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New Design Procedure for Wind Uplift Resistance of Architectural Metal Roofing Systems[1]

A. Baskaran[2]; H. Ham[3]; and W. Lei[4]

Abstract: Currently, there are no Canadian national guidelines for the wind uplift resistance of architectural metal roof systems. Thus, it is difficult to judge their suitability and performance based on a common standard. Given the increasing use of metal roofs, it has been determined that there is a need for the development of a design guide, that would be applicable to all regions of Canada. Metal roofs can be classified into two groups: Structural and architectural. This paper focuses on the wind uplift performance of architectural metal roof systems. Several parameters influence the wind uplift performance of the architectural metal roofs. This study finds that air leakage of the structural deck is one of the significant factors that influences the wind uplift performance. This is based on experimental investigations carried out at the Dynamic Roofing Facility of the National Research Council of Canada, using the Special Interest Group on Dynamic Evaluation of Roofing System dynamic wind test protocol. Architectural roofing panels with three different types of commonly used, seam-interlocking mechanisms (joint details) were investigated. It has been noted that the resistance to wind uplift pressure increases dramatically as the air leakage ratio decreases. A modeling method is also described which quantifies system response by simulating the wind gusts over roof specimens with different leakage ratios that can represent field assemblies. The 1995 National Building Code of Canada was utilized for the estimation of the wind-induced loads and the present study provided extensive experimental data for various systems with each type of seam detail. Based on this analysis, a simplified design procedure was developed. The simplified procedure is presented through case studies of metal roof assemblies located in the Canadian provinces of British Columbia, Ontario, and Quebec.

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CE Database subject headings: Roofs; Metals; Dynamic tests; Leakage; Building codes; Design criteria.

Introduction

Use of metal as a waterproofing roofing material goes way back to the Roman Empire. In the early 1800s roofers started experimenting with tinplate, which was less expensive than the other materials such as copper, zinc, etc. With more experimental research done, in the mid-1900s corrugated, galvanized, metal sheets were mass produced and became a popular alternative to tinplate for industrial, agricultural, and commercial roofing. Generally, metal roofs can be categorized into two main categories: Structural and architectural. The structural panels are used on low-sloped roofs and are installed directly on the purlins. In those scenarios the panels perform both the structural and waterproofing functions of a roof. The most common structural panels are the standing seam panels that are used on nonresidential buildings. The architectural metal roofing panels are installed mainly on steeply pitched roofs, generally on a minimum slope of 3:12 (ratio of vertical to horizontal) to ensure proper water run-off. Installations of the composite roof assemblies are quite different from the structural systems. The architectural panels are installed over a wood or steel deck or, in some applications, directly over an existing roof.

Metal panels installed on a roof are subjected to various levels of wind dynamics during their lifetime. Wind-induced dynamic effects cause the panels to deflect and introduce stresses at the attachment locations. Fig. 1 illustrates the interaction of the wind with the metal panels. As shown in Fig. 1, the metal panels are placed as rooftop cover and attached to the wooden deck with a variety of clip attachments. The metal panels are joined by different types of locking mechanisms. Wind-induced suction lifts the metal panel between the seams (joints). The magnitude of the wind-induced suction and the type of metal panel attachment determines the wind uplift resistance of the system. Also as shown in Fig. 1, each component offers certain resistance to wind uplift force and this can be represented through a *force resistance link* diagram (i.e., a load path diagram). All resistance links should remain connected for the roofing system to stay in place. Failure occurs when the wind uplift force is greater than the resistance of one or more of the resistance links.

International provisions [North American specification (ANSI 2001; ASTM 2002), European provisions [EUROCODE 3 Commission of the European Communities (1992)], and Australian (AS/NZS 1996)] are mainly focused on the fixing (attachment) mecha-

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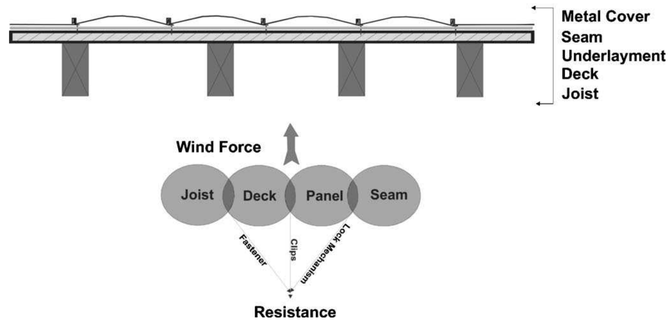


Fig. 1. Wind effects on metal roofing systems

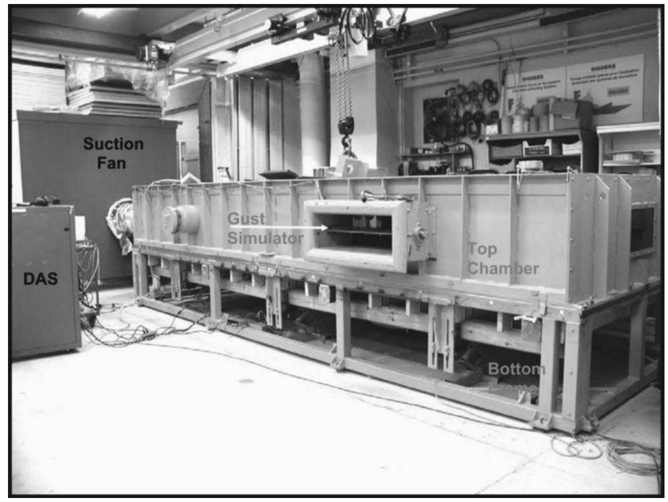


Fig. 2. Dynamic roofing facility

nisms of the structural roofing systems. A number of researchers have investigated the structural performance of metal roofs under static conditions (Mahendran 1990, 1997; Meyers et al. 1990; Schroter 1985). Currently there are no national or international guidelines or standards for the wind uplift resistance of architectural sheet metal roofing systems. Thus, it is difficult to assess the performance of an architectural metal roofing system based on an accepted design method for determining wind uplift resistance. Given the increasing use of architectural metal as roof covers [market shares are up from 3 to 7% (Cullen 1993)], there is a need to develop a technical guide for the wind resistance of architectural metal roof systems that would be applicable to all regions of Canada.

This paper presents the research work being carried out for the development of an overall test method and design procedure for evaluating the wind uplift resistance of architectural metal roofing systems. A modeling method is also described that quantifies system response by simulating the wind gusts over roof specimens with different leakage ratios that can represent field assemblies. The National Building Code of Canada (NRC 1995) was utilized for the estimation of the wind-induced loads and the present study provided extensive experimental data for system resistance data. Based on this analysis, a simplified design procedure was developed. The simplified procedure is presented through case studies of architectural metal roof assemblies located in the provinces of British Columbia, Ontario, and Quebec.

Experimental Approach

Dynamic Roofing Facility

All experimental work for the present investigations was carried out at the Dynamic Roofing Facility (DRF) established at the National Research Council of Canada (NRC/IRC). The DRF is shown in Fig. 2 and the features of the facility are provided by Baskaran and Lei (1997). The DRF consists of a bottom frame of adjustable height, upon which the roof specimens are installed, and a movable top chamber. The bottom frame and top chamber are 6,100 mm (240 in.) long, 2,200 mm (86 in.) wide and 800 mm (32 in.) in height. Wind suctions as high as 20 kPa (≈420 psf) over the roof assembly are produced by a 75 kW (100 HP) fan with a flow rate of 2,500 L/s (5,300 cfm). A computer uses feedback signals to control the operation of the DRF. To monitor the response of the roof system, typical design parameters such as pressure, force, and deflection were measured.

Dynamic Wind Test Protocol

A Special Interest Group for Dynamic Evaluation of Roofing Systems (SIGDERS) has been established at the NRC to develop a test standard for evaluating roofing systems under dynamic conditions. The SIGDERS dynamic load cycle was developed based on extensive wind tunnel studies. The procedure used for the development of the wind loading sequence can be found in Baskaran et al. (1999). The dynamic load cycle represented in Fig. 3 includes eight loading sequences in which a roof system is subjected to simulated gusts. To evaluate the ultimate strength of the roofing system, testing begins at Level A which uses a maximum test pressure of 90 psf. If all the resistance links (Fig. 1) remain connected, the roof is considered to have "passed" and obtains Level A rating. Testing then proceeds to the next level, where the maximum pressure is increased by 25% of Level A's maximum test pressure (see Fig. 3). For all the investigations in this study, this dynamic load cycle was applied.

Experimental Investigations

Investigated Panel Configurations

Twenty metal panel roofing systems having three different interlocking mechanisms were investigated. Details of the experimental procedure and system response for various induced loading conditions are documented by Ham and Baskaran (2000, 2001a). Only salient features are highlighted below. Cross-sectional representations of a typical test assembly and details of the three different attachment mechanisms are shown in Fig. 4.

- ***SNAP LOCK 2***: Fig. 4(a) shows details of the panel edges, which consist of a male leg on one side and a female flange on the other. The male rib height is 44 mm (1 3/4 in.) and width of panel is 457 mm (18 in.). The male leg of the panel is attached to the deck with *Clert Series 2000* clips. The clip is 44 mm (1 3/4 in.) high, 89 mm (3 1/2 in.) long and 38 mm (1 1/2 in.) wide. Two No. 12×1 in. pancake head fasteners were used per clip to attach the panels to the deck. The spacing of the clip varied from 457 to 610 mm (from 18 to 24 in.)

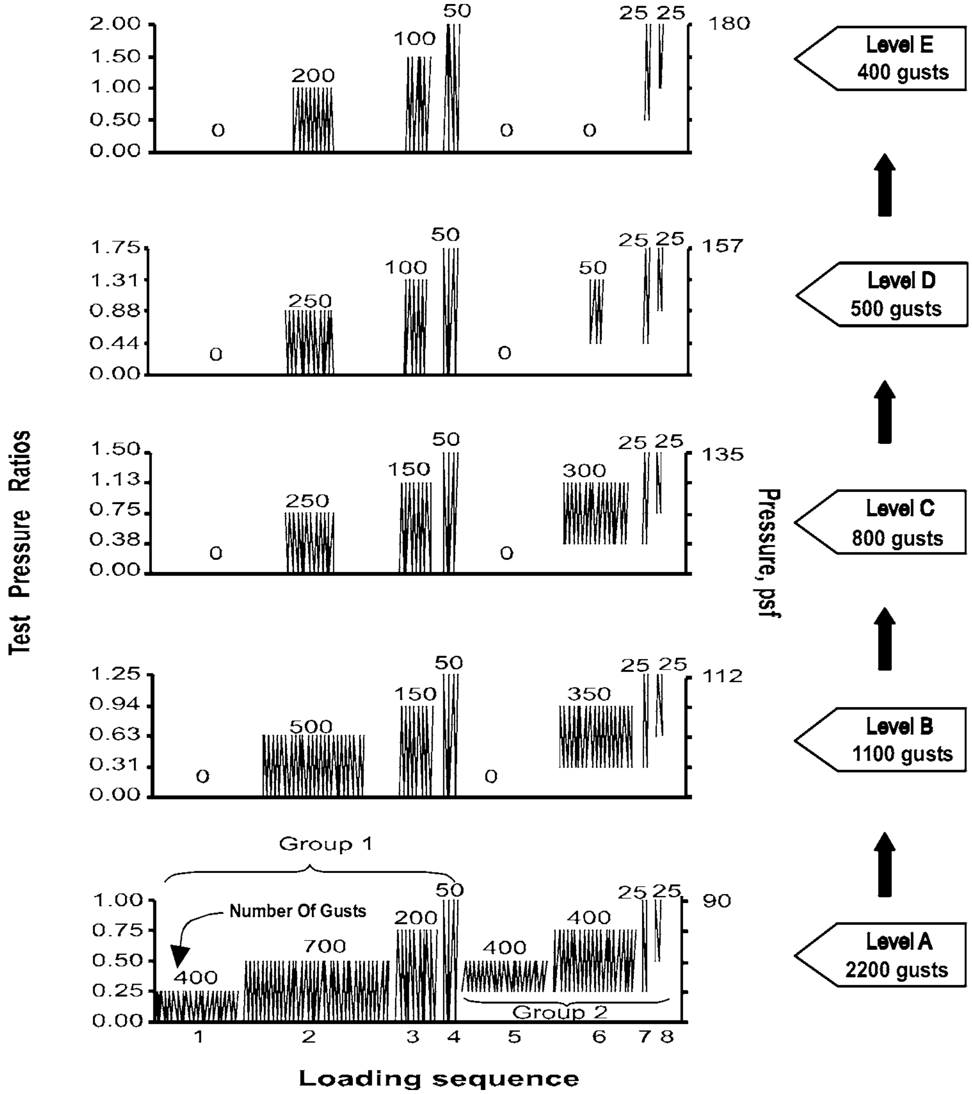


Fig. 3. SIGDERS wind load cycle

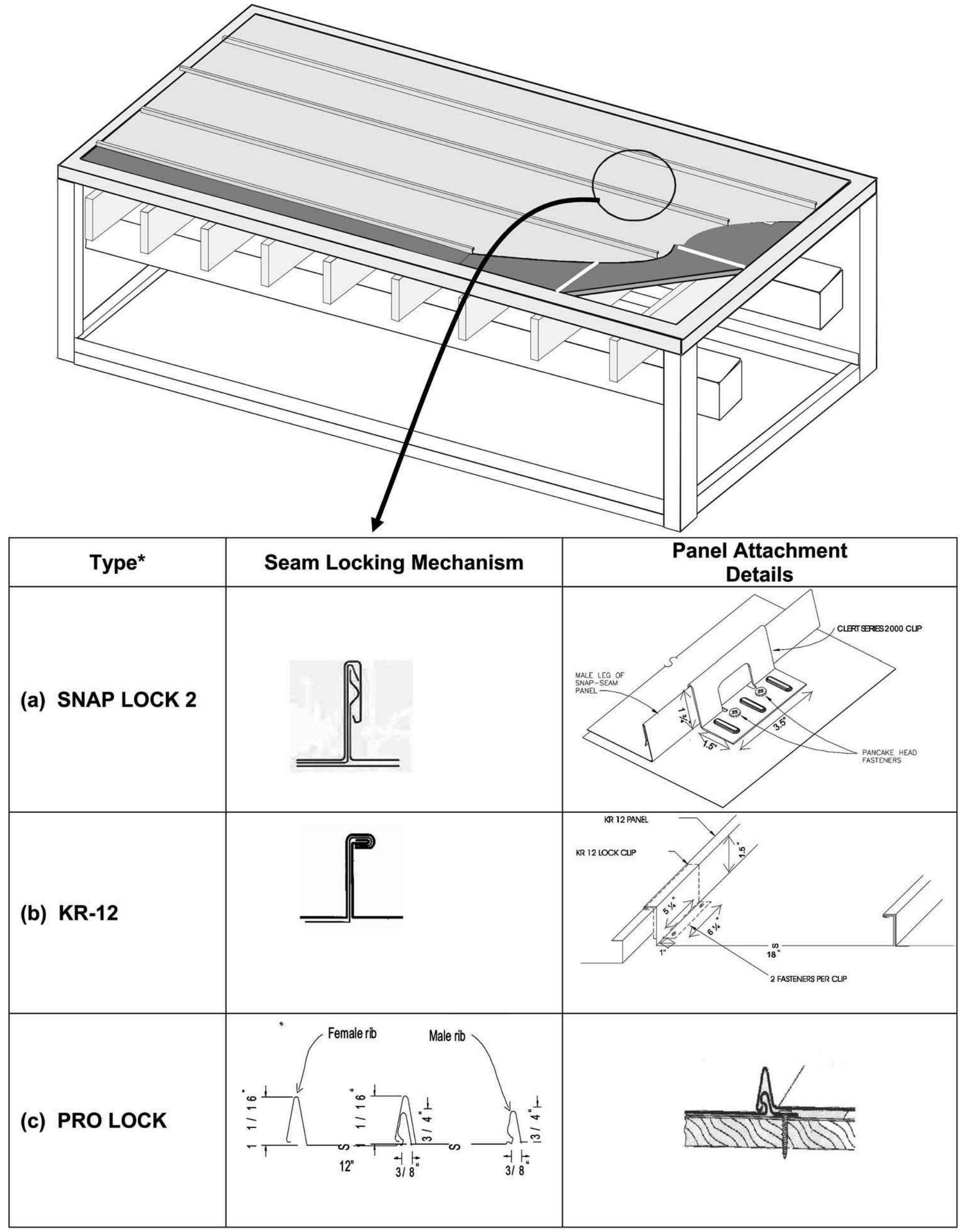
depending on the system tested. Once the male leg is attached, the female leg of the adjacent panel is placed over the male leg and the two legs snap together to provide the interlocking joint mechanism.

- ***KR*-12**: Fig. 4(b) illustrates the KR-12 panel, which has a rib height of 38 mm (1 1/2 in.). Within the locking mechanism, the KR-12 panel is attached to the deck using the KR-12 lock clip, which has dimensions of 38 mm (1 1/2 in.) height, 159 mm (6 1/4 in.) length, and 25 mm (1 in.) width. Two No. 12×1 in. fasteners are used per clip to attach the panel to the deck. The clip spacing is 305 mm (12 in.), 457 mm (18 in.), or 610 mm (24 in.), depending on the system tested. The edge of another panel is then engaged with the previously anchored edge of the first panel and a mechanical seaming machine locks the seam securely.
- ***PROLOCK***: Fig. 4(c) depicts the locking mechanism, which consists of a female flange of 27 mm (1 1/16 in.) height and a male rib of 38 mm (3/4 in.) height. The male rib of the panel is attached to the deck using *Phillips* head No. 8×1 in. fasteners. These fasteners are placed at a spacing of 342 mm (13 1/2 in.) along the male side of the panel's fastening flange. The female flange is then aligned over the male rib and, by using a rubber hammer, the female edge is snapped onto the male edge, thus engaging the edges of adjacent panels.

Simulated Deck Conditions

The performance of a metal roofing system under wind loading can be influenced by several factors, with air tightness of the deck being one of the most important parameters. The air tightness of the deck was represented in terms of the air leakage ratio, which is defined as the ratio of the leakage area to the deck area. Additional details of the air leakage calculations can be found in Ham and Baskaran (2001b). In the present study, the air tightness of the deck was investigated by simulating three groups of deck conditions, namely:

- **Group 1: Airtight Deck Condition**: The airtight deck condition was simulated by using five sheets of 16 mm (5/8 in.) tongue-and-groove plywood sheets installed over 51 mm ×254 mm (2 in.×10 in.) joists, as shown in Fig. 5.
- **Group 2: Air Permeable Deck Condition**: Different air leakage ratios were simulated as follows:
  1. Field conditions were simulated by using the H-clip attachment in between the plywood deck sheets. These sheets, 13 mm (1/2 in.) thick, were installed over the 51 mm×254 mm (2 in.×10 in.) joists. The spacing be-



* All sheet panels are 24 Ga (0.76mm) thick steel metal

Fig. 4. Typical test assembly and attachment details

tween the plywood sheets, created by the H clips, provided the pathway for airflow.

2. The air leakage path created by the H clips was further blocked by applying caulking strips at preferential locations, thereby reducing the air leakage ratio.
3. Using tongue-and-groove plywood deck and making 12 mm (1/2 in.) diameter holes in the wooden deck.
4. Using 12 mm (1/2 in.) plywood deck and fastening the sheets to 51 mm × 203 mm (2 in. × 8 in.) joists and making square holes of 100 mm (4 in.) wide in the deck.

A typical layout of an air-permeable deck condition with air leakage ratio, A_L, of 0.14% is shown in Fig. 6. As can be seen from the layout, 5 pieces of 12 mm (1/2 in.) plywood were used in the deck arrangement. H clips were used between the plywood sheets in such a way that there were two gaps of 2 mm (0.08 in.) between the plywood attachments. Air leakage is allowed along these gaps. The sample calculation for air leakage ratio is also given in Fig. 6.

- **Group 3: Air Permeable Deck Condition With Underlayment**: As shown in Fig. 7, either peel-and-stick sheets or No. 30 organic saturated felt papers were used as an underlayment between the wooden deck and metal panels. Within this group, the air leakage ratios ranging from 0.08 to 0.18% were simulated and investigated.

Results and Discussion

As mentioned, 20 experiments (Systems 1–20) were done using the three different panel types and simulating various leakage conditions of the deck. For most of the systems, more than one

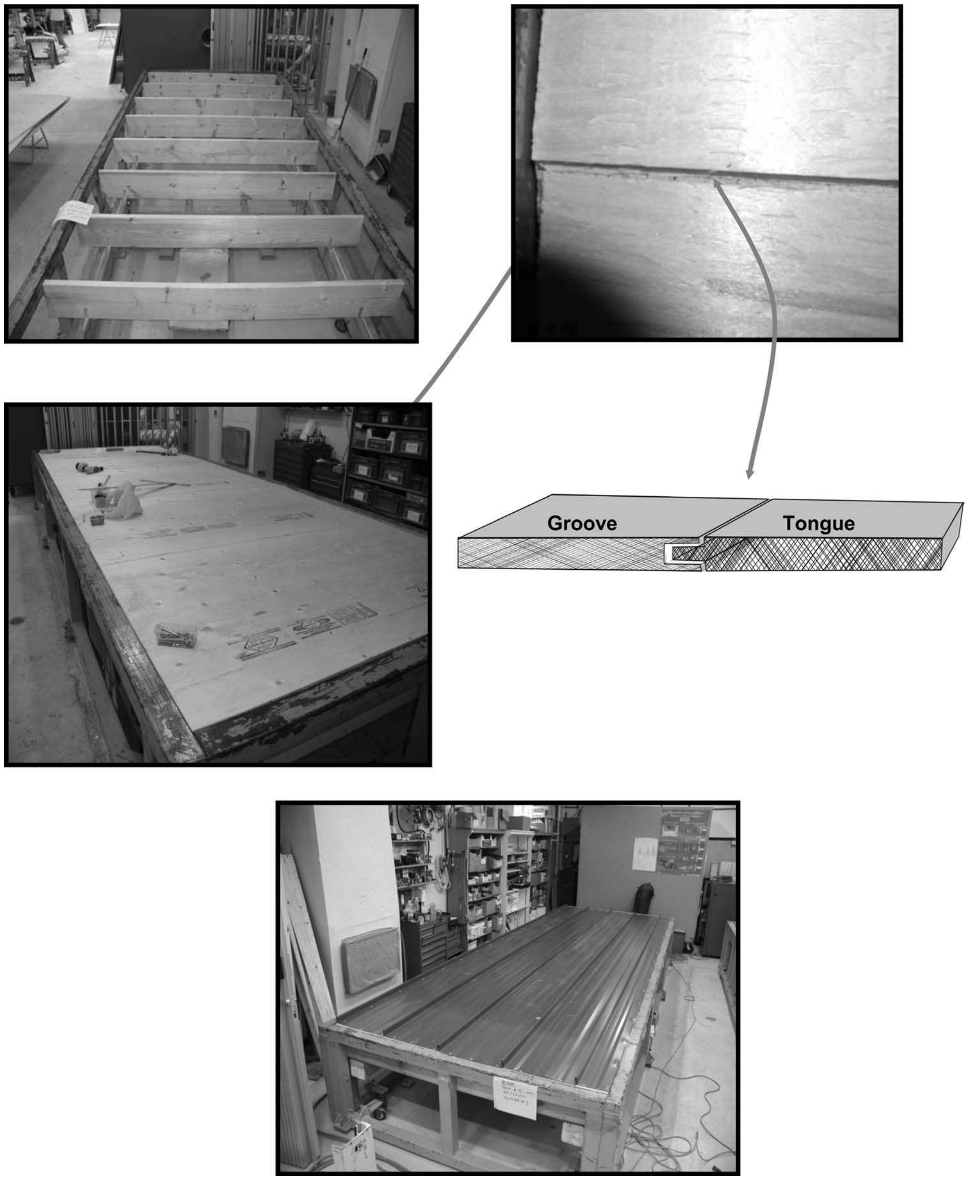


Fig. 5. Typical layout of the airtight deck condition

specimen was investigated. The calculated leakage ratios for each system configuration and the corresponding panel type are summarized in Table 1. For each system configuration, sensors were installed at selected locations, to measure the system's response during wind testing. Time histories of the applied pressure and induced load on the fasteners, as well as the deflection of the panel, were collected and analyzed (Ham and Baskaran 2000, 2001a). The data obtained from different configurations are summarized in three groups as shown in Fig. 8. It is evident that the air leakage of the deck is one of the significant factors for influencing the wind uplift rating of the system.

1. In Group 1, it was observed that for the airtight deck conditions ($A_L=0\%$), the KR-12 metal panel showed a better wind uplift resistance when compared to the PROLOCK metal panel system. The measured load on the KR-12 metal panel system was high compared to the PROLOCK system and this may be attributed to the wider (406 mm compared to 305 mm) panel size of the KR-12 metal panel system. With constant clip attachment spacing as panel width increases, the tributary area increases as such the panel resistance to load decrease.
2. In Group 2, the data can be divided into two sets, $A_L < 0.1\%$ and $A_L > 0.1\%$. For the first set of $A_L < 0.1\%$, the tested systems behaved more like the systems in Group 1 (airtight deck conditions) with all metal roofing systems exhibiting high wind uplift resistances which were in excess of 4,788 Pa (100 psf). However, a variation in the measure loads was observed. In the second set, with $A_L > 0.1\%$, it is evident that there are dramatic decreases in the wind uplift rating when the A_L ratio increases from 0.1% to higher values. All these systems failed below 2,154 Pa (45 psf) and the measured failure load decreased with the increase of A_L ratio for the same panel type.
3. In Group 3, the main objective was to see the influence of the underlayment on the systems having air leakage. It was observed that systems with peel-and-stick as underlayment performed better than systems with felt paper as underlayment. The performance of systems with peel-and-stick as underlay-

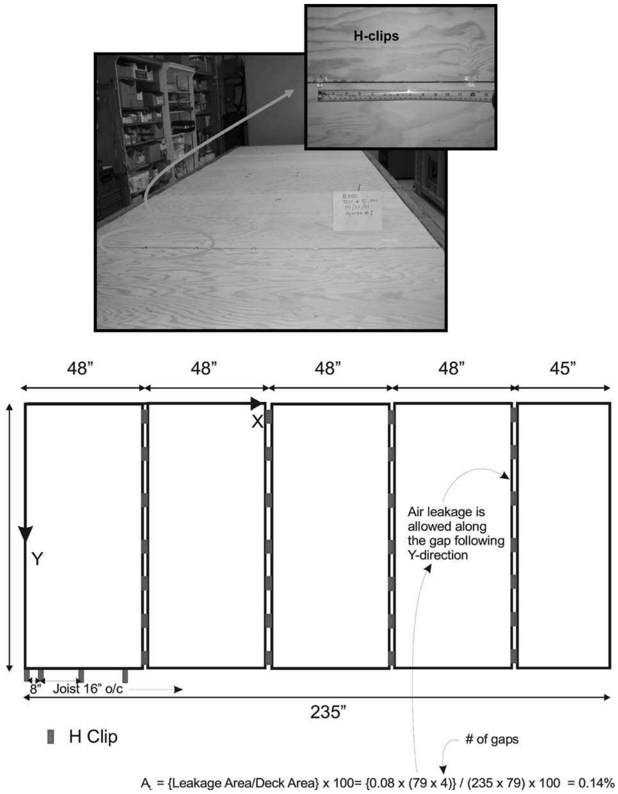


Fig. 6. Typical layout of the air permeable deck condition and calculation of leakage ratio

ment were similar to the airtight configuration in achieving wind uplift rating. Nevertheless, once again the leakage ratio played a major role in influencing the wind uplift resistance. It appears from this data that despite differences in the panel configuration or other parameters, a significant effect on the wind uplift rating results from differences in air leakage ratio A_L.

Failure modes of the systems were also investigated after the wind test. Typically, three different failure mechanisms were observed according to the three different deck conditions (Baskaran and Ham 2003). Systems from the Group 1 with airtight deck conditions failed because the net load on the deck exceeded the strength of the deck-to-joist connection. In other words, the fastener attachment of the deck pulled out from the joist. In the case of the Group 2 systems with an air-permeable deck condition, panel seams opened or separated during wind testing. The weakest link of this group is the seam-locking mechanism of the metal panels. For the Group 3 configurations with felt papers as underlayment, the observed failure mechanism was panel fastener pullout from the wooden deck and tearing of the underlayment. This preliminary failure triggered the panel seam opening as a secondary failure. Although the Group 3 systems with peel-and-stick as underlayment also had the same failure mechanism, in addition deck pullout from the joist was also observed in one system.

Simplified Design Procedure

Currently there are no Canadian guidelines for the wind uplift resistance of metal roof systems. One of the main objectives of the present experimental investigation is the development of a simplified design procedure that can be used by practicing engineers. The proposed simplified procedure uses the National Building Code of Canada (NRC 1995) for wind uplift load calculation, experimental information as resistance data, engineering directives, and inputs from industrial clients for case study formulation. Moreover, the development of a simplified procedure requires several levels of generalization of the true wind-induced effect over a roof assembly. Often, these generalizations warrant compromise from the technically sound approach to the practically acceptable procedure. Similar simplified design procedures developed in the past (Kind and Wardlaw 1976) for ballasted roof assemblies were received well by all parties concerned with roofing, including researchers, manufacturers, roofing associations representing the contractors, and building owners. As presented, the procedure is applicable to three provinces of Canada (British Columbia, Ontario, and Quebec) and it can be extended to other provinces on as-needed basis. It is a five-step procedure as follows:

1. Calculate roof cover design pressure;
2. Estimate wind uplift design pressure;
3. Select reduction factor for air permeable deck conditions;
4. Identify a suitable system with required resistance; and
5. Correlate uplift pressure with resistance.

Step 1: Calculate Roof Cover Design Pressure

The roof cover design pressure calculation is shown as a flowchart in Fig. 9. As shown, first the designer identifies the province and region in that province for the location of the building using Fig. 10. Then based on the building height, design suction pres-

Fig. 7. Typical layouts of the air permeable deck condition with underlayment

Table 1. Summary of the Tested Assemblies and Wind Uplift Ratings

Group	System	Panel type/name	A_L(%)	Panel width (mm)	Panel width (in.)	Clip spacing (mm)	Clip spacing (in.)	Sustained clip fastener load (N)	Sustained clip fastener load (lbf)	Sustained uplift pressure (Pa)	Sustained uplift pressure (psf)	Failure mode
1	1	KR-12	0	406	16	610	24	1,848	420	5,746	120	FM1
2	2	KR-12	0.03	457	18	610	24	1,408	320	5,746	120	FM2
2	3	KR-12	0.09	508	20	457	18	686	156	5,410	113	FM2
2	4	KR-12	0.27	457	18	457	18	224	51	1,101	23	FM2
2	5	KR-12	2.4	508	20	508	20	356	81	718	15	FM2
2	6	KR-12	2.4	305	12	305	12	656	149	1,436	30	FM2
2	7	KR-12	2.4	305	12	305	12	—	—	2,155	45	FM2
1	8	PROLOCK	0	305	12	305	12	1,540	350	5,410	113	FM1
2	9	PROLOCK	2.4	305	12	305	12	774	176	2,155	45	FM2
3	10	PROLOCK-F	0.08	305	12	305	12	330	75	2,155	45	FM3
3	11	PROLOCK-F	0.11	305	12	305	12	726	165	3,256	68	FM3
2	12	SNAP LOCK 2	0.09	457	18	457	18	1,056	240	6,464	135	FM2
2	13	SNAP LOCK 2	0.13	457	18	457	18	585	133	2,155	45	FM2
2	14	SNAP LOCK 2	0.14	457	18	457	18	554	126	2,155	45	FM2
2	15	SNAP LOCK 2	0.18	457	18	457	18	427	97	2,155	45	FM2
2	16	SNAP LOCK 2	2.4	457	18	457	18	1,012	230	2,155	45	FM2
3	17	SNAP LOCK 2-F	0.11	457	18	305	18	554	126	2,155	45	FM3
3	18	SNAP LOCK 2-F	0.18	457	18	305	18	563	128	2,155	45	FM3
3	19	SNAP LOCK 2-S	0.11	457	18	305	18	532	121	4,309	90	FM3
3	20	SNAP LOCK 2-S	0.13	457	18	305	18	712	162	3,256	68	FM3

Note: F=felt paper; S=self-adhered membrane; FM1=deck-to-joist connection failure; FM2=panel delamination due to failure of seam-locking mechanism; and FM3=fastener pullout from the deck and tearing of the underlayment.

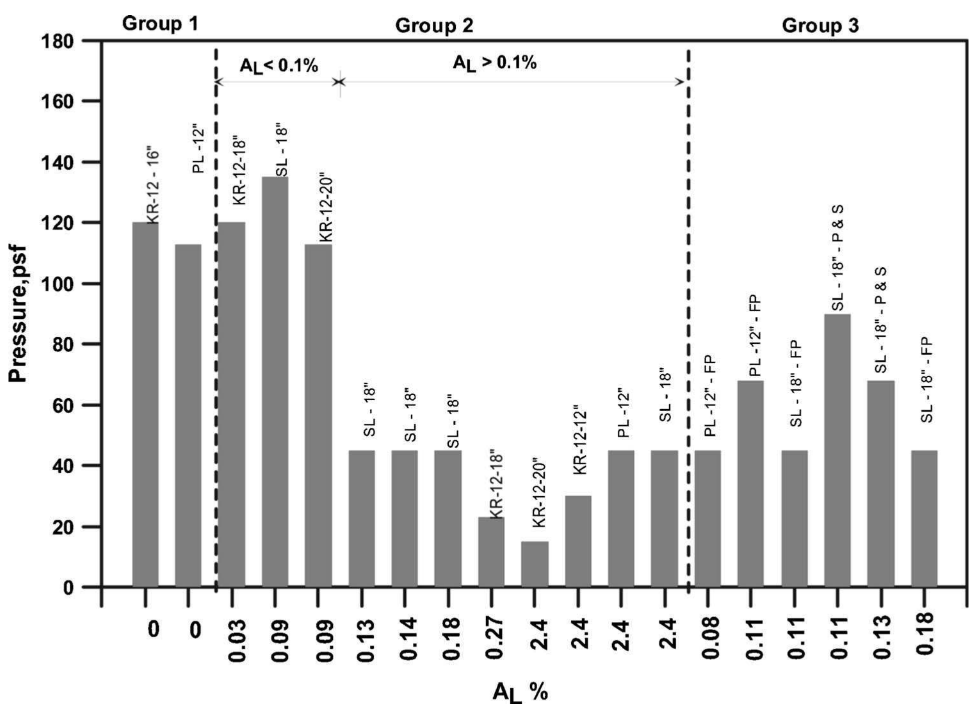


Fig. 8. Wind uplift ratings of the assemblies for three different groups of air leakage ratios

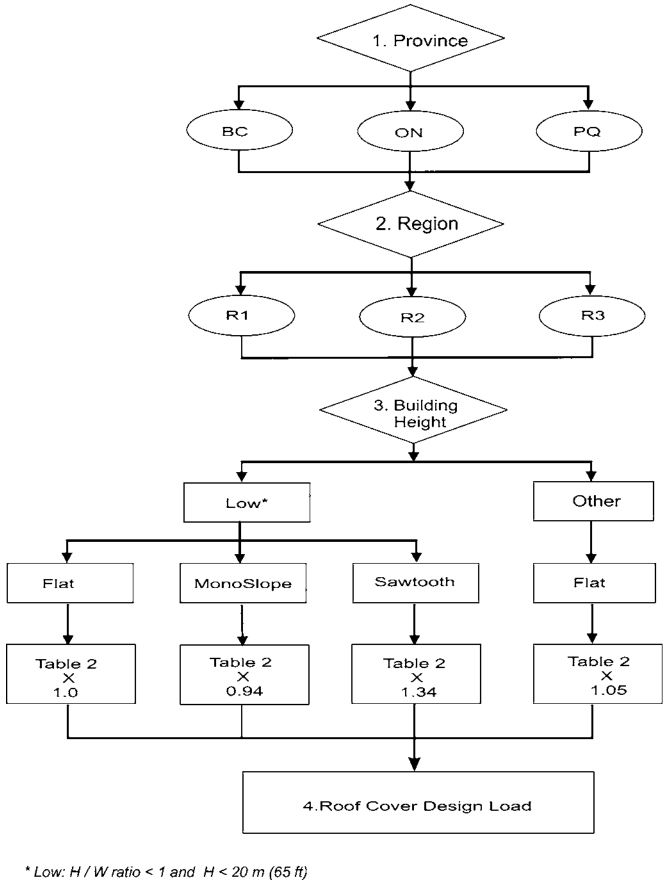


Fig. 9. Flowchart showing the steps involved in the calculation of the roof cover design load

sures can be obtained from Table 2. Suction pressures reported in Table 2 are calculated in accordance with the National Building Code of Canada NRC (1995) and its Part 4 user guide. As it is a standardized procedure, details are not documented in this paper and can be found elsewhere (Baskaran and Smith 2005). During the present design procedure the following assumptions are made:

1. Building is designed to provide postdisaster services;
2. Low-rise buildings are defined as buildings with height-to-width ratios less than 1.0 and a reference height less than 20 m;
3. Roof types are defined based on slope as shown in the Steps 1.1–1.4;
4. Dynamic pressures, q, for the design of claddings, are based on 1/10 probability and are taken from the Appendix C of the NBCC (NRC 1995);
5. Pressure coefficients are selected assuming a corner area of 1 m^2 using the Figs. 13(a and b) of the NBCC; and
6. Uniform Internal pressure conditions are assumed.

Based on the previous assumptions, calculations are performed by running a macro in the Microsoft EXCEL program. Computed cladding pressures are superimposed using a map viewer program to identify the three different regions for each of the province. Multiplication factors were calculated such that all three provinces can be classified into a common three different wind regions.

- *Step 1.1:* Low-rise building with flat roof (less than 3°)
  Cladding design pressure
  =suction pressure reported in Table 2
- *Step 1.2:* Low-rise building with monoslope roof (greater than 3° and less than 10°)
  Cladding design pressure
  =0.94×suction pressure reported in Table 2
- *Step 1.3*: Low-rise building with saw tooth roof (greater than 10° and less than 30°)
  Cladding design pressure
  =1.34×suction pressure reported in Table 2
- *Step 1.4* Other buildings with flat roof
  Cladding design pressure
  =1.05×suction pressure reported in Table 2

Step 2: Estimate Wind Uplift Design Pressure

Wind uplift pressure=cladding design pressure× factor of safety. Building codes and wind standards recommend minimum design values. Selecting an appropriate factor of safety depends on the designer, and it should be 1.0 or higher. Note that at present, in the roofing industry the safety factor ranges from 2.0 to 4.0 de-

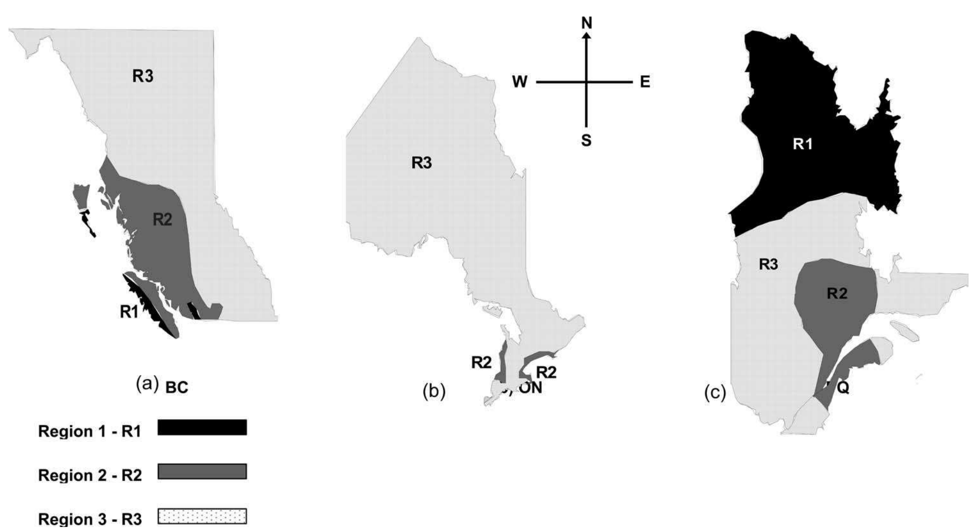


Fig. 10. Wind pressure regions for the province of (a) British Columbia (BC); (b) Ontario (ON); and (c) Quebec (PQ)

Table 2. Flat Roof Suction Design Pressures

Building height		Region 1				Region 2						Region 3			
		PQ and ON		BC		PQ		BC		ON		PQ and ON		BC	
(ft)	(m)	(psf)	(kPa)	(psf)	(kPa)	(psf)	(kPa)	(psf)	(kPa)	(psf)	(kPa)	(psf)	(kPa)	(psf)	(kPa)
30	9.2	99	4.75	81	3.89	74	3.54	63	3.01	66	3.15	50	2.41	46	2.20
35	10.7	102	4.89	84	4.00	76	3.65	65	3.09	68	3.24	52	2.48	48	2.29
40	12.2	105	5.02	86	4.12	78	3.75	66	3.17	69	3.32	53	2.55	49	2.33
45	13.7	107	5.14	88	4.20	80	3.84	68	3.26	71	3.41	54	2.61	50	2.38
50	15.3	110	5.26	90	4.32	82	3.92	70	3.34	73	3.49	56	2.67	52	2.47
55	16.8	112	5.36	92	4.40	84	4.00	71	3.42	75	3.58	57	2.72	52	2.51
60	18.3	114	5.45	93	4.48	85	4.07	72	3.46	76	3.62	58	2.76	53	2.55
65	19.8	116	5.53	95	4.55	86	4.13	73	3.50	77	3.66	59	2.81	54	2.60
70	21.4	117	5.62	96	4.59	88	4.20	75	3.58	78	3.75	60	2.85	55	2.64
75	22.9	119	5.70	98	4.67	89	4.25	76	3.62	79	3.79	60	2.89	55	2.64
80	24.4	121	5.77	99	4.75	90	4.31	77	3.66	80	3.84	61	2.93	56	2.69
85	25.9	122	5.84	100	4.79	91	4.36	77	3.70	81	3.88	62	2.96	57	2.73
90	27.5	123	5.91	101	4.83	92	4.41	78	3.74	82	3.92	63	3.00	58	2.78
95	29	125	5.97	102	4.91	93	4.46	79	3.78	83	3.96	63	3.03	58	2.78
100	30.5	126	6.03	103	4.95	94	4.50	80	3.83	84	4.01	64	3.06	59	2.82

pending on the selection of the components. This can account for any variation in the local exposure condition or roofing system behavior or to reduce the risk factor for the assumptions made in Step 1 or to have a design pressure beyond the code requirement.

Step 3: Select Reduction Factor for Air Permeable Deck Conditions

- *Step 2.1:* Calculate the ratio of leakage area by using the following formula:
  $A_L = \{leakage\ area/deck\ area\} \times 100\ (\%)$
- *Step 2.2:* Select a reduction factor from Fig. 11 to fulfill the following criteria:
  Reduction factor ≤ 1.0

Based on the input received from the industrial partners by taking several practical deck layout conditions, a procedure for calculating A_L was documented (Ham and Baskaran 2001b). A sample calculation is also shown in Fig. 8. For example, in conventional deck constructions, i.e., new 16 mm (5/8 in.) tongue-and-groove plywood has $A_L \cong 0\%$. When a 13 mm (1/2 in.) thick plywood deck was installed with H clips, A_L can be varied based on roof dimension, number of boards used, and clip locations. When deck construction permits air leakage through openings or joints, there will be significant reduction in the wind uplift resistance of the roof covering.

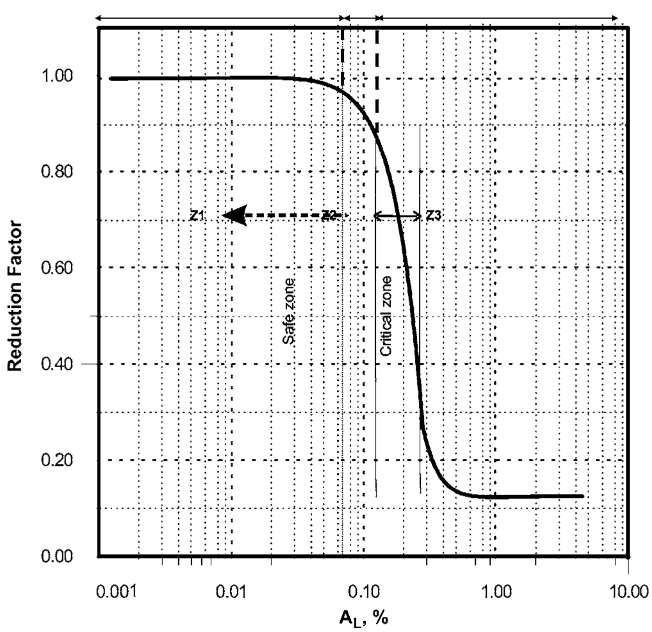


Fig. 11. Reduction factor versus air leakage ratio, A_L

The reduction factor curve, shown in Fig. 11, to account for the air permeable deck construction has been developed based on experimental data and modeling. The horizontal axis shows the A_L as a percentage and the vertical axis displays the reduction factor. It can be observed that the resistance to wind uplift pressure increases dramatically as the air leakage ratio decreases. It can also be estimated that a critical zone exists where the ultimate capacity changes dramatically $(0.12\% \leq A_L \leq 0.27\%)$. For air leakage zone, Z1 ($0.0\% \leq A_L \leq 0.09\%$), all tested metal panel systems can be used with any underlayment. For air leakage zone, Z2 ($0.09\% \leq A_L \leq 0.13\%$), SNAP LOCK 2 (with panel width smaller and equal to 18 in.) and PROLOCK (with panel width smaller and equal to 12 in.) metal panel systems can use a self-adhered air barrier as underlayment. For air leakage zone, Z3 $(A_L > 0.13\%)$, all metal panel systems should use self-adhered air barrier as underlayment for better wind uplift resistance.

Step 4: Identify a Suitable System with Required Resistance

Using Fig. 12, select a panel configuration and its wind uplift rating. This rating represents a nonconservative scenario of metal coverings installed over an airtight deck configuration. Therefore, multiply by a reduction factor (calculated in the Step 3) to obtain the wind uplift resistance of the system.

Wind uplift resistance = panel wind uplift rating × reduction factor

Step 5: Correlate Uplift Pressure with Resistance

Wind uplift resistance > wind uplift pressure
Step 4 > Step 2

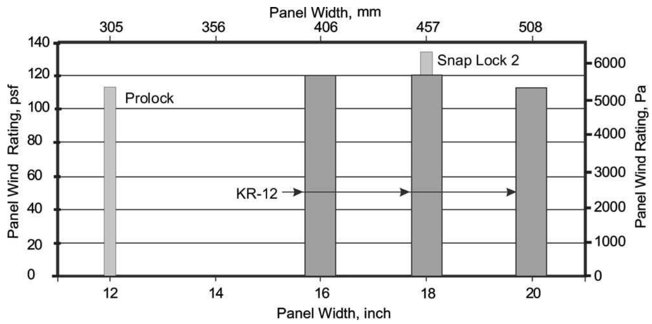


Fig. 12. Wind uplift rating versus panel width

Concluding Remarks

This paper has documented that air permeability of the structural deck is an important factor that affects the wind uplift performance of architectural metal roofing systems. Application of a self-adhered, modified bituminous underlayment improves the wind uplift performance. A modeling method is described which quantifies system response with different leakage ratios that can represent field assemblies. The National Building Code of Canada (NRC 1995) was utilized for the estimation of the wind-induced loads and the present study provided extensive experimental data for various systems. Based on this analysis, a simplified design procedure was developed. The simplified procedure was presented through case studies of architectural metal roof assemblies located in the provinces of British Columbia, Ontario, and Quebec. The presented data was limited to metal roofing systems installed over wooden decks. Investigations are in progress for composite metal roof assemblies over steel deck.

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