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RiskTopics

Guide to secure roof systems in high-wind regions
May 2015

Because damage to roofing systems is the most common driver of loss during high wind events, special attention needs to be given to roof system design and detailing. Understanding the potential vulnerabilities of roofing system to windstorm and considering protective measures can effectively reduce the potential wind damages. Such damages are very often accompanied by water damage to the building contents.

Design and detailing of structural (load-bearing) components, e.g. columns, beams, roof slab, is commonly in compliance with structural design requirements. However, secondary elements, e.g. roof panels, gutters, flashings, and their connections to the structural components fail to meet code-defined requirements. This is due to the fact that the latter are usually "off-the-shelf" components, i.e. standard components, ordered and installed with no consideration of design code requirements and whose selection is based primarily on price considerations. Also, it is difficult to ascertain compliance of these components to code requirements after they have been installed.

The scope of this Risk Topic is to increase awareness of site management and risk engineers to some common issues, which could potentially influence wind performance of the building envelope. This paper does not purport to cover all issues related to building wind design nor all aspects of envelope performance.

Introduction

Good structural system performance is critical to avoid injury and minimizing damage to a building and its contents. It does not, however, ensure building protection. Good performance of the building envelope is also necessary. The envelope includes exterior doors, non-load bearing walls and wall coverings, roof coverings, windows, shutters, and skylights.

Historically, poor building envelope performance is the leading cause of damage to buildings and their contents during high wind events. The roofing system is one of the most vulnerable part of building envelope. Once the roof is damaged, the entire contents of the building become exposed to water and wind.

Factors influencing the wind forces on a structure include topography, height of adjacent buildings as well as the building itself, elevation above sea level, shape of roof, openings in the walls (measured, e.g. as a percentage of total area), direction of prevailing winds, etc. These issues are part of the structural design and covered in the structural design code.

This Risk Topic will focus on roof system components only, i.e. cladding, and secondary appurtenances, particularly on issues related to detailing. It does not cover all aspects related to the design of these components, but is intended to increase awareness of common issues contributing to failure due to wind forces.

Roof cladding systems

Roof systems and materials generally are divided into generic classifications: low slope and steep slope. Low slope roofing includes water impermeable, or weatherproof, types of roof membranes installed on slopes less than or equal to 3:12 (14 degrees). Examples of low slope roof type coverings are: **Built-Up Roof (BUR) and modified bitumen roof systems**, **Single Ply Membrane (SPM) roof systems**, and **Spray Polyurethane Foam-based (SPF) roof systems**. Steep slope roofing includes water-shedding types of roof coverings installed on slopes exceeding 3:12 (14 degrees). Examples of the latter types of roof coverings are **shingles and tiles roof systems** and **metal panel roof systems**. The latter can be used both for low slope and steep slope roofing. Main features and wind performance of each system are described below.

Built-up roof (BUR) and modified bitumen roof systems

Main Features:

- Built-up roof assemblies typically consist of a 4 or 5 ply cover attached (typically with bitumen) to substrates (either insulation board or deck, e.g. concrete). The substrate can either be adhered or mechanically fastened to the load-bearing system (purlins). The surfacing of these multiple plies of built up roof systems can be aggregate (such as gravel), glass-fiber or mineral surfaced cap sheets, hot asphalt or aluminum coatings.

- Modified bitumen roof membranes (Figure 1) are composed of reinforcing fabrics that serve as carriers for the hot polymer-modified bitumen as it is manufactured into a roll material. Polymer-modified roof systems typically are installed as a two-ply system and almost always are fully adhered to the substrate.

Figure 1: A sample of modified bitumen roof membrane with aluminum silicate coating.

Wind Performance:

- Built-up roofs and modified bitumen systems have demonstrated good wind performance provided the edge flashing, coping or gutter does not fail (which is a common type of failure mode), see Figure 2. Therefore, detailing of such components and their connections, i.e. size of screws, spacing, etc. is very important to ensure wind resistance of roof system.

- Aggregate surfacing (ballast) improves wind performance, but is prone to blow-off (Figure 3).

- Modified bitumen adhered to a concrete deck has demonstrated better resistance to progressive peeling after blow-off of the metal edge flashing.

- In tropical climates where insulation is not needed above the roof deck, it is recommended to use modified bitumen membrane torched directly to prepared surface of cast-in-place concrete deck.

- Since wind uplift forces at corners and edges of a roof are higher than in its main area (free-field), it is recommended to provide a parapet at least 90 cm high on the parameter of flat roofs, as these reduce the corner pressures by a factor of about 1.5. Otherwise, increase number of fasteners on edges by 50% and corners by 100% to secure built-up roofs and modified bitumen systems.

- The National Research Council of Canada (B1049) provides design recommendations for buildings with a modified bituminous roof system.

- Where the basic wind speed is up to 110 mph (180 km/h), a minimum 2-inch (5.0 cm) thick layer of insulation is recommended. Where the speed is between 110 and 130 mph, a total minimum thickness of 3 inches is recommended (installed in two layers). Where the speed is greater than 130 mph, a total minimum thickness of 4 inches is recommended (installed in two layers).

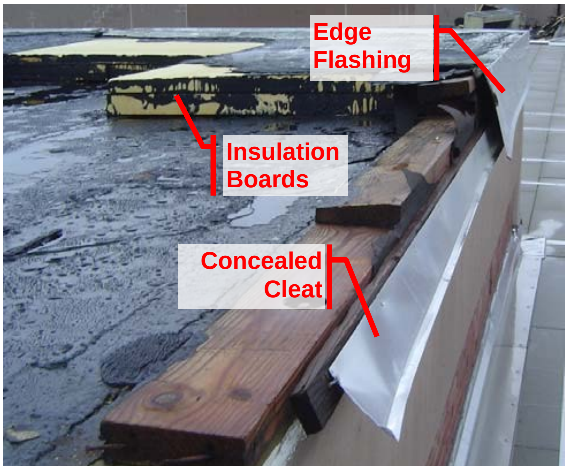

Figure 1: This metal edge flashing had a continuous cleat, but the flashing disengaged from the cleat and the vertical flange lifted up.

Figure 2: Aggregate ballast was scoured and blown from a large portion of the roof. (Source: FEMA 549)

Single Ply Membrane (SPM) roof systems

Main Features:

These assemblies consist of a single ply of water proofing material laid on a substrate. There are three main methods for securing single-ply roofing systems to the roof deck:

- Ballasted: the membrane is loose-laid over the substrate and then covered with ballast to resist wind uplift.
- Fully adhered: the membrane is adhered to the substrate with a continuous layer of adhesive (Figure 4).
- Mechanically attached: the membrane is loose-laid except for a discrete rows of fasteners (Figure 5). This type of membrane installation can be identified by checking seams for signs of anchorage plates.

Single ply membrane roofing is also sometimes attached to the roof using a combination of the above methods.

Wind Performance:

- Typical damage modes include membrane lifting and peeling after wind-induced damage (lifting) of gutters (Figure 6), edge flashing, or coping. Detailing of such components and their anchorage to the building, i.e. size of screws, spacing, etc. is very important to ensure wind resistance of roof system.

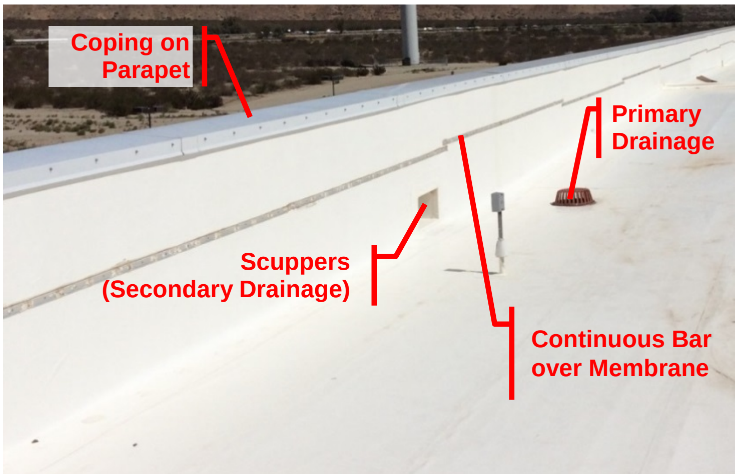

Figure 3: Fully adhered Single Ply Membrane. Note scuppers and primary drainage, coping on the parapet and continuous bar over membrane along the length of the wall (halfway up the height) to prevent tear-off of the membrane (location is in high wind zone).

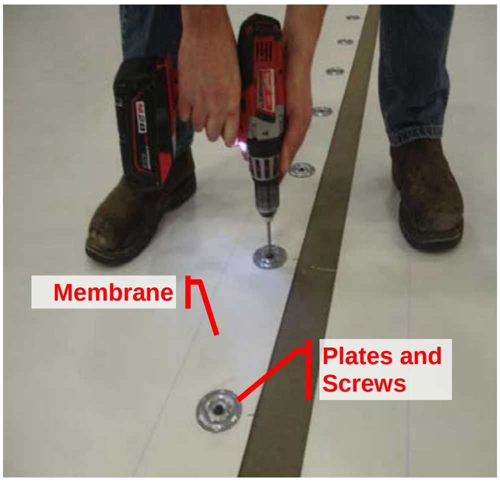

Figure 4: Mechanically attached single ply membrane. Note the attachment, i.e. anchorage plate, will be covered by membrane overlapping.

- Mechanically attached systems, e.g. with anchorage plate, are vulnerable in high wind zones because of stress concentration at the connection assemblies. To avoid tear propagation in the event that the membrane is damaged, it is highly recommended that only reinforced membranes be used for this attachment method.
- The National Research Council of Canada (B1049) provides recommendations related to mechanically attached single-ply roofing systems. EN 16002 specifies a test method to determine the resistance to wind load of mechanically fastened flexible sheets for roof waterproofing. But, the test method does not include the determination of the performance of the mechanical fastener and the substrate.
- CSA Group (A123.21) test method determines the wind uplift resistance of membrane-roofing systems when subjected to dynamic wind load cycles which is applicable to both mechanically attached membrane roofing systems; and adhered membrane roofing systems.
- Ballasted systems should not be used in high wind or hurricane areas because the ballast tends to become airborne, causing massive damage to adjacent buildings. ANSI/SPRI RP-4 provides wind guidance for ballasted systems using aggregate and pavers.

Figure 5: Single Ply Membrane (SPM) peeling due to gutter failure.

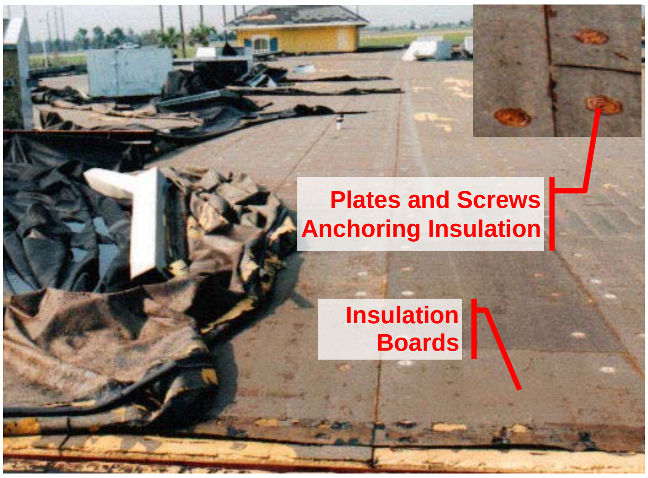

Figure 6: Adhered Single Ply Membrane (SPM) peeled off. Note the insulation boards are still in place.

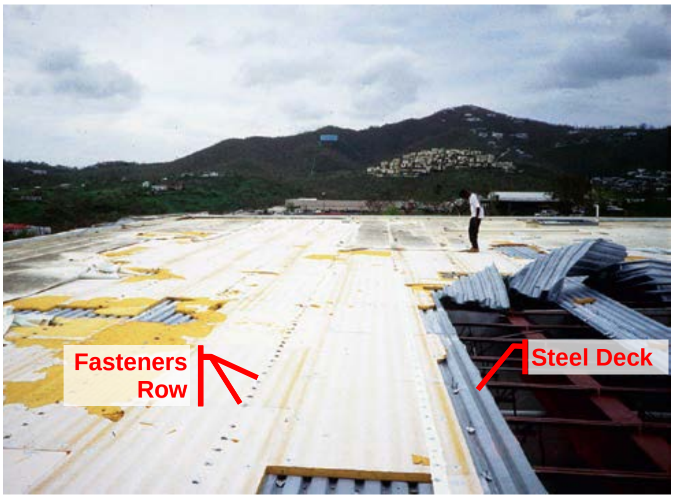

Figure 7: Fastener rows of the mechanically attached single-ply membrane ran parallel to the top flange of the steel deck. The deck fasteners were overstressed and a portion of the deck blew off and the membrane progressively tore. (FEMA 543)

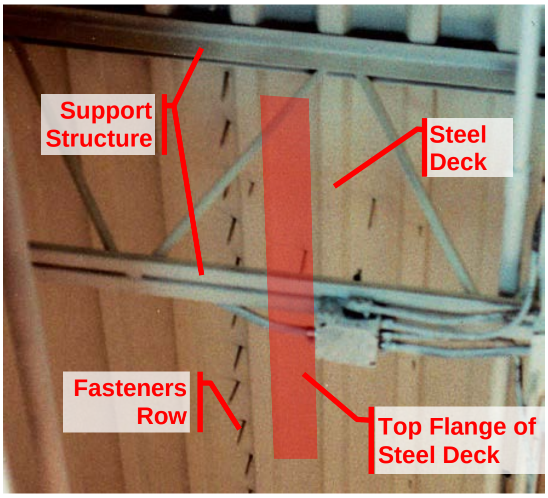

Figure 8: View of the underside of a steel deck showing the mechanically attached single-ply membrane fastener rows running parallel to, instead of across, the top flange of the deck. (FEMA 543)

- Typical high wind failures of fully adhered SPM include delamination of SPM from insulation (Figure 7); delamination of insulation board; or an inadequate number and spacing of plates and screws anchoring insulation to the deck.
- Another typical damage to roof membrane is caused by windborne debris, which results in punctures and tears.
- When a mechanically attached system is used on a steel deck, it is critical that the membrane fastener rows run perpendicular to the flanges to avoid overstressing the attachment of the steel deck to the deck support structure (Figure 8 and Figure 9).
- Since wind uplift forces at corners and edges are higher than in the main area (free-field) of roof, it is recommended to provide a parapet at least 90 cm high on flat roofs, as these reduce the corner pressures

by a factor of about 1.5. Otherwise, increase number of fasteners on edges by 50% and corners by 100% to secure single ply membrane.

Spray Polyurethane Foam-based (SPF) roof systems

Main Features:

The standard SPF roofing application consists of three components, the substrate, the SPF layer and the top coat:

- Substrate can be existing roof system (e.g. built-up roof or tile roof), roof deck (often concrete deck), or insulation board.
- Spray polyurethane foam-based roof systems are comprised of two elements; a two-component liquid that forms the base of an adhered roof system and a protective surfacing layer.
- The protective surfacing (top coating) is required for ensuring long-term performance of an SPF roof system. Its main function is to provide weatherproofing, ultraviolet (UV) protection, mechanical damage protection, and fire resistance.

Wind Performance:

- SPF-based roof systems perform well under wind loading, provided that the substrate, i.e. insulation board or existing roofing system, does not lift.
- SPF-based roof systems have moderate wind-borne missile impact resistance.
- Application of SPF cover to protect tile roofs (often for retrofitting) may not improve the uplift resistance of the latter because of inadequate performance of the attachment mechanism to the tiles.
- For an SPF roof system over a concrete deck, where the basic wind speed is less than 130 mph (210 km/h), it is recommended that the foam be a minimum of 3 inches thick (7.5 cm) to avoid missile penetration through the entire layer of foam. Where the speed is greater than 130 mph (210 km/h), a 4-inch (10.0 cm) minimum thickness is recommended. It is also recommended that the SPF be coated, rather than protected with an aggregate surfacing.

Shingles and tiles roof systems

Main Features:

- Roof shingles are a roof covering consisting of individual overlapping elements. Shingles can be of asphalt, wood, metal or synthetic materials. Tiles can be of clay or concrete materials.

Wind Performance:

- Even when shingles and tiles are properly attached to resist wind loads, their brittleness makes them vulnerable to breakage as a result of wind-borne debris impact (Figure 10). If a tile or shingle is broken, debris from a single tile can impact other tiles and shingles on the roof, which can lead to a progressive cascading failure.
- Tile missiles can be blown a considerable distance and a substantial number have sufficient energy to penetrate shutters and glazing, and potentially cause injury.

- In tile roof system and shingles, it is recommended that clips be installed at all tiles in the rake, ridge, eave, and hip zones. Wind resistance of shingles should be determined in accordance with UL 2390, ASTM C1568 or EN 14437.

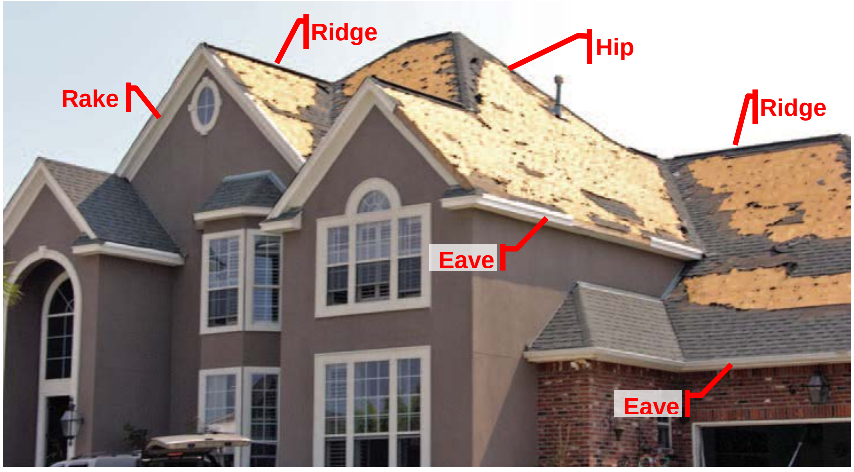

Figure 10: Asphalt shingle roof blown-off. (Source: FEMA P-55 / Volume II, "Coastal Construction Manual")

Metal panels roof systems

Main Features:

There are two main types of metal panels roof systems, classified based on connection mechanism of the metal panels to the roof deck:

- Through-fastened metal panel roofing: fixation of the panels to roof structure is achieved by bolts or screws, which are visible from the surface, but require water-proofing washers (Figure 11).

- Standing seam metal panel roofing: The panels are affixed to the underlying structural element with clips which are not visible from the roof (Figure 12). The panels can be either mechanically seamed (as marked with a circle in Figure 12) or snapped together (panels to each other and clips). The clips are affixed to steel purlins by screws or bolts. The purlins are part of the building frame (Figure 14).

Wind Performance:

- Overall, through-fastened cladding system has a very good performance record compared to other metal panel systems (minimum thickness 0.5 mm)

- In very high wind pressure, most common failure mode is tearing of through-fastened metal panel over the fastener head and stress washer (Figure 13) or tearing of the fastener shank from anchorage.

- For through-fastened metal panels screws are recommended in lieu of nails in timber construction.

- For through-fastened metal panel systems test methods UL 580, ASTM E 1592 or AS 1562.1 are recommended for qualification/approval. These tests evaluate the resistance of roof assemblies (i.e. the roof deck, its attachment to supports, and roof covering materials) to wind uplift pressures.

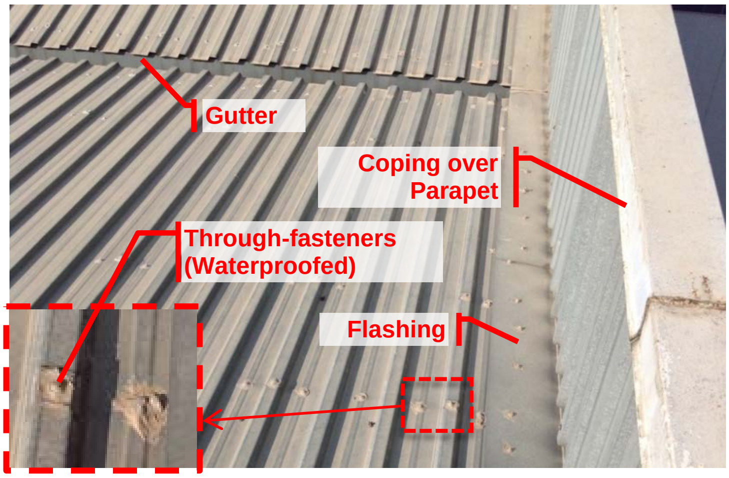

Figure 9: Through-fastened metal roofing. Note water-proofing of fasteners, flashing on the right and coping over the parapet.

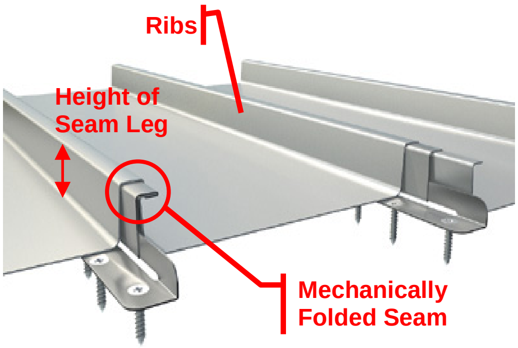

Figure 10: Standing seam metal panel roofing (with permission: http://collmillgroup.com.au/)

- Common problems of standing seam metal panels are excessive fastener spacing at perimeter and corners (Figure 14), i.e. inadequate number of connections of panel to load-bearing system, as well as flashing details (i.e. panel eaves, rakes, hips, valleys and ridges). Depending upon design wind loads, fasteners should typically be spaced from 3 inches (7 cm) to 12 inches (30 cm) on center at these locations.
- For standing seam metal roof panels with concealed clips and mechanically seamed, ribs spaced at 12 inches (30 cm) on center are recommended.
- The height of the seam leg is an important factor in wind uplift resistance of the metal panels (Figure 12). Generally speaking, the higher the leg height, the stronger the system.
- For standing seam systems ASTM E 1592 or AS 1562.1 testing are recommended as a test method for qualification of roofing systems because it gives a better representation of the system's uplift performance capability than UL 580.
- Steel metal panels have better resistance than aluminum panels.
- For copper systems located in areas with a basic wind speed greater than 90 mph (145 km/h) and for buildings with an eave height of 100 feet (30 m) or greater (regardless of basic wind speed), Type 316 stainless steel clips are recommended in lieu of copper clips, as the latter are very malleable and can easily deform under high wind loads.

Figure 11: Failure of through-fastened metal panel systems due fasteners excessive fastener spacing at perimeter and corners. Metal panel torn off over the fastener head.

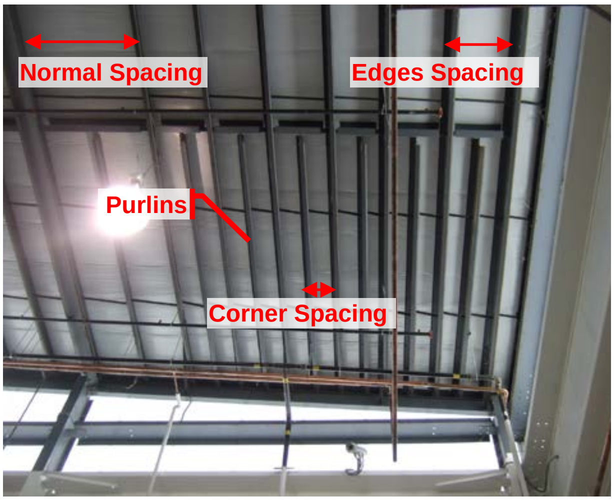

Figure 12: Proper spacing of purlins at the edges and corners (additional purlins are added to allow closer spacing of seam clips to the structure)

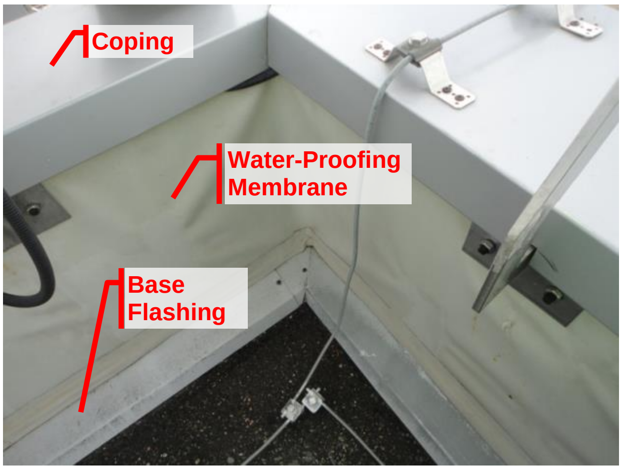

Figure 13: Sheet metal components for protection of the roof water-proofing membrane.

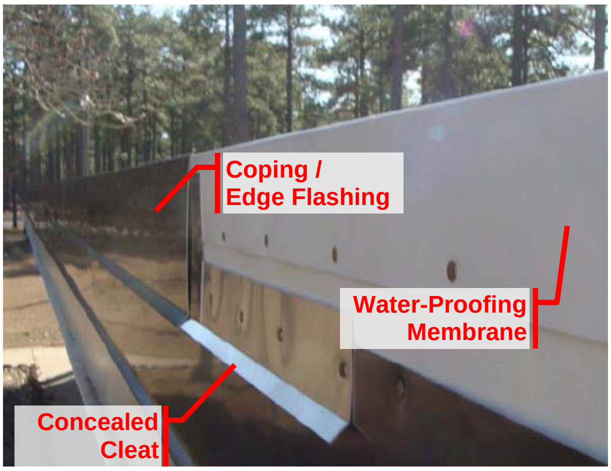

Figure 14: This coping is attached with stainless steel concrete spikes. the fasteners should be more closely spaced (the spacing will depend on the design wind loads).

Roof appurtenances

In addition to the roof cladding system, edge components are required in most systems to secure and terminate the roof covering. Such components include sheet metal strips (flashing) and coping (Figure 15 and Figure 16) and gutters. Correct detailing of these elements in terms of length of overlaps, type and spacing of mechanical fixation, etc. is very important to ensure integrity of the roof covering. Any deficiencies in these edge components will lead to catastrophic damage of the roof envelope. The wind resistance of these elements is to be taken into consideration during roofing system selection process and detailed guidance regarding proper installation to be obtained from the roofing system supplier.

Edge Flashings, Copings, Parapet Base Flashing

Roof membrane blow-off is almost always a result of lifting and peeling of the metal edge flashing or coping, causing lifting and peeling of the edge flashing and membrane. Therefore, it is important to carefully consider the design of metal edge flashings, copings, and the connection details. ANSI/SPRI ES-1, "Wind Design Standard for Edge Systems Used in Low Slope Roofing Systems" provides general design guidance, including a methodology for determining the outward-acting load on the vertical flange of the flashing/coping. It also includes test methods for assessing flashing/coping resistance.

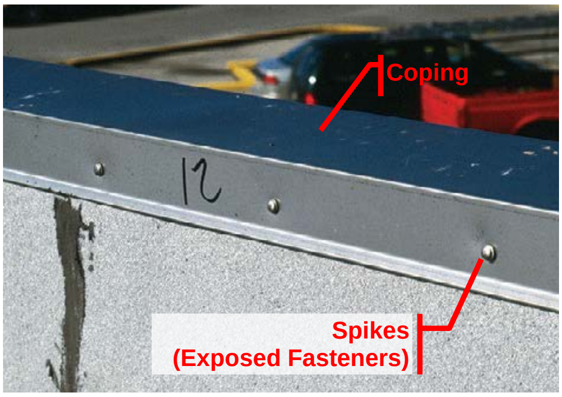

Figure 15: Both vertical flange of the coping were attached with exposed fasteners instead of concealed cleats (Source: FEMA 543)

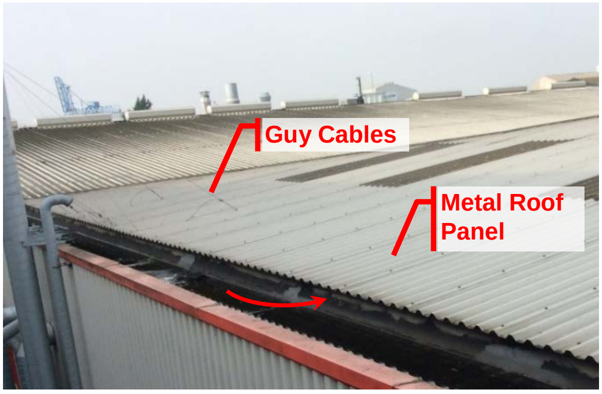

Figure 16: Notice improper edge detailing of roof panels (lack of flashing or additional fasteners). Wind penetration below the panels, as shown with the arrow, can peel-off the panels. Also the guy cables used for restraining the chimney are anchored to the roof panel elements, which is not good practice.

The edge flashing/coping attachment method often rely on concealed cleats (Figure 16 and Figure 2), which can deform under wind load and lead to disengagement of the flashing/coping (Figure 2) and, consequentially, lifting and peeling of the roof membrane. When a vertical flange disengages and lifts up, the edge flashing and membrane are very susceptible to failure. Normally, when a flange lifts, the failure continues to propagate and the metal edge flashing and roof membrane blow off. In lieu of cleat attachment, use of exposed fasteners to attach the vertical flanges of copings and edge flashings has been found to be a very effective and reliable attachment method (Figure 17). The fasteners should be more closely spaced in the corner areas (the spacing will depend upon the design wind loads). ANSI/SPRI ES-1 provides guidance on fastener spacing and thickness of the coping and edge flashing.

When base flashing is fully adhered, it has sufficient wind resistance in most cases. However, when base flashing is mechanically fastened, typical fastening patterns may be inadequate, depending upon design wind conditions. It is also important to recognize and specify different attachment spacing in parapet corner regions versus regions between corners.

Hip, ridge, and rake flashings

Proper detailing of edges, i.e. hip, ridge, and rake, is important is wind performance in sloped roofing system (Figure 18). when metal roofing (or hip, ridge, or rake flashings) blow off during windstorm, water may enter the building at displaced roofing; blown-off roofing can damage buildings. Because exposed fasteners, i.e. screws, are more reliable than cleat attachment, i.e. hidden connection points to the purlins, it is recommended that hip, ridge, and rake flashings be attached with exposed fasteners. Two rows of fasteners are recommended on either side of the hip/ridge line (Figure 19). Close spacing of fasteners is recommended (e.g., spacing in the range of 3 to 6" (7 to 15 cm) on center, commensurate with the design wind loads), in order to avoid flashing blow-off as shown in Figure 20.

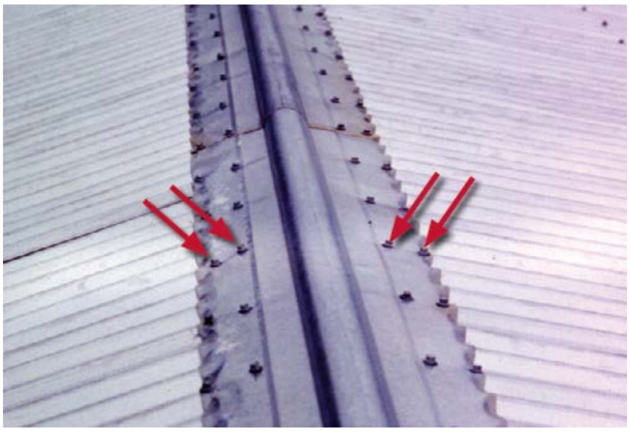

Figure 17: The ridge flashing on these corrugated metal panels had two rows of fasteners on each side of the ridge line. (Sources: FEMA "Hurricane Ike Recovery Advisories")

Figure 18: The ridge flashing fasteners were placed too far apart. A significant amount of water leakage can occur when ridge flashings are blown away. (Sources: FEMA "Hurricane Ike Recovery Advisories")

Gutters

Gutter uplift often results in progressive lifting and peeling of the membrane (Figure 20). To avoid this type of problem, attachments of gutters needs to be designed and detailed for uplift load. Not only the connection details, but also points of attachment are to be carefully considered to ensure that damage to the gutter does not result in peeling of the membrane. ANSI/SPRI GD-1 provides general design guidance and test method for gutters used with low-slope roofing.

Conclusion

The distribution pattern of wind pressures on a building is very complex, difficult to predict and highly variable within a short distance. Not only topographical features in the vicinity of the site but also architectural ones on the building itself impact the wind forces acting on a building. The various factors to be considered when designing a building and its elements to wind forces are covered in structural design codes. Not only sizing of structural, i.e. load-bearing, elements, e.g. beams, columns, roof slabs, are covered in these codes, but also the connection of non-structural elements, e.g. cladding, windows, etc. to the structural ones are defined as well. Unfortunately, requirements regarding non-structural elements are seldom complied with, due to the fact that these secondary components are "off-the-shelf", i.e. standard components, selected based primarily on price considerations. Wind damage to the building envelope is also very often accompanied by water damage to the building contents.

Selection of roof cover type is primarily dictated by the shape of the roof and its inclination. Disregarding the fact whether a building is "open" or "closed", i.e. area of openings, uplift forces generally tend to be higher at the corners and along the edges of a roof. As such, special consideration, e.g. closer spacing of mechanical connectors, pull-off testing of adhered membranes, etc. is to be given at these regions of the roof.

Edge flashing, coping and gutters play an important role in roof wind resistance. Roof membrane blow-off is almost always a result of lifting and peeling of the metal edge flashing or coping which causes the edge flashing and membrane to lift and peel. For buildings in high wind regions, provide face-fastened perimeter roof flashing, which allows easier verification of connection quality, in contrast to concealed fastener flashing.

In any case, ensure that not only structural, i.e. load-bearing, elements but also all secondary components comply with the latest version of the national structural design codes (or international best practice when codes are not available), not only in terms of force levels but especially detailing. Suppliers of roof components, e.g. gutters, skylights, gutters, etc. are to confirm that these components and associated appurtenances, e.g. mechanical connectors, comply with wind resistance requirements of local structural design codes.

References

FEMA P-55, "Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas", http://www.fema.gov/media-library/assets/documents/3293?id=1671, 4th Edition, August 2011.

FEMA 549, "Hurricane Katrina in the Gulf Coast: Mitigation Assessment Team Report, Building Performance Observations, Recommendations, and Technical Guidance", https://www.fema.gov/media-library/assets/documents/4069, July 2006.

FEMA P-499, "Home Builder's Guide to Coastal Construction – Technical Fact Sheet Series", https://www.fema.gov/media-library/assets/documents/6131, December 2010.

FEMA 339, "Building Performance Assessment Team (BPAT) Report - Hurricane Georges in Puerto Rico", http://www.fema.gov/media-library/assets/documents/615?id=1422, March 1999.

FEMA 489, "Hurricane Ivan in Alabama and Florida: Observations, Recommendations and Technical Guidance", http://www.fema.gov/media-library/assets/documents/2338?id=1569, August 2005.

FEMA 488, "Mitigation Assessment Team Report: Hurricane Charley in Florida", http://www.fema.gov/media-library/assets/documents/905?id=1444, April 2005

FEMA P-499, "Home Builder's Guide to Coastal Construction – Technical Fact Sheet Series," https://www.fema.gov/media-library/assets/documents/6131, December 2010.

FEMA, "Hurricane Ike Recovery Advisories", http://www.fema.gov/media-library/assets/documents/15100, April 2009.

FEMA P-361, "Design and Construction Guidance for Community Safe Rooms", http://www.fema.gov/safe-room-resources/fema-p-361-design-and-construction-guidance-community-safe-rooms, August 2008.

FEMA 543, "Risk Management Series – Design Guide for Improving Critical Facility Safety from Flooding and High Winds", https://www.fema.gov/media-library/assets/documents/8811, January 2007.

ASCE/SEI 7-10, "Minimum Design Loads for Buildings and Other Structures", American Society of Civil Engineers, 2013.

IBC 2012, "2012 International Building Code", June 2011.

ASTM E 1996, “Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes”, DOI: 10.1520/E1996-14, January 2014.

ASTM E 1233, “Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights, and Curtain Walls by Cyclic Air Pressure Differentia”, DOI: 10.1520/E1233_E1233M, January 2014

ASTM E1592, “Standard test method for the structural performance of sheet metal roof and siding system by uniform static air pressure difference“, DOI: 10.1520/E1592-05R12, 2012.

ASTM C1568-08, “Standard Test Method for Wind Resistance of Concrete and Clay Roof Tiles (Mechanical Uplift Resistance Method),” DOI: 10.1520/C1568, 2013

ANSI/SPRI RP-4, “Wind Design Standard For Ballasted Single-ply Roofing Systems”, December 2008.

ANSI/SPRI ES-1, “Wind Design Standard for Edge Systems Used with Low Slope Roofing Systems”, December 2013.

ANSI/SPRI GD-1, “Structural Design Standard for Gutter Systems Used with Low-Slope Roofs”, October 2010.

AS 1562.1-1992, “Design and installation of sheet roof and wall cladding – Part1: Metal”, Australian Standard, July 1992.

AS 4040.3-1992, “Methods of testing sheet roof and wall cladding - Resistance to wind pressures for cyclone regions,” Standards Australia, January 1992.

EN 16002:2010, “Flexible sheets for waterproofing. Determination of the resistance to wind load of mechanically fastened flexible sheets for roof waterproofing,” EUROPEAN COMMITTEE FOR STANDARDIZATION, 2010.

EN 14437:2004, “Determination of the uplift resistance of clay or concrete tiles for roofing – Roof system test method,” EUROPEAN COMMITTEE FOR STANDARDIZATION, 2004

VKF/AEAI, “Recommandations - Protection des objets contre les dangers naturels météorologiques”, Association des établissements cantonaux d'assurance incendie, 2007.

UL 580, “Standard for Tests for Uplift Resistance of Roof Assemblies”, November 2006.

UL 2390, “Test Method for Wind Resistant Asphalt Shingles with Sealed Tabs,” May 2003.

Canadian Cataloguing in Publication Data, “Building Technology–Flashings“, Best practice guide: building technology, 1998.

A123.21-14, “Standard test method for the dynamic wind uplift resistance of membrane-roofing systems,” www.csashop.ca, Canadian Standards Association, May 2014.

B1049, “Wind Design Guide for Mechanically Attached Flexible Membrane Roofs,” National Research Council of Canada, Institute for Research in Construction, 2005.

CTS Technical Report No 57, “Tropical Cyclone Yasi – Structural damage to buildings, ” CYCLONE TESTING STATION, April 2011.

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