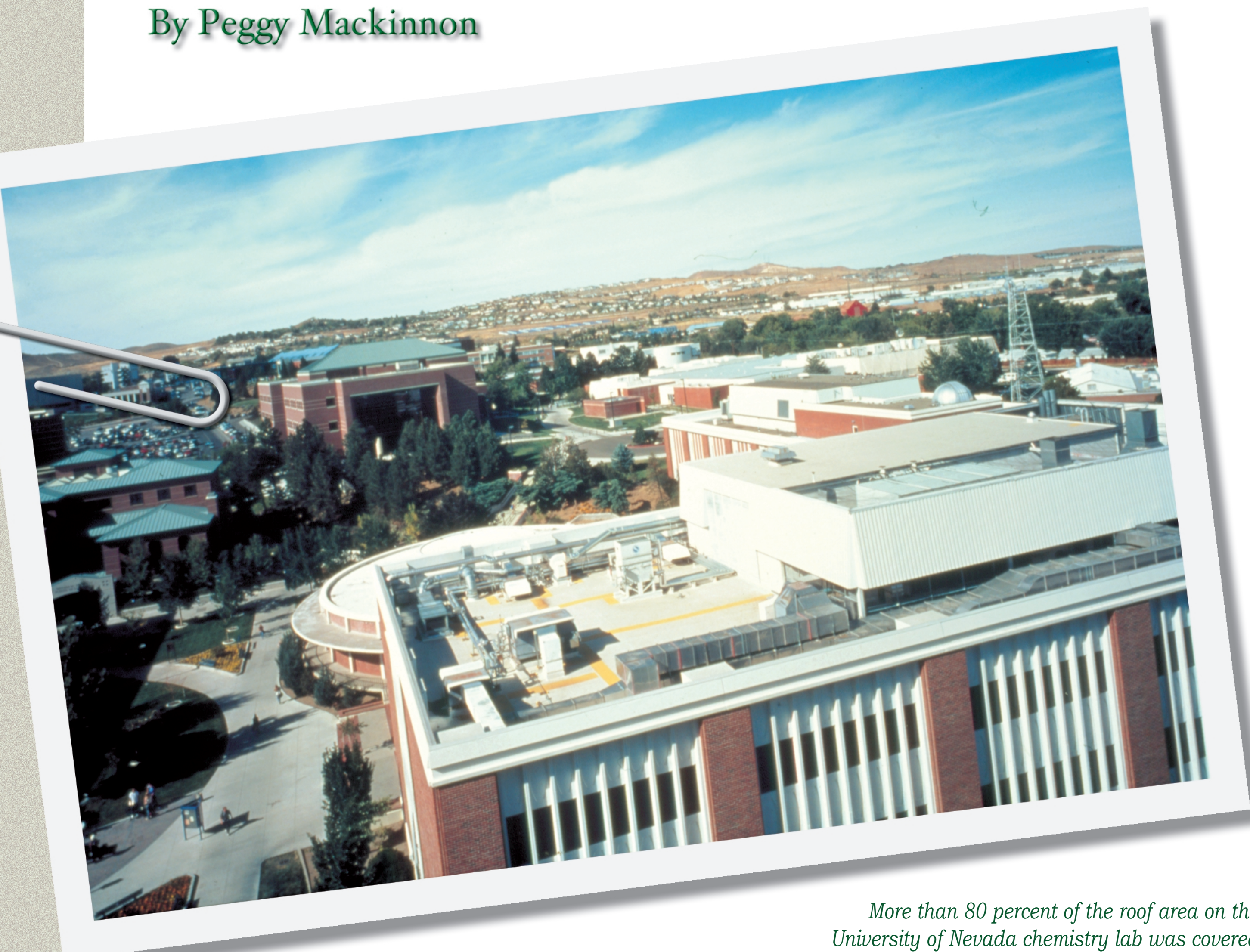
REROOFING CHEMISTRY LAB A CHALLENGE

By Peggy Mackinnon



More than 80 percent of the roof area on the University of Nevada chemistry lab was covered with mechanical equipment.

Judy Good, the foreman for D&D Roofing & Sheet Metal, Inc., said that reroofing the 14,000-square-foot University of Nevada chemistry lab was the most difficult job she has experienced in her 23 years of roofing. More than 80 percent of the surface was covered with mechanical equipment, some weighing several tons, which had to be moved. Because chemistry experiments were taking place during the reroofing project, ventilators were kept open for safety reasons. Moreover, years of pigeon droppings left up to two feet of residue that had to be removed.

"This was a very challenging job and very labor intensive," Good said. "We took this project one step at a time. We approached each area of the roof individually and solved problems in each area before moving onto the next. It required a lot of coordination."

The original roof had been installed in the 1970s and had deteriorated. In some cases, the concrete structure had been damaged, and the reinforcing was exposed. Leaks were common, due, in part, to the penetrations necessary to install mechanical equipment (HVAC, ventilation, air ducts). To address many of the challenges, Michael J. Perry, vice president for CRC Consulting Group, Inc., a professional member of RCI and the roof consultant on the project, specified a PVC roofing system. A Johns Manville UltraGard® SR60 PVC roofing system was installed over JM Tapered ISO 1™ roof insulation because the roof had minimal natural slope.

"We thought PVC provided a number of advantages for this project," Perry said. "We were able to accommodate the variety of flashing conditions and the minimum clearances we had to work with. We also could accommodate the relatively complex detailing necessary for covering the high walls, including a variety of levels, protrusions, and duct penetrations. We also thought that a PVC membrane might help inhibit the pigeon activity."

The first challenge was the size and quantity of mechanical equipment. According to Sam Chamberlin, operations manager for D&D Roofing & Sheet Metal, Inc., the mechanical part of the project was 2-1/2 times the cost of the roofing system. Coordinating with the mechanical engineer and electrician, a lot of the equipment was removed from the roof with a crane. Some equipment, however, could not be dismantled and had to be left in place. For example, a several-ton mechanical unit had to be raised 10 inches so the surface underneath could be roofed.

The equipment and penetrations required some unique flashing details. For the 80-ton air coil cooler, a cylindrical iron pedestal was wrapped with flashing and clamped to form the watertight base for the unit. All of the pitch pans were removed. The membrane was extended up 10-foot, stair-stepped parapet walls with clad metal used on the top of the wall. Massive bolts were concealed by coated metal. Each coated metal cover had 32 corners, and 16 covers were along each wall.

Another challenge was coordination. According to John Walsh, assistant project supervisor for the University of Nevada, there were restrictions on how long the equipment could be down, which required coordination with class schedules. If the ventilation system was down during chemistry classes, it could result in injury to the students.

Another significant issue was the years of build up of pigeon droppings. Not only did the roofing contractors have to remove the droppings, but it was also desired to prevent pigeon activity in the future. Old screening over the roof was replaced, and the university plans to install additional deterrents.

Asbestos abatement also was part of the project. Despite inclement weather, the roofing system was installed on time and with minimal change orders. Perry cited D&D's coordination as key to the success of the project.

"D&D did a great job in working closely with everyone to make sure the needs of the building owners were maintained throughout the project," Perry said. "They made every effort to follow plans and specifications. As a result, we ended up with a quality product." ■

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A multi-ton unit had to be raised 10 inches so that the surface underneath could be roofed.

Wind Pressure Measurements on Full Scale Flat Roofs

By A. Baskaran and M.G. Savage

ABSTRACT

A flat roof surface is known to be subjected to unusually high suction associated with a pair of vortices created under diagonally skewed wind. Prediction of the wind load and its influence on the roof system is an important engineering topic, but wind tunnel testing of this situation is not easy with a scaled model. Considering the physics of wind flow for the most critical case, a possibility to use a full-roof configuration has been investigated. Results are found to be encouraging, allowing the use of much more accurate structural details of roofing systems, such as flexible membranes.

INTRODUCTION

A flat roof surface is known to be subjected to unusually high suction induced by a pair of "horseshoe" vortices caused by the wind coming diagonally facing a corner of the building (Kind and Wardlaw, 1979). This phenomenon can cause very serious damage to the roofing system, such as dislocation of concrete "pavers" or insulation boards. It is also known that some architectural features of the building, such as parapets, varying in height, have some influence on these phenomena (Baskaran, 1986). At the same time, wind tunnel testing of this situation is a challenging task because the extent of damage depends a lot on the structural details, which can hardly be modeled properly in a reduced scale.

Since the early 1970s, several wind tunnel studies have focused on this issue, and there are commonly observed difficulties in modeling the structural details (Kind, Savage & Wardlaw 1988). Wind tunnel testing of a full-scale building, on the other hand, would be nearly impossible. By taking advantage of a very large test section of the 9m x 9m wind tunnel at the National Research Council of Canada (NRCC), Kind and Wardlaw carried out a series of comprehensive studies of the wind effects on a variety of roof assemblies during the period of 1975-1990. These formed the basis for several roofing standards internationally.

In wind tunnel studies, models had rigid roofs, and their deformation due to wind suction was assumed negligible. However, in a mechanically attached single ply roof, the membrane may oscillate once high suction is applied, which in turn may give a different wind-induced pressure distribution. Another engineering concern is the structural detail of how the roofing system is installed on the building. In order to examine these points, a pilot study was carried out. This paper reports benefits of the use of full-scale roof component materials for the wind tunnel tests of such roof sections.

EXPERIMENTS

The models used for this series of tests are 1/10 in linear scale and equipped with full-scale roof component materials, as shown in *Figure 1*. All tests were conducted at the 9m x 9m wind tunnel. Two different types of roofing membranes were used for

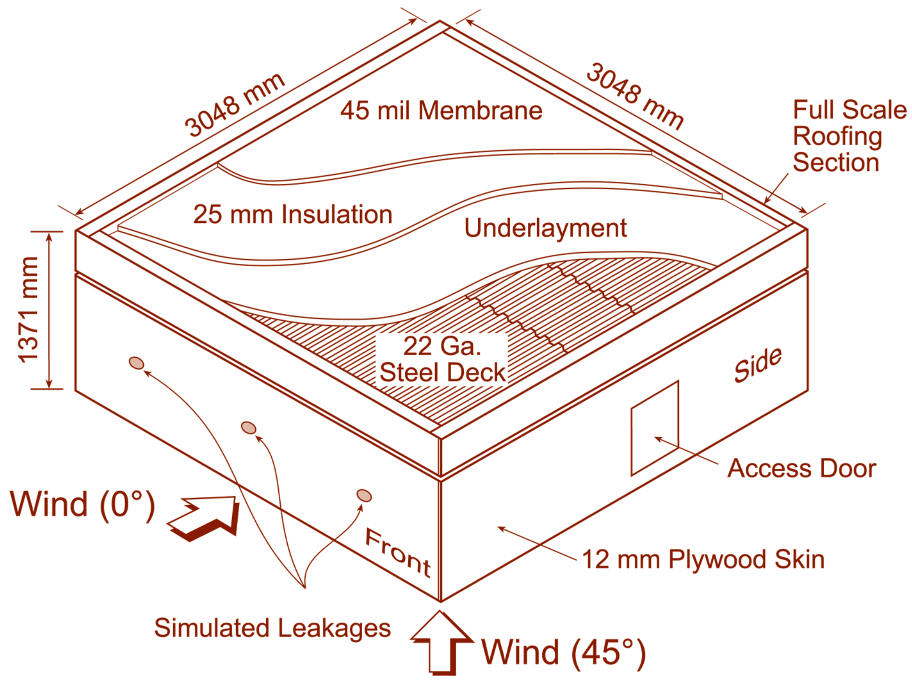

Figure 1: Roof assembly module with full-scale components.

this experiment; one is a reinforced polyvinyl chloride (PVC) membrane and the other is a non-reinforced membrane made of ethylene propylene diene monomer (EPDM). Physical, mechanical, and chemical properties of these two membranes are significantly different (Baskaran, Paroli & Booth, 1997). This is because PVC is a thermoplastic polymer, whereas EPDM is a rubber-based thermoset material.

A typical mechanical property of these membranes is shown in *Figure 2*, which compares the stress-strain behavior of two materials under the same tensile stress rate. The PVC membrane has significantly higher breaking load compared to EPDM. However, due to its reinforced nature, it can stretch only about 1/8 as much as EPDM.

Differences between two roofing assemblies used in the wind tunnel study are summarized in *Table 1*. The membranes were equipped with 89 and 100 special pressure taps for PVC and EPDM models, respectively, in a manner to minimize their influence on the mechanical properties of membranes. For both roof configurations, the influence of wind speed and direction and building height on wind pressure were examined. Details of the wind simulation are found elsewhere (Savage *et al.*, 1997; Baskaran et al. 1996).

COMPONENT	PVC	EPDM
Membrane	45 mil (≈1.14 mm) thick	45 mil (≈1.14 mm) thick
	Reinforced	Non-reinforced
	Spot fastener	Bar attachment
	Two perimeter (900mm) sheets Two field (1800mm) sheets	One sheet
	Seams hot air weld	Factory seam
Insulation	25 mm ISO	25 mm XEPS
Underlayment	6 mil (0.2 mm) vapor barrier	6 mm support board
Deck	22-gauge steel	22-gauge steel
Total of tested configurations	30	48

Table 1: Differences between PVC and EPDM roof assemblies

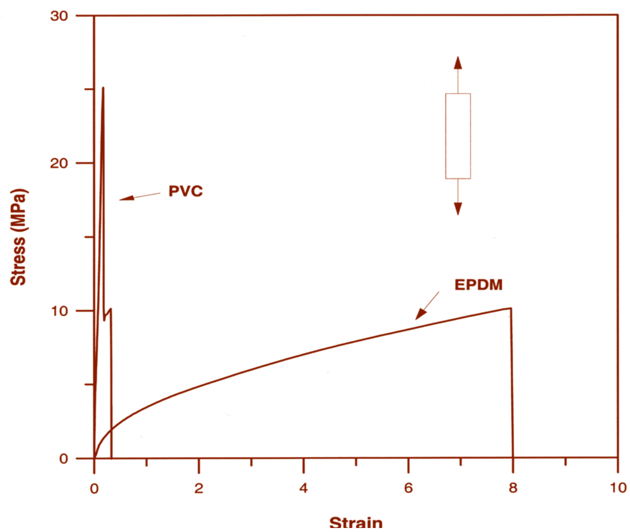

Figure 2: Mechanical property of typical membranes.

RESULTS AND DISCUSSION

Figures 3 and *4* compare the PVC and EPDM system response. They present an overall pattern of the mean pressure distribution for wind approaching normal to the building side and for the 45° skewed wind for each of the PVC and EPDM cases. High suction near the up-wind corner and moderate pressure distribution for the rest of the roof are commonly observed for both systems. The characteristic “horse-shoe” vortex zone for the 45° wind case is again clearly identified. These features are similar to the previous wind tunnel studies on rigid models.

Wind-induced suction over the assembly results in membrane deflection between the attachments to the roof deck. As indicated in *Table 1*, the PVC roof is composed of four sheets that are attached to the structural deck using mechanical fasteners. These four areas are referred to as S1, S2, S3, and S4 in *Figure 3*. During wind tunnel investigations, four zones of membrane ballooning were noticed. For the PVC roofs, maximum deflection was observed at the sheet S3, which is wider than S1and S2 and it is not restrained along its edges as it is in S4.

For the roofs with non-reinforced EPDM membrane, measured deflections were much higher than the PVC roofs. It is critical to note that the observed pressure distribution pattern was totally

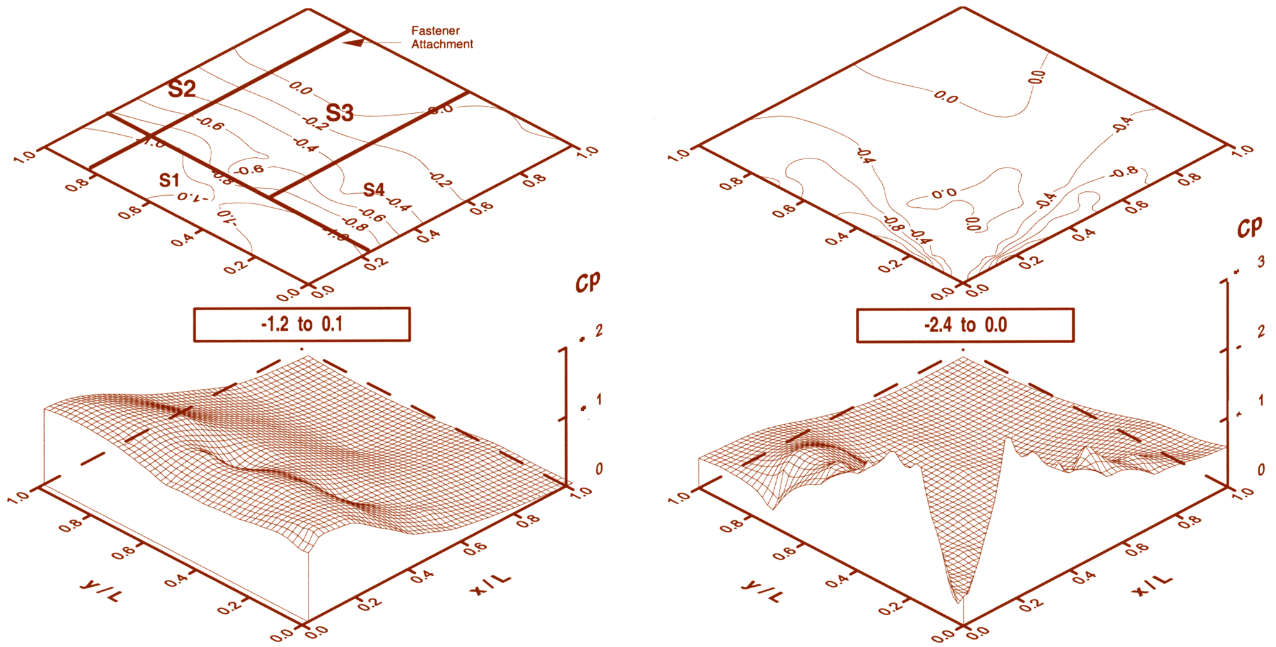

Figure 3: Mean pressure distribution with PVC roof membranes.

different from the deflected shape of the membrane. This indicates that neither the number of sheets used nor the way the membranes are attached to the roof deck had any significant influence on the wind-induced mean pressure distribution patterns. This also indicates that the deflected shape stays inside of the low pressure separation bubble, and it does not influence the mean pressure distribution.

EPDM roofs generally experienced higher mean suction than the PVC roofs for the same wind conditions. Maximum measured mean suction coefficient for EPDM was -4.5 compared to that of -2.4 for the system with PVC membranes. Also, the spatial distribution is different between the two cases. For the normal wind, as shown in *Figure 3*, the measured pressure is about -0.5 when x/L = 0.4 in the case of the PVC roofs. For the same location, the EPDM roof experienced -0.9 *(Figure 4)*. Positive pressure on the roof assembly indicates reattachment of the separated flow over the roof surface. *Figures 3* and *4* indicate longer distance before the reattachment for the case of PVC roofs compared to EPDM roofs.

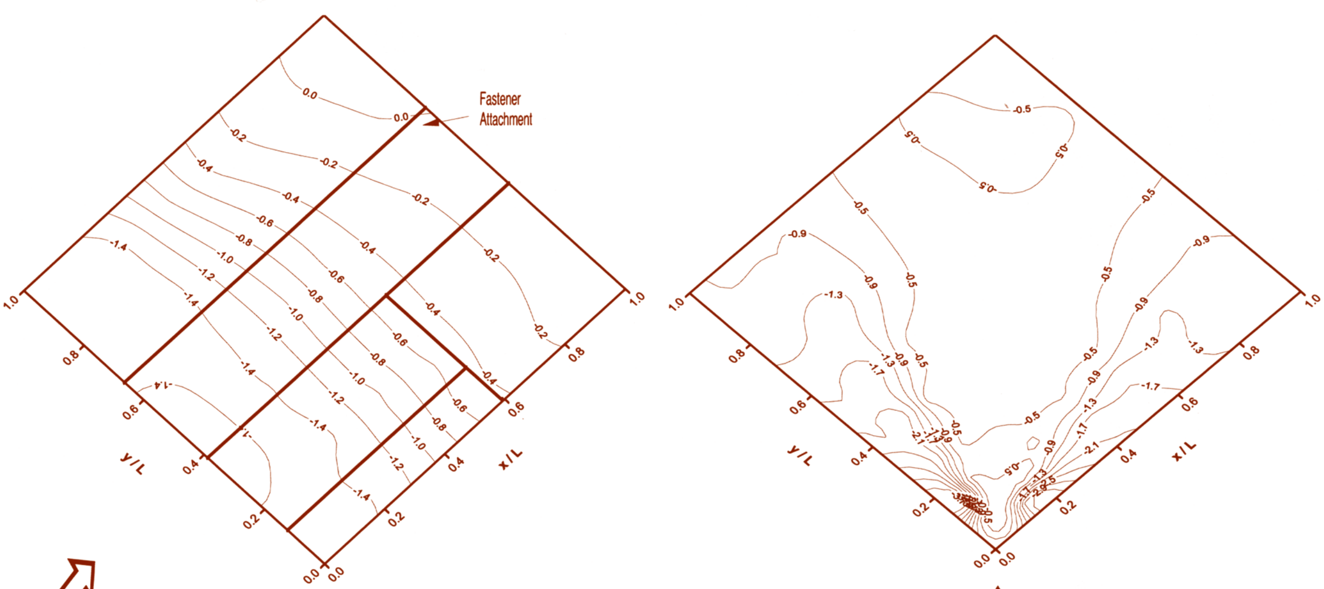

Figure 4: Mean pressure distribution with EPDM roof membranes.

-1.6 to 0.0

-4.5 to 0.0

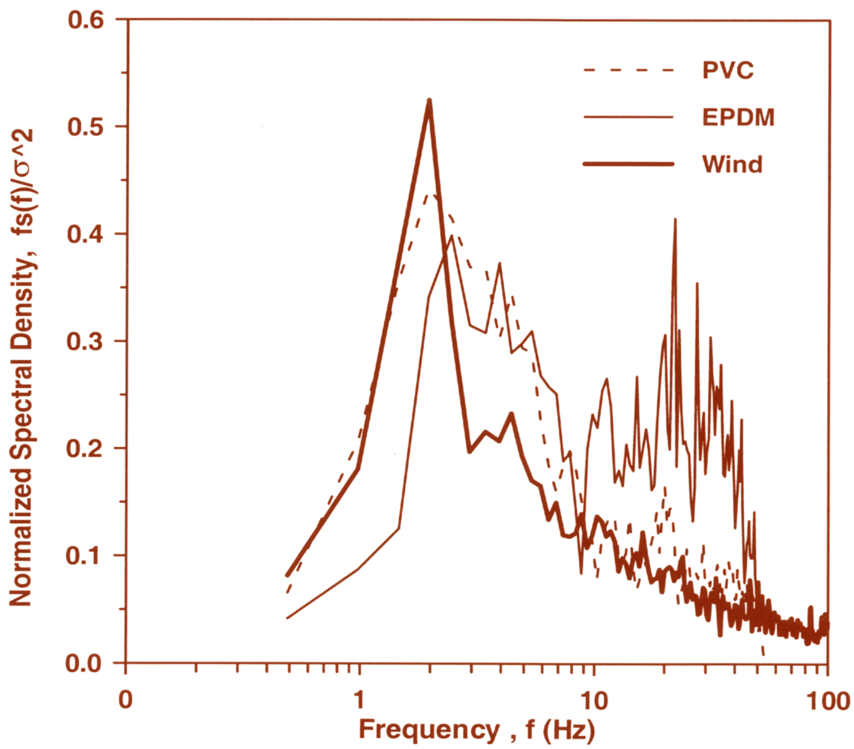

Figure 5: Comparison of pressure spectra from the PVC and EPDM roof assemblies.

In order to help understand the difference of wind effects between the two roofs, spectral analyses were performed on the pressure time histories. *Figure 5* shows the normalized spectral density of typical pressure records with PVC and EPDM roofs, measured at the perimeter region. A low-pass filter with cut-off frequency of 50 Hz was used to eliminate high-frequency noise that existed with the pressure records. The spectral density function of the approaching wind is also included for comparison.

Three distinct response regions have been noticed at three different frequency bands as follows:

1) Up to a frequency of about 2 Hz, the approaching wind and PVC record show similar energy distribution. In comparison to this, the EPDM record has less energy in the same frequency range.
2) For the frequency of 2 to 10 Hz, both PVC and EPDM have similar energy distribution, which is also higher than the energy of the approaching wind.
3) For frequencies above 10 Hz, the energy content of EPDM is much higher than that of the approaching wind or the PVC. This is due to the fact that a flexible membrane of EPDM exhibits more fluttering compared to less flexible PVC membrane. The fluttering vibration is caused by the approaching wind.

To identify the effects of membrane motion on the induced surface pressures, the above analysis could be extended to develop the concept of a transfer function. This provides the ratio of membrane response pressure to the applied flow pressure fluctuations as measured on rigid roof pressure models at each particular frequency.

The transfer function developed as such could be used for the correction of pressure readings measured on rigid roof models to include the membrane vibration effects. The success of this approach could open up a much larger and more general database for analyses useful for the design of roofing systems.

CONCLUSIONS

Wind tunnel studies were also carried out with the models on full-scale roof component materials. Flexible roof membranes could change the geometrical shape of the roof under suction and the resultant shape varies depending on the direction of approaching wind and the materials, and layout of the membrane attachments to the deck. However, the overall mean pressure distribution pattern on flat roofs was found to not be significantly influenced by the materials. This provides the possibility of introducing a transfer function to take the dynamic effects of membrane vibration into account as a correction factor applicable to the measured results from rigid flat roof models. ■

REFERENCES

Baskaran, A., *Wind Loads on Flat Roofs with Parapets,* M.Eng. thesis, Concordia University, Canada, 1986.

Baskaran, A., R.M. Paroli, and R.J. Booth, "Wind Performance Evaluation Procedures for Roofing Systems: Current Status and Future Trends," *Proceedings of the 5th International Conference on Building Envelope Systems & Technology,* Bath, U.K: 37-54, 1997.

Baskaran, A., M.G. Savage, F. Alfawakhiri, and K.R. Cooper, "Pressure Distribution Data Measured During the October 1995 Wind Tunnel Tests on a Mechanically Attached EPDM Single Ply Roofing Systems," LTR-A-004, National Research Council Canada, 1996.

Kind, R.J., M.G. Savage, and R.L. Wardlaw, "Prediction of Wind-induced Failure of Loose-laid Roof Cladding Systems," *Journal of Wind Engineering & Industrial Aerodynamics,* 29: 29-37, 1988.

Kind, R.J. and R.L. Wardlaw, "Model Studies of the Wind Resistance of Two Loose-laid Roof Insulation Systems," LTR-LA-234, National Research Council Canada, 1979.

Melbourne, W.H., "Wind Tunnel Blockage Effects and Corrections," *Wind Tunnel Modeling for Civil Engineering Applications,* Cambridge University Press: 197-216, 1982.

Savage, M.G, K.R. Cooper, and A. Baskaran, "Wind Tunnel Investigation of the Wind Loads on a Single Ply Mechanically Attached PVC Roofing System," LTR-A-012, National Research Council Canada, 1997.

ACKNOWLEDGEMENTS

The authors acknowledge the technical insight provided by Dr. D. Surry on *Figure 5.* The discussion and encouragement toward the project by Mr. R.L. Wardlaw are greatly appreciated. The presented research is being carried out for a consortium: Special

Interest Group for Dynamic Evaluation of Roofing Systems (SIGDERS). SIGDERS was formed from a group of partners who were interested in roofing design. These partners included: *Manufacturers* - Atlas Roofing Corporation, Canadian General Tower Ltd., GAF Materials Corporation, GenFlex Roofing Systems, Firestone Building Products Co., IKO Industries Ltd., Johns Manville, Sarnafil, Soprema Canada, and Stevens Roofing Systems. *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, Industrial Risk Insurers, National Roofing Contractors' Association, and Roof Consultants Institute. *Research Agencies* - Institute for Research in Construction, Institute for Aerospace Research, and Canadian Construction Material Centre.

Part of this paper was published originally at the 10th International Wind Engineering Conference.

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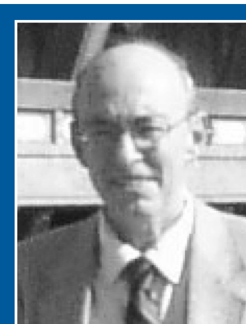

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M.G. Savage is a Research Officer for the Separated-flow Aerodynamics group at the National Research Council of Canada, Institute for Aerospace Research (NRC/IAR). His experience is in the field of wind engineering and his activities have involved wind tunnel studies to determine the effects of wind on several engineering structures. His focus has been the aerodynamics of bluff bodies and the effects of these aerodynamic forces on the dynamic stability and response to unsteady wind loads over a broad range of applications. Research projects have included experimental studies on building aerodynamics, wind uplift loads on flat roofs, power lines, and aeroelastic stability of long-span bridges. He has been involved in international collaborative research programs that have involved working in wind tunnels in Japan. Savage received his bachelor's degree in mechanical engineering from the University of Ottawa, Canada.

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