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Wind Uplift Design of Flexible Membrane Roofs

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INTRODUCTION

Wind is one of the essential considerations in roof design. Poor design or faulty construction, or the selection of non-compatible materials, can result in severe wind damage to the roof, the cost of which is often exceeded by losses associated with interior damage and interruption of occupancy.

North American roofing market was more than $25 billion Canadian and approximately one fourth of low slope buildings are roofed with Mechanically Attached Assembly (MAA) with single-ply membrane. During wind suctions, membranes of the MAA can lift and billow. A new publication from the Institute for Research in Construction provides engineers, architects and building officials with information on how to better design mechanically attached flexible membrane roof assemblies to resist wind uplift. This publication, *"A Guide fro the Wind Design of Mechanically Attached Flexible Membrane Roofs*" will help improve roof performance and reduce losses as a result of roof failure in high winds.

DESIGN PROCESS

Unique Characteristics of Mechanically Attached Roofing Systems

Mechanically attached systems are attached at discrete points or rows, moderate-to-strong wind will cause the membrane to lift and billow between the attachment points or rows (Figure 1). Wind fluctuations cause the membrane to flutter, or rapidly flap up and down. The dynamic (or cyclical) loading induced by the fluttering can cause fatigue of the membrane, the

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membrane fasteners, the substrate below the membrane fasteners, or the fastener/deck engagement locations. To avoid wind-induced failure of the roof system, the designer should consider and account for the effects of dynamic loading. The resistance of each link (Figure 1) should be greater than the total wind uplift force.

It is important for designers to recognize that building codes may not adequately address wind uplift performance of roof systems, including systems with mechanically attached membranes. The information and enhancements presented in this *Guide* will increase the likelihood of good high-wind uplift performance for flexible membrane roofs.

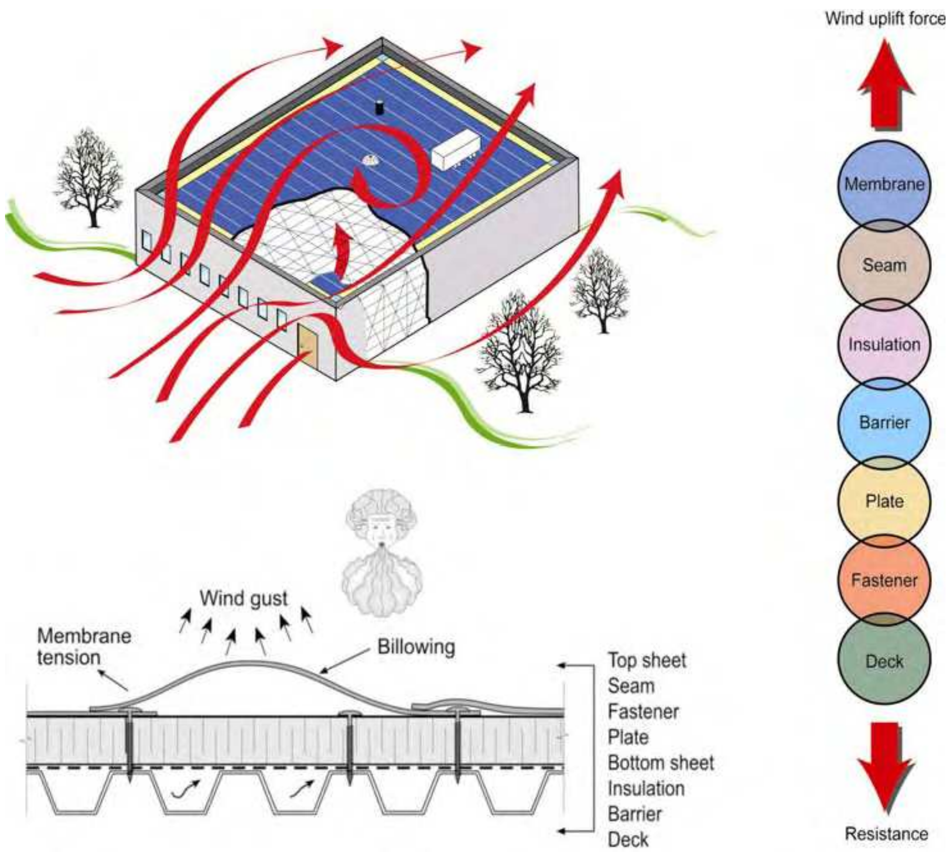


Figure 1: Wind Uplift Performance of Mechanically Attached System

WIND UPLIFT LOAD CALCULATION

The first step in designing a roof assembly to resist winds is the determination of the design wind loads. There are several differences between the load calculations for the roofing structure as compared to those for the roof coverings. This chapter focuses on the load calculation for the roof covering/cladding; several methods used to determine the uplift loads for roof claddings are presented. For all methods, the latest edition of applicable codes and design manuals should be used, and a check should be made to ensure that any local load requirements or regulations are used for the design.

Canada

For Canada, wind loads on buildings must be determined in accordance with the applicable provincial building code which, in turn, adopts the National Building Code of Canada 2005 (NBCC) as the model code. In the NBCC, the reference dynamic pressure is based on a mean hourly wind speed at a height of 10 m (33 ft.) for flat, open exposures. Roof covering loads are based on a mean recurrence interval of 50 years (i.e., an annual probability of 0.5). The NBCC' wind load calculation procedure for roof coverings can be summarized in six steps as follows:

- calculation of dynamic pressure
- definition of the corner zone
- calculation of external wind pressure component
- calculation of internal wind pressure component
- calculation of net wind pressure
- development of the loading diagram

WIND UPLIFT RESISTANCE EVALUATION

The resistance of the roof assembly to wind uplift is a function of the components used (membrane, seams, fasteners, deck, etc.) and their arrangement. Testing is required to determine the wind resistance of a roof assembly. Roof system component manufacturers provide design resistance values for their systems based on uplift testing. It is critical to use a test method that provides a meaningful measure of the uplift performance of the system.

Development of SIGDERS Dynamic Test Method

To satisfy industry demand for test methods that are more accurate than the existing North American test procedures, the Institute for Research in Construction at the National Research Council of Canada (NRC) began, in 1994, to develop a new method for evaluating mechanically attached roof membrane systems. SIGDERS, the Special Interest Group for Dynamic Evaluation of Roofing Systems, was formed to support this research. The goal was to develop a method that would:

- mimic real wind effects
- achieve failure modes observed under real conditions
- be easier to apply in the laboratory than existing tests
- allow for variation in roof design
- produce results quickly
- conform to local standards.

As shown in Figure 2, the SIGDERS protocol has five rating levels (A to E).

- Each level consists of eight load sequences with different pressure ranges. The eight load sequences can be divided into two groups.
- Group 1 represents wind-induced suction over a roof assembly. It consists of four sequences, where the pressure level alternates between zero and a fixed pressure. Group 2 represents the effects of exterior wind fluctuations combined with a constant interior pressure on a building. Internal pressure variations are explicitly codified in the recent NBCC and ASCE 7 documents. The SIGDERS test protocol accounts for such variations.

- The test pressure ratios (y-axis) can be calculated from the design pressure, in accordance with the NBCC or ASCE 7. The pressures for each load sequence are calculated as percentages of the test pressure. An example is shown with a test pressure of 60 psf (2.87 kPa) on the right hand side of the axis.
- To evaluate the ultimate strength of the roofing system, testing should be started at Level A and, if it passes, it should be advanced to the next level and so on. To obtain an uplift resistance, all specified numbers of gusts in a given level must be completed.

The standardization process was completed and recently CSA published it as *CSA A123.21-04 – Standard Test Method for the Dynamic Wind Uplift Resistance of Mechanically Attached Membrane Roofing Systems.* This can assist roof designers and manufacturers in North America to evaluate and specify flexible membrane roofs based on the SIGDERS test protocol.

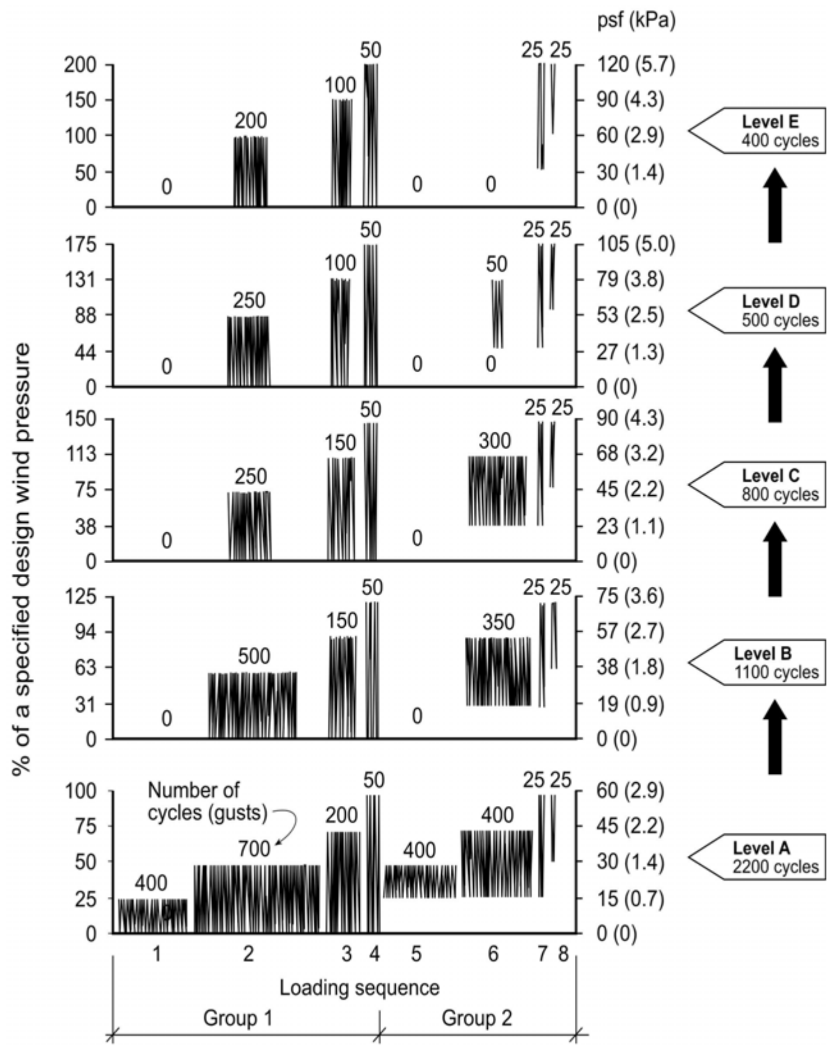


Figure 2: CSA A123.21-04 – Dynamic Wind Load Cycle

DECKS

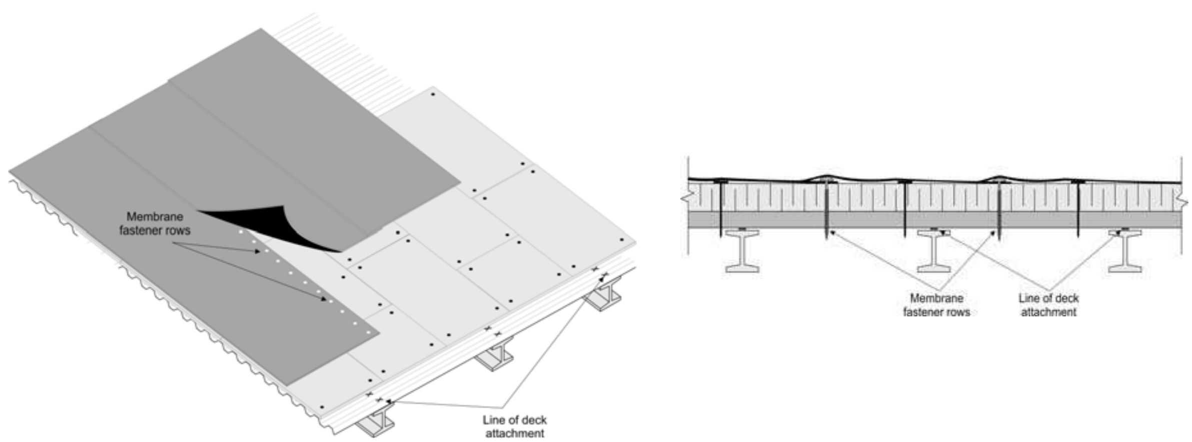
Deck Attachment

The deck and the deck attachment are essential features for resisting the complex and dynamic wind load distribution of mechanically attached flexible membrane roof systems. The deck attachment to the supporting structure must be sufficient to resist the design uplift loads (adjusted for the safety factor). The deck attachment should be equal to or greater than the attachment used in the assembly the designer references to determine the roof assembly's uplift resistance. It is desirable for the membrane fasteners to engage the top flange of the deck, because top flange engagement reduces the moment arm of the fastener and minimizes localized deck deformation.

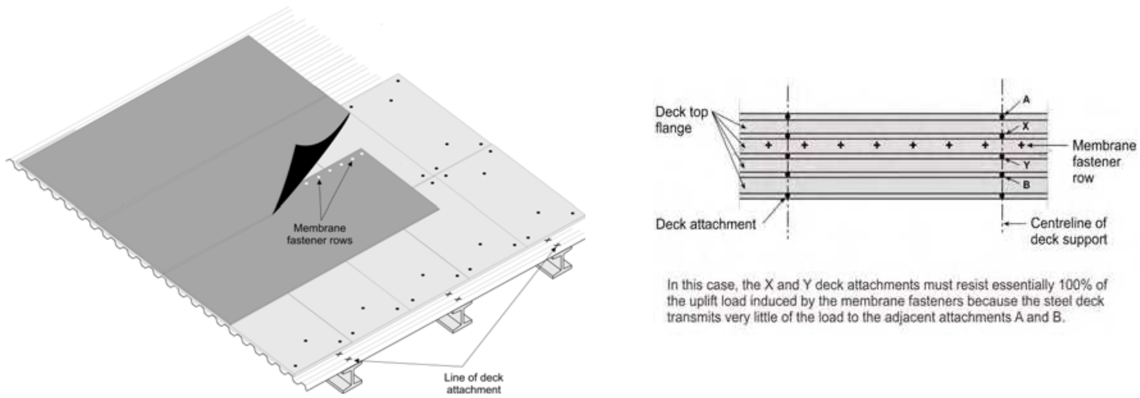
Deck/Fastener Row Orientation

The orientation of the fastener rows with respect to the deck flanges affects the influence area of the deck attachment to the support structure. The *influence area* is defined as the area that contributes uplift load to the connection of the deck to the supporting structural beam/joists.

During the membrane attachment, the membrane fastener row can align either perpendicular (Figure 3a or parallel (Figure 3b) to deck flanges. If the membrane fastener rows are perpendicular to the flanges, the influence area is decreased. This results in a lower load being transferred to the deck attachment. Also, perpendicular row layout avoids the potential of overstressing the deck side lap fasteners. Therefore, specifying fastener rows perpendicular to the deck flanges is recommended.



(a): Membrane fastener rows perpendicular to the deck flanges



(b): Membrane fastener rows parallel to the deck flanges

Figure 3: Influence area as a function of fastener row orientation

AIR AND VAPOUR BARRIER (RETARDER)

The function of the air barrier (retarder) in a roofing assembly is to minimize air leakage through the roof. Therefore, an air barrier (retarder) can greatly minimize the amount of membrane flutter and associated fatigue. Designers should consider incorporating an air barrier (retarder) into the roof assembly in locations where moderate winds are nearly a daily occurrence.

INSULATION

One of the important properties that influence the wind uplift resistance is the clamping force. The clamping force is also depends on the plate/batten design, the compressibility of the insulation under the membrane. Loss of clamping force can be caused by:

- insulation creep, where the insulation relaxes after fastener applications
- inadequate compression resistance of the insulation to prevent overturning of the fastener plate/batten
- shrinkage of insulation due to thermal or moisture effects or material instability
- deformation of the fastener plate/batten
- fastener backout
- localized deformation (for steel decks) in the vicinity of the fastener

MEMBRANES

There are two families of mechanically attached membrane systems: polymer-based and asphalt-based. Some mechanical and physical properties (for example, tensile strength and dimensional stability) of the membrane itself can influence wind uplift performance of the roof system, while other physical properties (for example, membrane colour) are of little significance. Dynamic testing is the preferred method for evaluating the wind uplift performance of membranes.

The membrane attachment method can significantly influence wind uplift performance of the roof system. Attachment method variables include the number and type of fasteners, thickness, and type of battens, gauge and type of plates, and width and type of seams. Appropriate testing is necessary to evaluate these factors.

<u>Asymmetrical Seams</u>

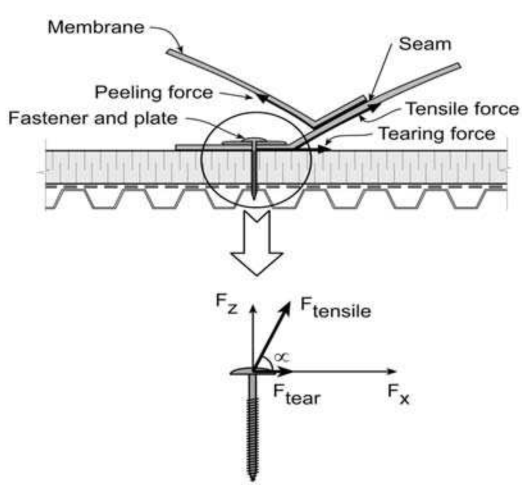
The asymmetrical seam attachment arrangement is the most common one for mechanically attaching thermoplastic membranes. As shown in Figure 4(a) asymmetrical seams are subject to higher eccentric force distributions and membrane stress than other types of seams. Under high winds, an asymmetrical seam can experience forces that can cause:

- seam peeling, fastener backout, or pullout from the deck
- tearing in the membrane in the vicinity of the attachment or the seam
- permanent deformation of the fastener plates
- crushing of the substrate below the plate due to overturning forces on the fastener plate
- crushing of insulation due to rocking forces on the fastener shank.

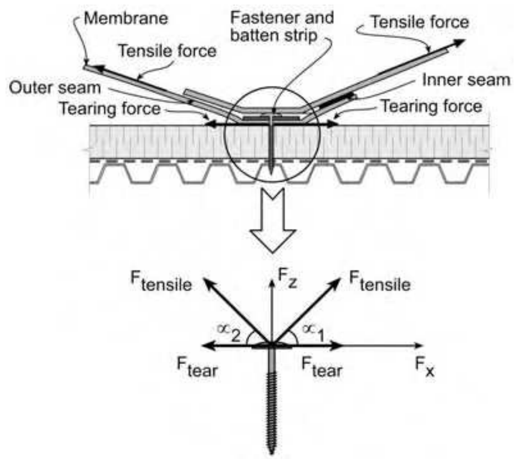
<u>Symmetrical Seams</u>

Compared to asymmetrical seams, symmetrical double-sided seams (Figure 4(b)) offer two major advantages. First, the wind load is transferred by two seamed areas at each seam location instead of one as in the case of the asymmetrical arrangement. Second, since twice the seamed area is available to share the load, the load borne by each seamed area is reduced.

Systems with double-sided seams can be expected to withstand higher wind loads than systems with single-sided seams. The batten strips can spread the wind uplift along the length of the seam rather than localizing it at the fasteners or in the membrane around the vicinity of the fastener plates. The majority of the wind uplift forces are transferred to the deck through a structural load path with minimal eccentricity. However, this attachment arrangement can cause fastener pullout from the deck.



(a): Asymmetrical seam



(b): Symmetrical seam

Figure 4: Influence of membrane attachment methods on wind uplift force

FASTENERS

Fastener Thread Design

Fastener thread design plays a vital role in the wind uplift resistance of mechanically attached roof assemblies. Thread design can influence the fastener pullout resistance. Designs should specify anti-backout fasteners. These are fasteners that have a thread design that reduces the potential for backout. Also, thread design issues are evaluated by appropriate roof system testing.

Fastener Plate

Fastener plates should provide and maintain adequate clamping force on the membrane to avoid membrane tearing and slippage of the membrane from under the plate. Plates with barbs provide increased resistance to membrane slippage. However, because the barbs are not very strong, not all substrates are capable of receiving the barbs. For example, a barbed plate would not be suitable for a membrane applied directly over a plywood deck. The plate also needs to be resistant to deformation. Membrane slippage from underneath the plate is a factor that is evaluated by dynamic testing.

Fastener Spacing

Fastener row spacing and the spacing of fasteners within those rows are a function of the:

- design wind uplift loads (from the NBCC, local code or ASCE 7)
- resistance of the roof assembly as determined from testing
- desired safety factor
- sheet width (for systems with fasteners placed within the seam)
- fastener pullout resistance, which is a function of fastener design and deck properties.

Wind uplift resistance should be increased (e.g., by increasing the fasteners per unit area) in the corners and perimeter to account for the increased wind load in those areas.

CONCLUSION

Mechanically attached flexible membrane roofs are effective roofing systems, especially for large roof areas, but are susceptible to failure unless designers and manufacturers consider and account for dynamic lifting of the membrane due to wind.

The SIGDERS consortium research has resulted in testing protocols and information that significantly advanced understanding of the behaviour or flexible roofs. This information is summarized in this *Guide*. Furthermore, the Appendices provide case examples of roof designs using SIGDERS findings.

ACKNOWLEDGEMENTS

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Manufacturers Atlas Roofing Corporation, Canadian General Tower Ltd., Carlisle Syn Tec., GAF Materials Corporation, GenFlex Roofing Systems, Firestone Building Products Co., IKO Industries Ltd., ITW Buildex, Johns Manville, Sarnafil Roofing, Soprema Canada, Stevens Roofing, Tremco and Trufast

Building Owners Canada Post Corporation, Department of National Defence, Public Works and Government Services Canada.

Industry Associations Canadian Roofing Contractors' Association, Canadian Sheet Steel Building Institute, National Roofing Contractors' Association and Roof Consultants Institute.