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Baskaran, B. A.

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Dynamic Wind Testing of Commercial Roofing Systems

by A. Baskaran

Single-ply roofs (SPRs) behave differently than built-up roofs and a simple test method is needed to ensure that they perform well under dynamic wind conditions. This Update describes a new test protocol developed by an industry-supported consortium project led by NRC's Institute for Research in Construction.

Wind Effects on Roofs

Wind damage is the reason for many roofing insurance claims but little is known about the performance in wind of the SPRs often installed on low-slope commercial and industrial buildings. However, it is known that SPRs react differently to wind effects than conventional built-up roofs.

Wind passing over and around a building with a low-slope roof (Figure 1a) exerts positive pressure on the windward wall, negative pressure (suction) on the leeward wall and the walls parallel to the flow direction, and suction over most of the roof area. The suction generated at any particular roof location depends on the wind speed, wind direction, turbulence intensity or gusts, building topography, building geometry and

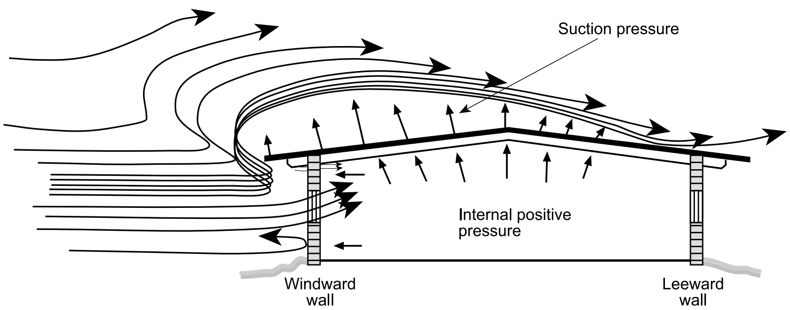

Figure 1a. Wind-induced suction over a roof

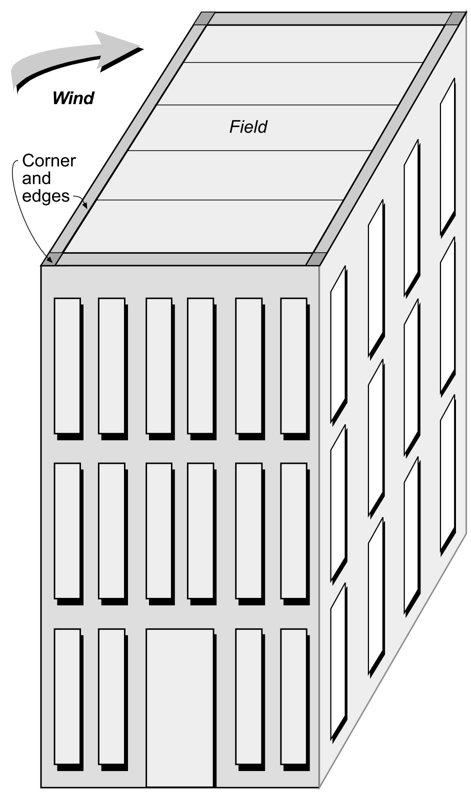

Figure 1b. Commercial roofs, with their almost-flat profiles and low parapets, can experience high local suction pressures along the roof perimeter.

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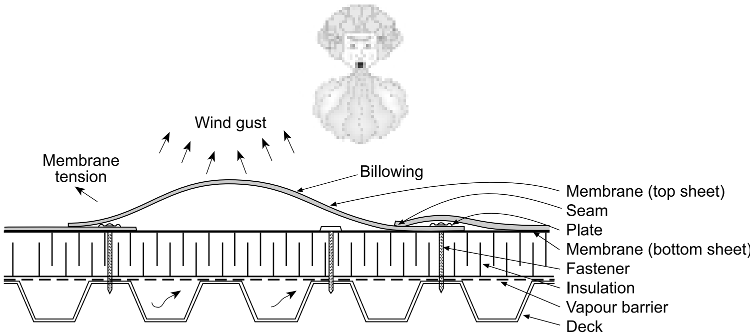

Figure 2. Wind effects on single-ply mechanically attached roof assemblies

architectural features, and varies with time. Commercial roofs, with their almost-flat profiles and low parapets, are likely to experience high local suction pressures along the roof perimeter (Figure 1b).

Waterproof membranes are attached to the structural roof deck using fasteners (Figure 2). The attachment locations are then overlapped with another membrane sheet and the upper and lower sheets seamed together. Wind-induced suction repeatedly lifts the membrane between the attachments and causes membrane elongation and billowing. The magnitude of the wind-induced suction and the membrane's elastic properties determine the extent of billowing.

Each roof component contributes resistance to the wind uplift force as illustrated by a force-resistance link diagram (Figure 3). All resistance links must remain connected for the roofing system to be durable and remain in place. Failure occurs when the wind uplift force is greater than the resistance of any one of these links. For example, the roof assembly is considered to have failed when a fastener (link 4) pulls out from the deck even though the membrane and its seams are in good condition. Similarly, failure is considered to have occurred when a seam (link 2) opens under gusting wind while other components remain intact.

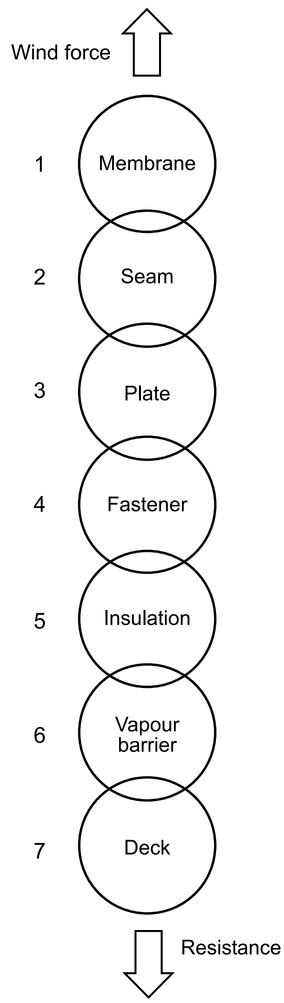

Figure 3. Force-resistance link diagram of single-ply roofs

Testing and Certification of SPR Roofs

When designing a new roof, the designer consults a building code to determine the design wind pressure for the geographic location and selects a roofing system and details (such as fastener spacing) appropriate for the local climatic wind conditions. To establish reliability, manufacturers of SPR systems test samples in accordance with standard methods to certify the systems will be able to withstand design wind loads; however, existing test methods have limitations.

North American Test Methods
Existing certification standards used in North America to assess wind uplift ratings of SPR systems include those issued by Factory Mutual (FM)[5] and Underwriters' Laboratories.[7] Although easy to apply, these standards were developed for built-up roofing and do not simulate the dynamic wind conditions that generally cause mechanically fastened SPR roofs to fail.

European Test Methods
The common European testing method (European Union of Agrément – UEAtc)[4] simulates actual wind conditions better than North American tests and, as a result, produces better estimates of actual wind uplift resistance of roofs. It uses a pressure load cycle based on meteorological data to simulate dynamic wind loading and accounts for size and edge effects, but the procedure is very time-consuming. For example, one UEAtc cycle with 1415 gusts takes nearly 3 hours to complete, and it can take as long as 50 hours for a full investigation.

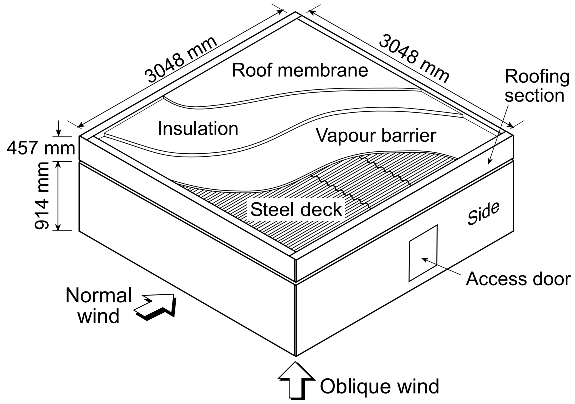

Figure 4. Wind tunnel model

The goal of the SIGDERS project was to develop a test 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
- meet most North American building code requirements

SIGDERS Test Protocol

To develop a more effective test method for certifying mechanically fastened SPR systems, IRC formed a consortium called SIGDERS (Special Interest Group for Dynamic Evaluation of Roofing Systems).

The first phase of the research was the full-scale wind tunnel testing of SPR systems with PVC and non-reinforced EPDM membranes (Figure 4). Both steady and gusty wind conditions were simulated and pressures measured at a number of locations to observe the fluctuations experienced by an SPR.

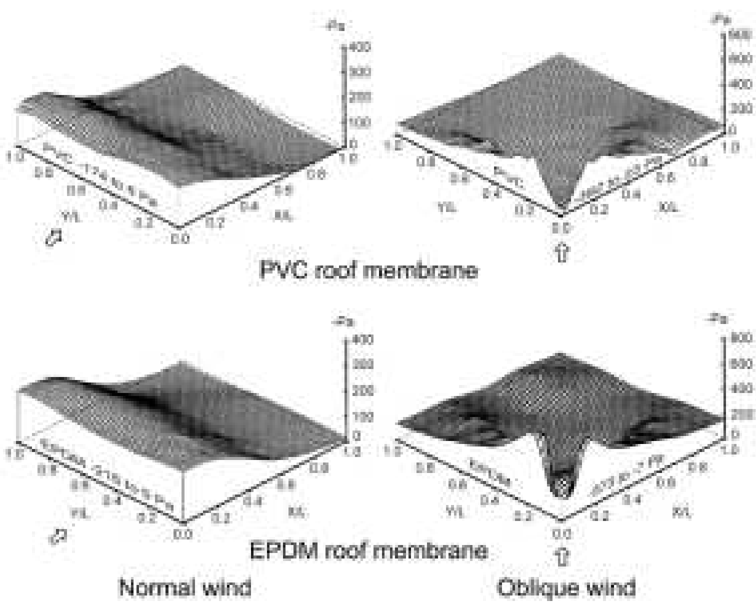

Figure 5. Wind pressure distributions measured from the wind tunnel on full-scale roofs

The typical mean wind pressure distributions for both normal and oblique winds are shown in Figure 5. Wind-induced pressures are negative (suction) and higher near the edges and corners than they are at the field of the roof. The tests showed that EPDM experiences a higher mean pressure than PVC for both normal and oblique wind conditions.

Based on the wind tunnel results, a review of existing standards, and computer simulations, and using IRC's Dynamic Roofing Facility (DRF), IRC researchers devised a test loading procedure that allows a roofing system to be tested at any design wind pressure. This procedure,[3] represented in Figure 6, includes eight loading sequences in which a roof system is subjected to simulated gusts. The loading sequences are grouped into five different levels (Levels A to E).

There are two groups of cycles at each test level: Group 1 cycles, which simulate *wind-induced suction* over a roof assembly, and Group 2 cycles, which simulate the *effects of exterior wind fluctuations* combined with a constant interior pressure on a building. Each group consists of four loading sequences in which the pressure level alternates between zero and a fixed pressure. Allowable internal pressure variations are explicitly specified in recent North American wind standards and the National

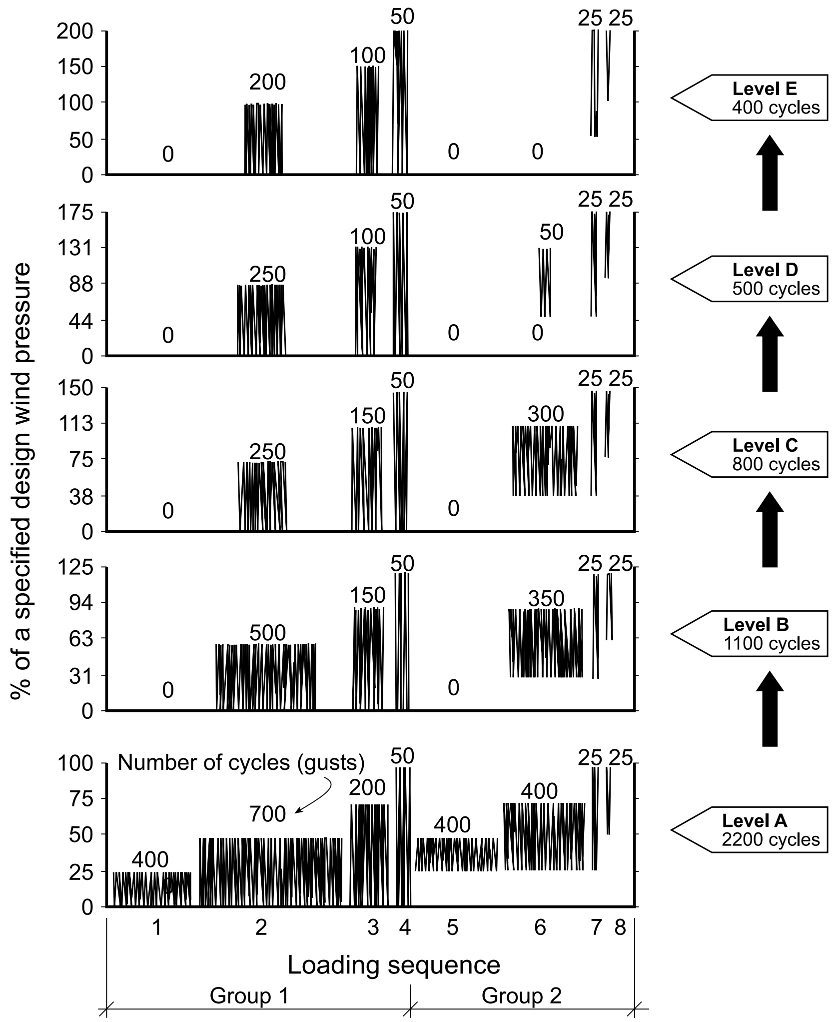

Figure 6. SIGDERS dynamic wind load cycle

Building Code (NBC),[1,6] and are taken into account in the SIGDERS test protocol.

Each loading sequence is performed at a pressure that is a percentage of the design wind pressure stipulated by applicable building codes and standards for a given type of building and a particular location, starting with lower pressures and increasing gradually with each level. For example, the Level A tests include one sequence of 400 cycles (gusts) at 25% of the design wind pressure, another sequence of 700 cycles at 50% of the design wind pressure, and so on, for a combined total of 2,200 cycles.

To evaluate the ultimate strength of the roofing system, testing begins at Level A. If all the resistance links (Figure 3) remain connected, the roof is considered to have "passed" and obtains a rating. Testing then proceeds to the next level, where the pressure is increased (see Figure 6).

Comparison of Test Protocols

IRC's Dynamic Roofing Facility, used in the development of the SIGDERS loading cycle, permitted a comparison of the results obtained using the SIGDERS loading cycle with the results from both the UEAtc and FM procedures. Table 1 compares the test parameters and attributes of the FM,[5] UEAtc[4] and SIGDERS[2] test protocols. As shown in the table, the SIGDERS dynamic test protocol for SPRs produces failure modes similar to UEAtc, but has several additional benefits, such as the consideration of membrane flutter and the completion of tests in much less time.

Benefits of the SIGDERS Test Protocol

Support for the SIGDERS project by the roofing industry reflected a genuine need for new methods to ensure that roofing systems can perform in high, gusting winds. The new test protocol overcomes the limitations of current test methods. It has been submitted to the Canadian Standards Association for consideration as a national standard for Canada. It is likely that other jurisdictions in North America will benefit from this research as well. The test protocol will provide manufacturers with assurances that their products have been effectively tested and building owners with roofs that have longer service lives.

Table 1. Features of the FM, UEAtc and SIGDERS test methods

Parameter	FM	UEAtc	SIGDERS
Source data	N/A	Wind climatic data	Roof pressure time histories
Relationship with wind speed	Yes	No	Yes
Relationship with applicable codes and standards	No	No	Yes
Internal pressure	No	No	Yes
High-frequency fluctuations	No	Yes	No
Membrane flutter	No	No	Yes
Testing time*	< 0.5 hours	55 hours	5 hours
Maximum number of gusts	N/A	No	5000
Low-intensity gusts (<40% of test pressure)	N/A	71% of test cycles	18%
Medium-intensity gusts (40-75% of test pressure)	N/A	28% of test cycles	68%
High-intensity gusts (>75% of test pressure)	N/A	1% of test cycles	14%
Correction for temperature	No	Yes	No
Correction for specimen size	No	Yes	Yes
End product	Static evaluation	Fastener design load	Dynamic evaluation

*Varies according to roofing system

Recently, SIGDERS released a report[2] describing the procedures for using the dynamic load cycle and installing the roof assembly, and reporting the test data. Once the SIGDERS test protocol becomes a national standard, manufacturers will be able to have their products tested, and after certifications are obtained, designers will be able to specify SPRs that meet the SIGDERS test requirements.

Summary

Developed by IRC in cooperation with manufacturers, building owners and roofing associations, SIGDERS is a new test protocol for easily evaluating the ultimate strength of flexible membrane roofing systems under dynamic wind conditions. Once implemented as a national standard, the protocol will contribute to improved predictability and service life of these roofing systems.

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7. Underwriters' Laboratories Inc., Standard for Uplift Pressure of Roof Assemblies (UL 560), 1996.

SIGDERS consortium members

Manufacturers
Atlas Roofing Corporation
Canadian General Tower Ltd.
Carlisle SynTec Incorporated
GAF Materials Corporation
GenFlex Roofing Systems
Firestone Building Products Company
IKO Industries Ltd.
Johns Manville
Sarnafil
Soprema Canada
Stevens Roofing Systems
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Building Owners
Canada Post Corporation
Department of National Defence
Public Works and Government Services Canada

Associations
Canadian Roofing Contractors' Association
Canadian Sheet Steel Building Institute
Industrial Risk Insurers
National Roofing Contractors' Association
Roof Consultants Institute

Dr. A. Baskaran *is a senior researcher in the Building Envelope and Structure Program of the National Research Council's Institute for Research in Construction.*

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**For more information, contact Institute for Research in Construction, National Research Council of Canada, Ottawa K1A 0R6
Telephone: (613) 993-2607; Facsimile: (613) 952-7673; Internet: http://www.nrc.ca/irc**

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