood blocking).
- **Configuration 3:** The cleat was nailed ¾ in. (1.9 cm) down from the top edge at 6 in. o.c. into the face of the wood nailer.
- **Configuration 4:** The cleat was nailed ¾ in. back from the outer edge of the cleat at 6 in. o.c. into the wood nailer.

PHYSICAL TESTING

Test Decks

Each 11 ft (3.3 m) square test deck was secured to the top of an 11 × 11 ft base building. The same base building was used for each test deck. The base building was secured to the turntable in the wind tunnel. The interior of the base building was accessible via a small door. Data acquisition systems, tubing, and wiring were contained within this interior space. With the roof test deck installed onto the base building, the roof membrane was approximately 6 ft (1.8 m) above the floor of the wind tunnel.

Wind Tunnel

The wind tunnel can generate a maximum wind speed of 157 mph. However, maximum wind speed occurs approximately 10 ft (3.0 m) above the floor of the wind tunnel; the wind speed was lower at the height of the roof deck used in our testing. The reported wind speeds were measured at the roof height, with a maximum of approximately 134 mph (215 km/h) being achieved.

Two sets of tests were performed on each of the four edge metal configurations: aerodynamic and failure assessment. This paper provides an overview of the aerodynamic testing; however, the primary focus, perhaps having a more immediate effect on the roofing industry, is the failure assessment portion of the research. **Figure 5** shows the test deck in the wind tunnel.

FIGURE 5: Photo of a test deck in the wind tunnel (inactive).

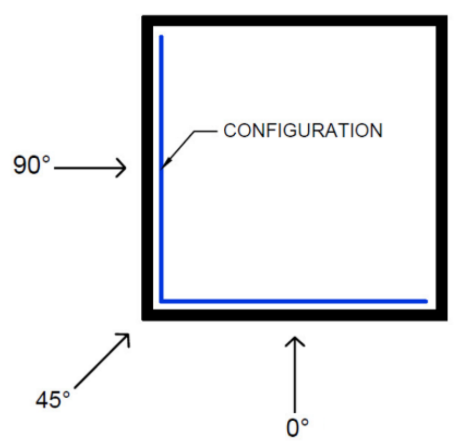

FIGURE 6: Wind directions used for Failure Assessment testing.

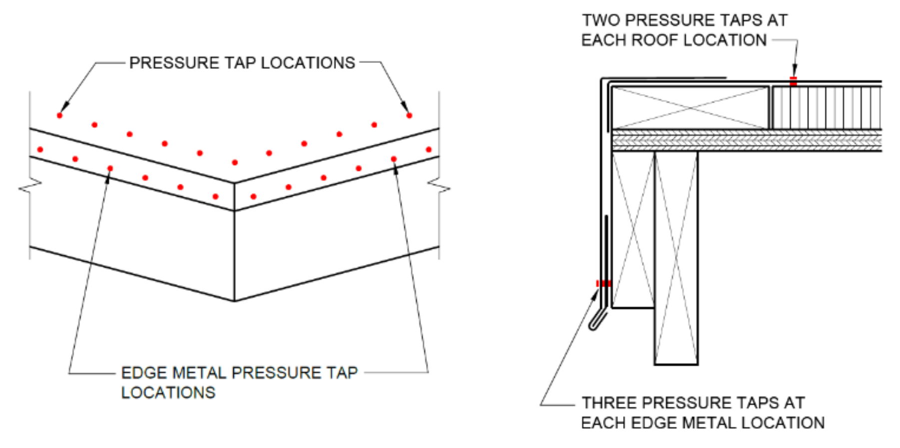

FIGURE 7: Graphic showing pressure tap locations on the roof and edge metal, with a section view showing the number of pressure taps at each tap location.

Aerodynamic and Failure Assessment Testing

Aerodynamic tests were performed to determine pressure coefficients, and failure assessment testing was performed to assess failure modes of various installations.

Aerodynamic experiments were conducted at mean wind speeds ranging from 26 to 87 mph (41 to 140 km/h) at the mean roof height of 5 ft 9 in. (1.75 m) using simulated Exposure Category C (Open Terrain). At each wind speed used, pressures were recorded (using 58 pressure taps) at 15-degree rotations from 0 degrees to 360 degrees for the aerodynamic data collection testing. This work was done to incorporate a wide range of wind directions to determine pressure coefficients at many wind directions. This helps determine the most vulnerable wind direction acting on edge metal systems. This information, ultimately, could be implemented into standards and test methods that might be used for code reference.

In addition to aerodynamic tests, high-speed failure assessment tests were also performed. Wind speeds started at approximately 80 mph (128 km/h) and peaked at approximately 134 mph (215 km/h). Seven wind speed levels were used, increasing by roughly 8 to 9 mph (12 to 14 km/h) each level. The same terrain exposures were used. Each level (**Fig. 6**) included three wind directions: 0 degrees, 45 degrees, and 90 degrees. Wind testing was halted immediately after a system failure was observed so that the team could further investigate and document the system performance and determine the mode and extent of the failure.

DATA COLLECTION

The deck systems were instrumented with pressure sensors and accelerometers to collect data throughout the wind tunnel testing. Pressure taps were installed across the roof membrane system and the edge metal systems to quantify the wind-induced pressure differential. Accelerometers were installed on the edge metal to investigate wind-induced dynamic effects in the system.

FIGURE 8. Photos showing pressure taps. The left photo shows outermost pressure taps on the fascia. The right photo shows the pressure taps for the membrane. *Note: the pressure taps were trimmed flush to the fascia and membrane prior to testing.*

Each configuration had 58 pressure taps (**Fig. 7**). Pressure taps were located on the outer vertical surfaces of the fascia, cleat, and substrate, respectively, as well as on the upper (or top) horizontal surfaces of the insulation and membrane. Data were recorded for one configuration at a time due to the symmetry of the test deck. For the edge metal, pressure taps were placed at 6 in. (15 cm) from the corner, then spaced every 12 in. (305 mm) (**Fig. 8**). Each side of the configuration has a total of six pressure tap locations.

The pressure taps on the roof surface were placed to match the spacing of the pressure taps on the vertical faces of the edge metal system. At each rooftop pressure tap location, a pressure tap was installed on the exterior surface of the insulation and on the exterior surface of the TPO.

RESULTS AND OBSERVATIONS

Aerodynamic Testing

The results of the aerodynamic testing showed the following:

- Wind direction affects peak outward and upward pressures

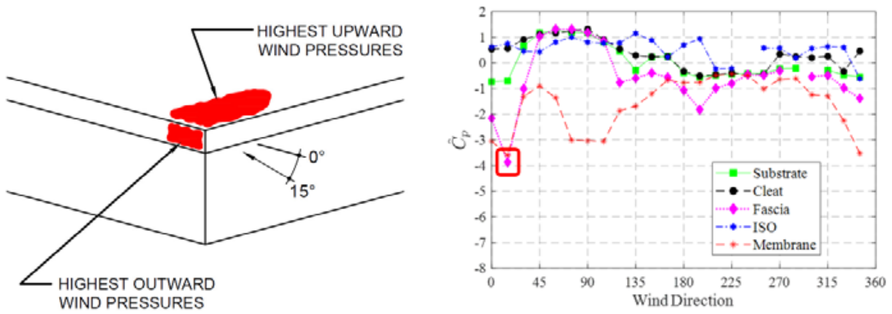

FIGURE 9. Graphic showing a 15 degree wind direction ("near parallel") creates the highest wind pressures on the vertical face of the fascia and the horizontal roof surface.

- Area averaging influences pressure coefficients

Analysis of the data obtained during the aerodynamic testing was done by FIU students and the primary investigators who were part of this research. Using the data from the aerodynamic testing, pressure coefficients were determined for each pressure tap location. One result of the aerodynamic testing showed that near-parallel wind flows (i.e., 15 degrees from parallel) created the highest outward and upward wind pressures on the fascia and roof surface[5] (**Fig. 9**).

It is important to note that when wind hits a building, a negative pressure is exerted on the fascia (due to suction) and positive pressure is exerted on the inner face of the fascia (due to wind getting behind the edge metal). In effect, the fascia is simultaneously being *pulled off* from the outside and *pushed off* from the inside.

Failure Assessment Testing

Failure occurred when the fascia (with or without the cleat) flipped upward and back onto the roof. Wind-induced actions such as bending, oscillation, fastener pull-out, and cleat disengagement as well as the location of these actions were also observed and recorded by video. The wind speeds at which these actions and failures occurred were recorded. Importantly, field observations of poststorm damage have documented edge metal failure when the wind angle was presumed to be perpendicular to the edge metal. It is likely that the overall context of the building and its specific environment might affect the most damaging wind angle. Additionally, while there are straight-line wind storms, many high-wind storms (e.g., hurricanes) have a spiral effect, effectively covering all wind angles.

Configuration 1

Configuration 1 used cleat 1, the 6 in. (15 cm) cleat. The cleat fastener was located 1¾ in. (4.4 cm) above the break line for the drip edge. Configuration 1 was the only configuration to have a failure before reaching the wind tunnel's maximum wind speed. During the "low-speed" aerodynamic testing, the fascia released from the cleat nearly the entire length of the test deck, but did not flip up and onto the roof. It was observed that the cleat was likely set too high, and therefore, the engagement of the cleat and the fascia was greatly reduced. The failure assessment testing was initiated without adjustment of the fascia or cleat. During the next wind-speed level, the fascia completely folded back onto the roof its entire length. At that point, the system was considered to have failed. Observations made of the failure found the cleat was indeed set too high (approximately ¼ in. [.06 cm]) relative to the location of the drip edge portion of the fascia. This reduced the amount of engagement between the cleat and the drip edge (**Fig. 10**).

Interestingly, configuration 1 was believed to be the most robust of the four installation methods; building-code-required tests for edge metal systems generally confirm this assumption. During this testing, however, this configuration failed at the lowest wind speed due to the misalignment of the cleat fastener. This emphasizes the importance of a well-engaged cleat–drip edge interface.

Configuration 2

Configuration 2 used cleat 1, the 6 in. (15 cm) cleat. The cleat fastener was located 4½ in. 11 cm) above the break line for the drip edge. A small amount of cleat/drip edge separation with some minimal fluttering of the fascia was seen in the higher wind-speed levels. The small amount of fluttering was located adjacent to the corner where the drip edge receiver was disengaged from the cleat (approx. 6 to 10 in. [15 cm] in length). There was little outward permanent deformation of the fascia and cleat system; the edge metal system appeared to remain able to perform until the point it failed. The failure occurred at approximately 134 mph. The failure was immediate; there was a small amount of flutter at the

FIGURE 10: Photo of failure mode of Configuration #1.

FIGURE 11: Photos of failure mode of Configuration #2.

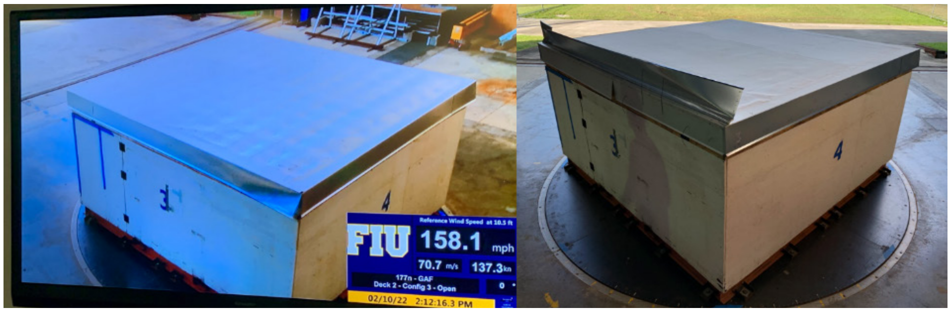

FIGURE 12: Photo of failure mode of Configuration #3.

FIGURE 13. Photo of failure mode of Configuration #3 up close.

FIGURE 14: Photo of failure mode of Configuration #4.

corner, then it was folded up and on top of the roof (**Fig. 11**).

Configuration 3
Configuration 3 used cleat 2, the L-shaped cleat. The cleat fastener was located on the vertical portion of the cleat approximately ¾ in. (1.9 cm) from the top. Like the other configurations, there was some separation at the corner seam, some fluttering where the cleat became unattached from the receiver (approximately 18 in. [45 cm] from the corner), but overall the fascia stayed in place and was observed to be able to perform until failure occurred.

At approximately 134 mph (215 km/h), the fascia folded up and over the horizontal surface (**Fig. 12**). The drip edge separated from the cleat. The cleat did not have any permanent deformation and remained in place (**Fig. 13**).

Configuration 4
Configuration 4 used cleat 2, the L-shaped cleat. The cleat fastener was located on the horizontal leg approximately ¾ to 1 in. (1.9 to 2.5 cm) from the face. This configuration began fluttering at a lower wind speed relative to configurations 2 and 3, which was not unexpected considering the location of the cleat fastener. There was some separation of the cleat and drip edge (approximately 12 to 18 in. [30 to 45 cm] from the corner) as fluttering increased with the increase in wind-speed levels.

The portion of the cleat closest to the corner stayed in place while the portion of the cleat farthest from the corner folded upward (**Fig. 14**). Some of the nails pulled out at the far end of the fascia. This seemed to imply that there was a greater pressure at the far end of the "left side" of configuration 4 relative to the other configurations.

Overall, the edge metal system appeared to remain able to perform up to the point of failure, albeit there was larger outward permanent deformation with increased wind-speed levels. Permanent outward deformation, even at a small scale, creates vulnerability (i.e., reduced weatherproofing performance) at the roof-to-wall interface.

It is noteworthy that when the cleat and fascia lifted and were folded back, the edge of the roof was exposed, which is more likely to compromise the weathertightness of the roof-to-wall interface. This type of failure only occurred with the L-shaped cleat when it was nailed in the horizontal flange.

Summary of Test Results

Pressure coefficients

- Pressure coefficients (i.e., GCp values) for specific pressure tap locations were found to be higher than GCp values used in code-referenced standards.
- Historically, the most conservative wind direction has been presumed to be "near perpendicular" relative to edge metal, and as such, is reflected in the code-required test methods. In contrast, this research showed "near-parallel" winds (15 degrees from

parallel) were most conservative when determining wind pressures acting on the edge metal.

Performance

- For all cases (except the misinstallation previously noted), the edge metal system did not fail until the wind speeds reached approximately 134 mph (215 km/h) at the test deck.
- The structural dynamics of an edge metal system change based on the location of the cleat fastener. With a low-fastened cleat (i.e., near the drip edge), the fascia is constrained at both ends. Conversely, with a high-fastened cleat (i.e., near the top of the fascia or into the horizontal), the edge metal system can flutter more easily because there is no substrate attachment on the lower portion of the cleat or fascia. The stiffness of the metal (i.e., gauge and yield strength) becomes an important factor.

Failure assessment

- During the failure where the cleat was set too high, a small (approximately ¼ in. [0.6 cm]) misalignment reduced the amount of engagement between the cleat and the drip edge and significantly reduced the wind speed at failure of the edge metal system.
- Failure occurred when the fascia (with or without the cleat) flipped upward and back onto the roof, resulting in a roof edge condition that was considered to have been immediately vulnerable to high winds as well as water entry into the building.
  - As noted in the "Failure Assessment Testing" section, there was some disengagement of the fascia from the cleat at wind speeds less than 134 mph (215 km/h). This could compromise long-term performance and would likely need to be repaired if this were to occur on an existing building.
- For configurations 1, 2, and 3, the fascia became detached from the cleat at the corner for a short length. The fascia remained nearly in place (with small [1 to 2 in. {2.5 to 5.0 cm}] permanent deformation), and appeared to be largely functional. The extent of functionality reduction due to permanent deformation was not attempted to be quantified during this research.
- For configurations 1, 2, and 3, the failure (i.e., complete displacement of the fascia piece) was initiated because of the disengagement/release of the drip edge "receiver" from the cleat. Once disengaged, the fascia was more easily folded up and over onto the horizontal rooftop by high winds.
- For configuration 4, the cleat did not entirely disengage from the fascia. Both pieces of metal failed—the metal folded up and over along the length—while still engaged at the drip edge. Failure occurred because the metal yielded; only a few nails pulled out, and only at the far corner.
- Only configuration 4 had nails pull out of the substrate. A small number of nails fastening the fascia on the horizontal at the furthest end from the corner pulled completely out of the 2x6 wood nailer. No specific reason was determined.
- None of the nails fastening any of the cleats in any configuration pulled out of their respective 2x6 wood blocking.

CONCLUSION AND RECOMMENDATIONS

Testing of edge metal roof systems completed as part of WHIP-C provided the opportunity to investigate the aerodynamic and failure performance of four different cleat and fascia systems. The following is worth noting:

- Installation practices
  - Three configurations (2, 3, and 4) failed at the wind speed of 134 mph (215 km/h).
  - Considering the low wind speed that was needed to prematurely fail the edge metal with a misaligned cleat, and that all four configurations failed at the same wind speed, this suggests that the drip edge/cleat engagement is as critical to long-term wind performance as the location of the nail.
  - High-nailed L-shaped cleats performed well—in fact, better than expected. Edge metal, with an L-shaped cleat, fastened high (either face) performed equivalently (to failure) to the low-fastened cleat installations that have been presumed to have higher wind resistance. This finding does not align with previous field investigations that concluded that high-nailing reduces wind uplift resistance. However, it is still recommended to locate cleat fasteners as low on the cleat as possible.
    - The L-shaped cleat is a very simple, cost-effective way to increase accuracy during installation. An L-shaped cleat is considered to be "self-locating." This provides an effective quality control advantage for installers and inspectors, which helps to ensure proper cleat/drip edge engagement. It is a very reasonable approach to help protect against blow-offs due to cleat/drip edge misalignment. Additionally, using an L-shaped cleat does not preclude nailing low on the cleat.
    - Oftentimes, there is only a single wood blocking on the top of a wall, which can mean that fastening low on the horizontal surface becomes difficult. This research shows that this does not necessarily reduce the wind resistance of edge metal systems. However, an ES-1-tested edge metal system should be installed as tested to meet building code requirements.
    - High-nailing would be found to be very weak (low resistance) when using test methods that are in the building code as requirements.
  - Cleat/drip edge engagement is critical to long-term wind resistance. Using a cleat that "self-locates" is prudent.

Note that the attachment of the substrate for the edge metal (e.g., a 2x wood nailer) is of critical importance.[1] The edge metal is only as good as the substrate it is attached to. Designers should ensure there is a properly designed and executed load path that has appropriate capacity to resist the anticipated design loads.

- Performance evaluation
    - Failure assessment testing (i.e., testing to failure) helps uncover issues or expand knowledge so that performance can be assessed more confidently.
    - The highest wind pressures acting on the face of the edge metal came from a "near-parallel" direction.
    - The highest wind pressures were within 1 to 2 ft (30 to 60 m) of the corner. Averaging pressure coefficients across a large area may underestimate the wind pressures that should be used for design of edge metal systems at the immediate corner.
    - Load sharing happens between the L-shaped cleat and the fascia when the cleat is nailed on the horizontal top flange (e.g., configuration 4). This is to be expected, given that both pieces of the edge metal system—the fascia and the cleat—are nailed in the horizontal portion of the substrate, allowing the two individual pieces to move simultaneously. Remember, the cleat is one gauge heavier than the fascia in these studies and often in the field.
- Codes and industry practices
    - Cleat engagement is critical; the margin of error is small. Current designs, listings, and specifications typically use a ¾ in. (1.9 cm) cleat. Is this adequate? Perhaps drip edges and cleats should be longer, as was recommended decades ago.[6] Any improvement in the strength of the cleat/drip edge engagement (e.g., stiffer cleat, larger engagement) may prove beneficial to the overall performance of the edge metal system.

Future Work

Additional research on this topic would be beneficial to better understand if "high-nailed" L-shaped cleats really do perform as well as was indicated by this full-scale wind tunnel research program. Also, it is important to consider the development of new test methods that might better replicate outcomes discovered during full-scale wind tunnel testing. Current test methods use static testing; dynamic testing methods may better replicate field conditions as well as potentially address long-term fatigue of metal components.

Other questions that may need to be addressed include the following:

- What is the most conservative wind direction to test edge metal?
- Are more stringent requirements at corners appropriate based on what was learned about area-averaging of pressure coefficients?

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