# Effects of dynamic wind loads on roofing systems

Baskaran, B. A.



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# The Effects of Dynamic Wind Loads on Roofing Systems

**By Dr. A. ("Bas") Baskaran, P. Eng**

*This article offers a brief summary of the findings of past modeling research activities, and recommends future areas in the dynamic modeling of both the driving forces and roofing system response.*

## Why Alter Evaluation Procedures?

North American procedures for evaluating the wind performance of roofing systems address only static conditions. As shown in Figure 1, wind flow around buildings creates pressure fluctuations over a roofing system. Negative pressure is created by flow separation on the outside of the roof. Positive pressure, known as building internal pressure, is generated by the temperature difference across the envelope and due to the mechanical ventilation system installed in the building.

These pressures have both static and transient components. The static component is simply the mean pressure. The transient component varies as a random process and its dominant frequencies depend on the frequency of the upstream wind and geometry of the building. Thus, the wind uplift pressure is dynamic. The response of the roofing system is also dynamic. This means a proper three-dimensional and time-dependent (i.e., dynamic) analysis is essential for adequate estimation of wind effects on roofs.

## How is it Being Done?

In a research project recently begun in Canada, test procedures and numerical models are being developed to evaluate the performance of mechanically-attached roofing systems under dynamic wind-loading conditions. The

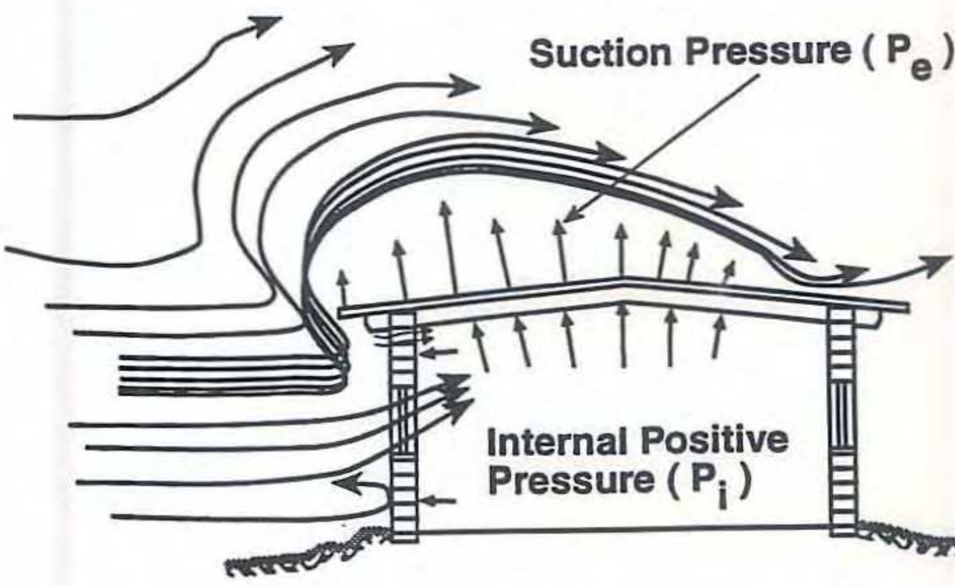


**Figure 1:** *Wind Flow Schematic Over Roofing System*

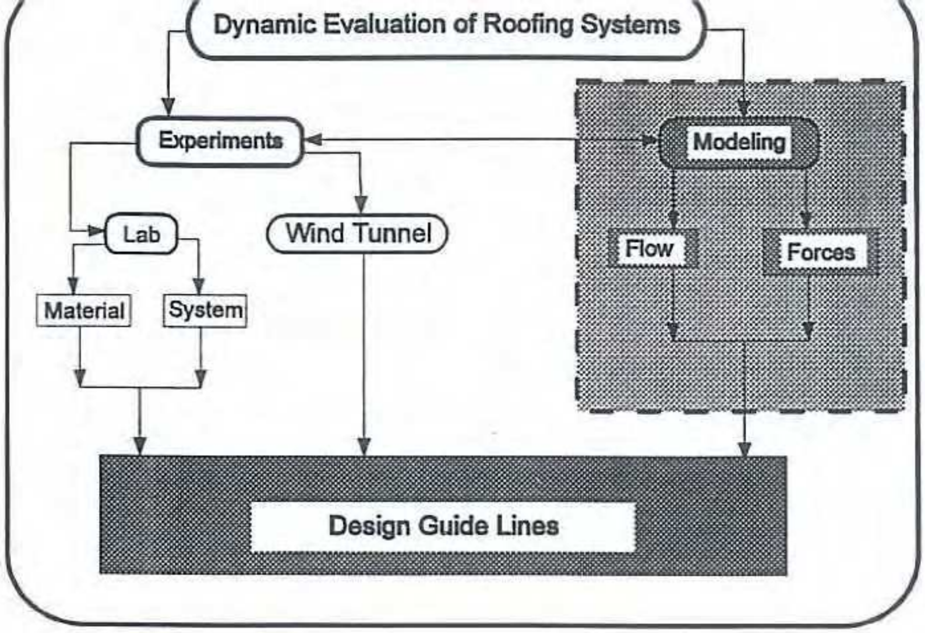


**Figure 2:** *Project Flowchart*

analyses and the test results will be combined to produce a design manual for the roofing industry.

The experimental task includes laboratory tests to evaluate materials, system performance and wind tunnel dynamic load measurements. Numerical modeling involves development of a Finite Element Method (FEM) structure model and a Computational Fluid Dynamics (CFD) wind-loading model.

The work is being done by scientists at the Institute for Research in Construction, one of the institutes of the National Research Council of Canada. Since wind tunnel testing is involved, colleagues at the NRC's Institute for Aerospace Research are also involved in the program. They are working under the aegis of a newly-formed interest group which brings together a wide range of clients concerned about roofs, including manufacturers (Canadian General Tower Ltd./Prospex Roofing Products Ltd., Carlisle SynTec Systems, Cemfort Inc., Firestone Building Products Co., JPS Elastomerics Corp. - Construction Products Group, Soprema Canada, and Vicwest Steel); building owners (Department of National Defence, Public Works and Government Services Canada); and managers and architects (Canada Post Corporation). Also involved are two associations—the Canadian Roofing Contractors' Association (CRCA), and its American counterpart, the National Roofing Contractors' Association (NRCA).

It is an example of the close relationship that exists between industry and the IRC.

**A North American consortium, Special Interest Group for the Dynamic Evaluation of Roofing Systems (SIGDERS), has been set up by NRC and has members from roofing contractor associations, manufacturers and building owners/managers.**

## Which Type of System is Under Investigation?

In conventional systems, the membrane is on the top, and thus exposed to variations of wind and temperature. These systems may be either built-up roofing (BUR) or single-ply roofing (SPR). In either case, the basic components are the same: deck, insulation, barriers, membrane and attachment systems.

There are three ways to hold the membrane in place in SPR systems: by fastening it mechanically, by attaching it to the substrate with a solvent, adhesive or hot bitumen, or by holding it down with gravel ballast or concrete pavers. The NRC study initially focuses on mechanically-fastened SPR systems.

## How SPR Fails

Because wind uplift forces are dynamic, different failure mechanisms can be recognized for mechanically-attached SPR systems:

- Fastener backout, with resultant membrane puncture.
- Fastener pullout, caused by fatigue cracks in the steel deck around the borehole. The fasteners then pull out of the deck, leading to failure of the attachment system.
- Zipper effect, where failure of one fastener for what-

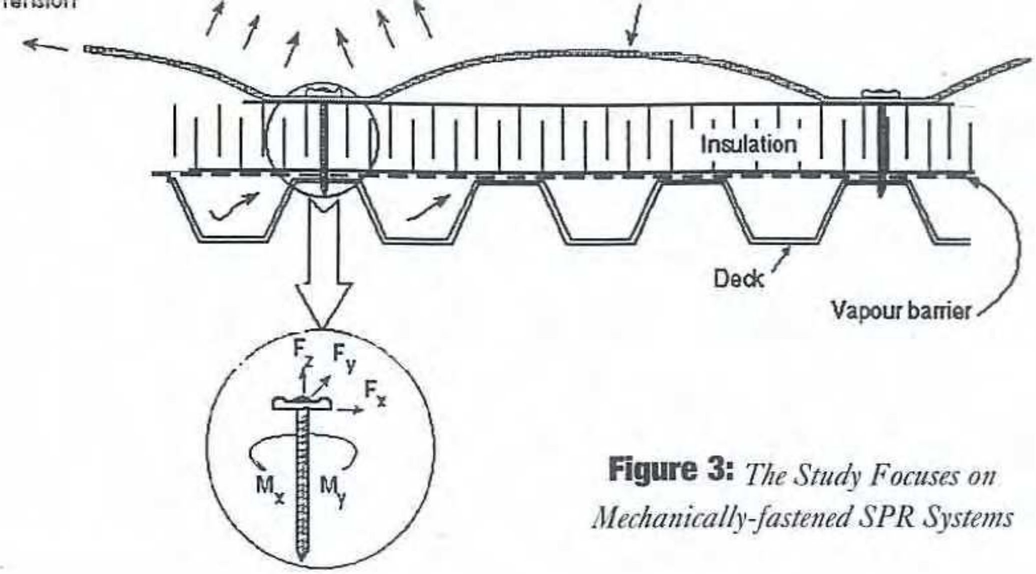


**Figure 3:** *The Study Focuses on Mechanically-fastened SPR Systems*

ever reason can lead to the failure of adjacent fasteners because of force redistribution.

- Attachment plate deformation, which occurs in the case of spot attachment systems. Plates are deformed upward as a result of the tendency of the membrane underneath to lift and arch under wind uplift forces. This type of failure may be the most common, and ultimately causes the membrane to tear at attachment points.
- Membrane tearing as a result of excessive ballooning.

## What We Know[1]

Past uses of numerical models for the static and dynamic evaluation of SPR systems have been carefully reviewed. The modeling approach was found advantageous in understanding system performance. For example, computer models can be economical, efficient tools for studying parameters such as variation in the applied wind loading as well as geometrical and material changes in roofing systems.

The review considered studies involving adhered and ballasted SPR systems, and mechanically-attached SPR assemblies. Some of the studies suggested specific solutions to specific problems. Others served to point the way to further research.

In 1985, a study by the National Institute of Standards and Technology (NIST) calculated thermally-induced stresses in a bituminous built-up membrane on two layers of glass fiber insulation boards over a metal deck. Analysis showed stresses were adversely affected by not staggering the insulation panels. When the membrane was laid above a continuous gap through the two layers of insulating board, stress levels were dramatically higher (63 percent) than in a configuration having no staggered joints between the layers.

**Maximum wind uplift pressure increased as the paver size decreased.**

Calculations are also continued for stresses induced by linear thermal gradients across the roof systems using both adhered and loose-laid EPDM membranes. Researchers found that along the gaps between the insulation boards, peak stresses in the adhered system were about 0.20 MPa and about 0.12 MPa in the loose-laid system. These low levels of stress were attributed to the low modulus of the membrane material. As the modulus increased, so too did the stress levels.

Simpson Gumpertz & Heger Inc. investigated the effect of wind pressure on an inflated SPR membrane and its attachment mechanism. It was shown that the system response varied with a number of factors, including the rate of air flow into the space beneath the membrane, the stiffness of the membrane, wind characteristics and the dimensions of the membrane strip. The study reported that the failure mechanism of SPR systems is initiated by air infiltration into the space beneath the membrane, followed by ballooning of the membrane with fluctuations in wind pressure. If, however, the membrane was laid flat on an air-impermeable roof deck with no way for the air to flow beneath it, then the full fluctuating component of the wind pressure should be used for design.

Also, in 1993, a Colorado University research team developed a numerical model to simulate wind loads on roofing systems using loose-laid concrete pavers as ballast. They showed that for a given external pressure distribution, the pressure under the pavers depended only upon the ratio of the space between the pavers to the space beneath them. When this ratio approached zero, the pressure distribution beneath the pavers was virtually uniform. Moving in the other direction, as the ratio approached infinity, the pressure beneath the pavers approached the external pressure distribution. The study also showed that for a given aspect ratio (length/width) of the paver, the maximum uplift pressure increased as the paver size decreased. Also, for a given paver size, maximum uplift increased with the increase in aspect ratio.

Turning to mechanically-attached systems, Firestone in 1990 investigated the response of EPDM membranes to wind uplift forces. It used FEM to predict maximum fastener loads, the ballooning phenomenon (including the maximum height achieved), and stresses at the edges of a test table. The investigators concluded that FEM modeling could substitute for large-scale wind uplift testing for roofing systems subjected to very high loads, and that only small-scale tests were needed.

A European study in 1992 calculated the membrane stresses and fastener forces under static loads. Calculating vertical deflection and membrane stresses under a constant load at any point, it was found that the central fastener carried the highest load—about 78 percent of theoretical fastener load. When the central fastener failed, the load on the next fastener increased by about 1.4 times. It was found that membrane material had a negligible effect on fastener loads. Previous studies have also shown that the higher the uplift suction, the greater the proportion fastener force is directly induced due to the membrane ballooning. Conservatively, it is reasonable to assume that the force applied on a fastener was approximately 2.5 times the wind uplift force.

## Where Do We Go From Here?

It would be ideal for roof designers to have software capable of performing complete system design. This would give them a numerical tool to investigate and design roofing systems for various components subjected to different induced stresses such as wind, temperature, and rain. Similarities exist in the studies reviewed. However, it is evident that the existing knowledge is not comprehensive and a systematic approach is needed in the following areas:

- **Driving forces:** Fluctuations of the wind-load variations on the roofing system are not modeled, and thus applied loads did not vary with time or space. Since nothing occurs in isolation, a study is needed on the effect of load combinations—temperature and wind, for example, or membrane aging and wind.
- **Assembly details:** The majority of the studies modeled only the roofing membrane, ignoring the contributions from such other components as insulation and decks in the system response. Systematic modeling of details of the roof assembly, taking its three-dimensional variations into account, would also be helpful, especially when considering different types of insulation. More work is needed on the analysis of individual components such as spot attachment anchors, insulation, decks and the like. A model to study such variables as fastener spacing would assist in the development of design guidelines.
- **Numerical techniques:** Researchers applied either the FEM or a simplified technique in modeling the SPR system response. The development of predictive models using Computational Fluid Dynamics (CFD) would aid this work by providing the wind-induced loads on the roofing system.

[1] *Full documentation of the review can be found in "Application of Numerical Dynamic Evaluation of Roofing Systems, Part 1: Review of the State of the Art," by Dr. A. Baskaran and Dr. A. Kashef, Internal Report No. 690, Institute for Research in Construction, National Research Council Canada, Ottawa, Ontario, Canada, K1A 0R6. To obtain a copy, please contact Bas Baskaran at 613/990-3616.*

## About The Author

Dr. Bas A. Baskaran *is a research officer at the National Research Council of Canada, Institute for Research in Construction (NRC/IRC). He received his bachelor of engineering degree from Annamalai University, Madras, India. His master of engineering and doctoral degrees were from Concordia University, Montreal, Canada, where he remains as adjunct faculty. At the NRC/IRC, he is researching the wind effects on building envelopes through experiments and computer modeling. He is an executive member of RICOWI and a member of an ASCE subcommittee on Numerical Flow Modeling and Condition Assessment of the Building Envelope Systems. Baskaran has authored and/or co-authored about 60 research articles in the area of wind effects on buildings.*