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Application of numerical models to determine wind uplift ratings of roofs

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Abstract. Wind uplift rating of roofing systems is based on standardised test methods. Roof specimens are placed in an apparatus with specified table size (length and width) then subjected to the required wind load cycle. Currently, there is no consensus on the table size to be used by these testing protocols in spite of the fact that a table size plays a significant role in evaluating the performance. This paper presents a study with the objective to investigate the impact of table size on the performance of roofing systems. To achieve this purpose, extensive numerical experiments using the finite element method have been conducted to investigate the performance of roofing systems subjected to wind uplift pressures. Numerical results were compared with results obtained from experimental work to benchmark the numerical modeling. Required table size and curves for the determinations of appropriate correction factors are suggested. This has been completed for various test configurations with thermoplastic waterproofing membranes. Development of correction factors for assemblies with thermoset and modified bituminous membranes are in progress. Generalization of the correction factors and its usage for wind uplift rating of roofs will be the focus of a future paper.

Key words: wind uplift; roofing system; test method; numerical model; thermoplastic; correction factor.

1. Introduction

1.1. Background

Wind resistance rating of roofing systems is based on standardised test methods. Roofing manufacturers install test specimens with respective components such as deck, insulation, membrane, etc., on a test frame (Fig. 1). Air pressure, uniform with respect to the space, is applied on the system until failure occurs, e.g., membrane tearing and/or fastener pull out. In this process, the system configuration (e.g., fastener spacing and fastener row spacing) is similar to systems as installed in the field. Although the test specimen is subjected to pressures in accordance with the design requirements, the test specimen size (length and width) is normally smaller than the size of a real roof. Therefore, the measured system response in the lab (induced fastener loads and membrane deflections) might be different from the field performance. As shown in Fig. 1, this is mainly

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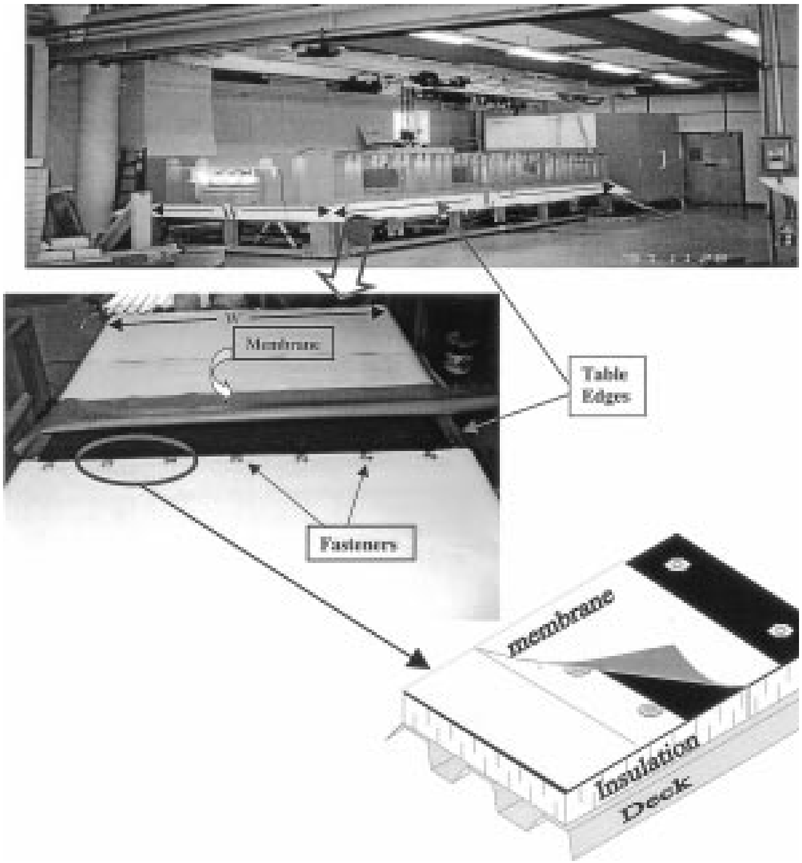

Fig. 1 Nomenclature of a test rig used for wind uplift testing

because the test rig edges offer some resistance to the applied pressure.

Careful examination of Fig. 1 reveals that the table size is important in evaluating roofing systems. It should be selected properly to obtain realistic wind uplift resistance in the certification process. For example, the use of narrow tables would increase the edge effects on the system response particularly for roofing systems having wider membranes. On the other hand, use of wide tables may not be economical for routine testing procedures. If the testing table sizes are sufficient, then the roofing system response remains constant or minimum changes may occur.

As grouped in Table 1, existing test methods consider different table sizes during the certification of roofing systems. For instance, the FM (Factory Mutual 1986) tests use a table size of 1500 by 2700 mm (5’ by 9’) or 3700 by 7300 mm (12’ by 24’) depending on the roofing system. A chamber size of 3000 by 3000 mm (10’ by 10’) is used by the UL (Underwriters Laboratories 1991) standard. Present research efforts by a North American roofing consortium, the *Special Interest Group for Dynamic Evaluation of Roofing Systems* (SIGDERS) established at the National Research Council of Canada, have led to the development of a facility making it possible to evaluate roofing systems dynamically (Baskaran and Lei 1997). A table size of 2200 by 6100 mm (7.2’ by 20’) is used by SIGDERS.

Table 1 Existing table sizes for certification of roofing systems

No.	Test Protocol	Table Size, mm (ft)	Country	Reference
1	FM 4470 Standard	1500× 2700(5× 9)	U.S.A.	FM Research 1986
2	Revised FM 4470	3700× 7300(12× 24)	U.S.A.	FM Research 1992
3	UL 580 Standard	3000× 3000(10× 10)	U.S.A.	UL Inc. 1991
4	UEAtc Standard	1500× 6100(5× 20)	Europe	Gerhardt *et al*. 1986
5	BRERWULF	5000× 5000(16.4× 16.4)	UK	Cook *et al.* 1988
6	NT Build 307 Standard	2400× 2400(8× 8)	Norway	Paulsen 1989
7	SIGDERS	2200× 6100(7.2× 20)	Canada/U.S.A.	Baskaran and Lei 1997

1.2. Need for a numerical model

Despite the significance of table dimensions, to the authors' knowledge there still exist no criteria or specific standard to suggest a required table size. A number of parameters can influence the required table size, in particular, fastener spacing (F_s), fastener row spacing (F_r) and membrane modulus of elasticity (E). Therefore, it has been decided to develop a Finite Element (FE) based numerical model for the problem discussed above.

Only limited numerical studies (Lewis 1980, Rossiter and Batts 1985, Gerhardt and Gerbatsch 1989, Easter 1990, Zarghamee 1990, Bienkiewic and Sun 1993) were made to evaluate the roofing system performance. Baskaran and Kashef (1995) identified several research needs by systemically documenting the state-of-the-art in this area. All the existing studies focused on the performance evaluation of a particular system rather than to concentrate effect of table size on the system performance. As mentioned, currently, there is no consensus on the table size to be used by these testing protocols in spite of the concern that the test rig edge effect of table may play a significant role in evaluating performance. Focusing on this issue the paper presents and discusses the involved steps of the numerical study as follows :

- Adopting a numerical model to simulate the experimental results;
- Benchmarking the model using the experimental data;
- Investigating the effect of table size on the roofing system response; and
- Developing correction factors for tables smaller than the required one.

2. Selecting a numerical model

2.1. General

Numerical techniques can offer flexibility in exploring scenarios that would be too expensive, or difficult to set up experimentally. In addition to the economical advantages, the analytical models are generally faster than experimental approaches for solving problems where there is a need to investigate the impact of various influencing parameters. Effect of driving forces in various protocols could be also modified more efficiently in the numerical models. The discussed issue, namely the effect of table size on roofing system performance, is an ideal opportunity to explore the modelling capabilities of numerical approaches.

ABAQUS version 5.8 (1998), a commercially available Finite Element program with non-linear analysis capability was used to carry out all the numerical analyses. The large strains and deformations that occur during loading of the membrane were accommodated by simulating the geometrical non-linearity (large deformation theory). In non-linear analysis, the state of the model at the last step is taken as the initial conditions for the start of next step. Small load increments were used to accommodate the flexibility of membrane and continued until the roofing system sustained level. The model excludes any simulation post-ultimate degradation and thus it only simulates the roofing performance prior to the system failure.

2.2. Experimental approach

Experimental data for this study was obtained from the Dynamic Roofing Facility (DRF) located at the Institute for Research in Construction of the National Research Council of Canada (IRC/NRC). As shown in Fig. 1, the test apparatus consists of a bottom frame of adjustable height upon which the roof specimen and a removable top chamber are installed. The bottom frame and top chamber are 6100 mm (240’’) long and 2200 mm (86’’) wide and 800 mm (32’’) high. The top chamber is equipped with six windows for viewing, and with a gust simulator, which consists of a flap valve connected to a stepping motor through a timing belt arrangement. Pressure suction as high as 10 kPa (209 psf) over the roof assembly is produced by a 37 KW (50 HP) fan with a flow rate of 2500 L/sec (5300 cfm). A computer, by using feedback signals, controls the operation of the DRF. The computer regulates the fan speed in order to maintain the required pressure level in the chamber. Operation of the flap valve simulates the gusts in the form of uniform cyclic pressure loading over the surface of the roofing system. Closing the flap valve allows pressure to build in the chamber, while opening the valve bleeds the pressure. More information of the DRF features are given in Baskaran and Lei (1997).

The modelled roofing system had thermoplastic membranes as the waterproof component. There are two main kinds of thermoplastic roof membranes: Poly-Vinyl Chloride (PVC) and Thermo-Plastic olefin (TPO) mostly used in single ply roof assemblies. Fig. 2 shows a typical mechanically attached TPO roof assembly used in the experimental investigation. For this configuration, three sheets were installed on the experimental table and fastened to the structural deck along the four seams. Two different testing protocols, Factory Mutual (FM 4470) static test, and the SIGDERS dynamic load cycle, were used to compare static and dynamic evaluation of a roofing system. To monitor the system response (i.e., pressure, force, and deflection), instrumentation was used. Force balances and ultrasonic sensors were used to measure the tensile forces in the fasteners and uplift movements of the membrane respectively. Applied suctions were also measured by a pressure transducer (P1). Signals from all of these instruments are monitored by a computer.

Fig. 2 also shows the seam details consisting of the 22-Ga steel deck, 0.76 mm (0.03’’) thick, with a profile height of 38 mm (1.5’’) and a flute width of 150 mm (5.9’’) as structural support. Insulation boards as the thermal barrier with dimensions of 100 by 1500 by 3000 mm (4’’ by 48’’ by 96’’) were mechanically attached to the steel deck. TPO sheets were attached by 127 mm (5’’) long fasteners with plastic disc 51 mm (2’’) in diameter to the deck along the seam. The seam had an overlap of 127 mm (5’’) with the fastener placed 38 mm (1.5’’) from the edge of the bottom sheets, and 89 mm (3.5’’) from the edge of the overlapping sheets. The portion of the seam beyond the fastener row was welded with hot air such that a waterproof top surface was obtained. The width of the welded portion varied between 38 and 45 mm (1.5’’ and 1.75’’). More details of the system layout and experimental data can be found in Baskaran, Lei and Richardson (1999). For benchmarking the numerical models, three different TPO roof system layouts (48/18, 67/12, 72/18)

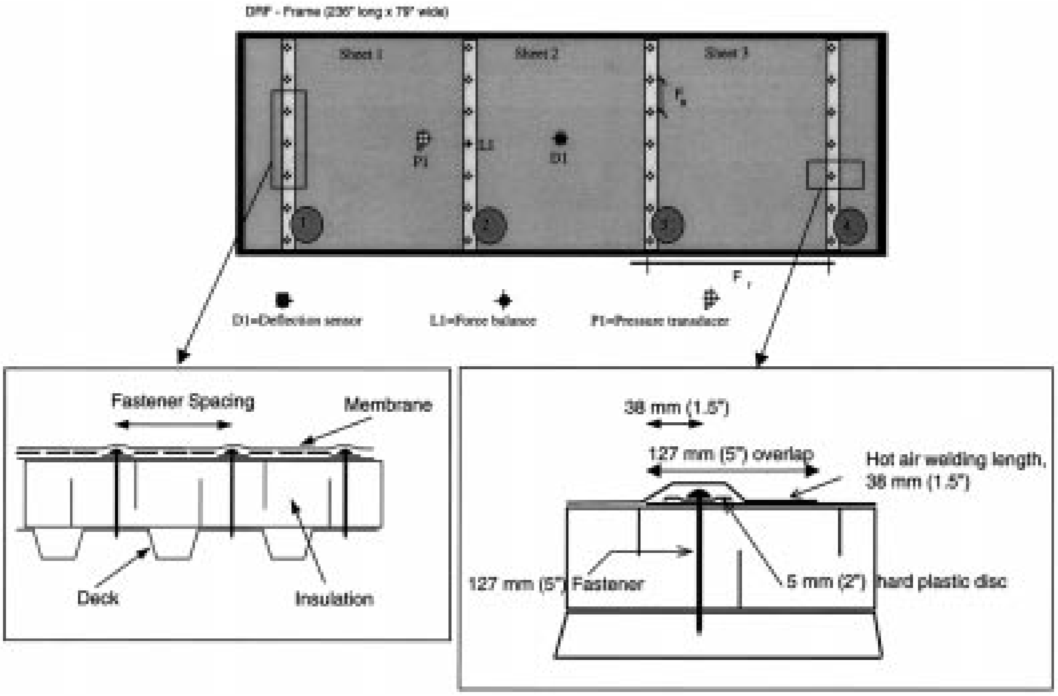

Fig. 2 Typical roofing system layout and seam details used in the experimental investigation

were selected. The first number in the pair represents the fastener row spacing and the second number accounts for the fastener spacing and values are in inches.

2.3. FE model

Fig. 3 shows the FE model representation for the experimental roof system presented in Fig. 2. Membrane properties were considered in the numerical modelling due to the greater flexibility of membrane compared to other components in roofing systems, namely the insulation and steel deck. In other words, the deflections of the steel deck and insulation were assumed negligible in comparison to the membrane deflection. A rectangular grid of 4-node and shell elements were used in each case to discretize the membrane. The shell elements had a thickness of 1.04 mm and an equivalent modulus of elasticity of 300 MPa (43.5 ksi). The modulus of elasticity and the thickness of the membrane were obtained through mechanical tests in accordance to the ASTM standard (ASTM D 751-98). In the model, the membrane edges were restricted from any movement and fastener locations were modified to account for the plastic fastener plates. Element sizes were decreased near the seam to consider concentrated stresses at seam area.

Seam details were modelled by doubling the thickness of the shell element at the seam areas as schematically illustrated in Fig. 3, to simulate the spliced region of the membrane. Fixed bar type elements were used to simulate fastener attachments with the steel deck. Fasteners were assumed as spring supports with axial stiffness of 20 N/mm (114 lbf/in). Different material properties were simulated for fastener plates in the seam areas using shell elements. These plastic plates were 3 mm (0.1’’) thick with a diameter of 50 mm (2’’) and a modulus of elasticity of 500 MPa (72.5 ksi). For

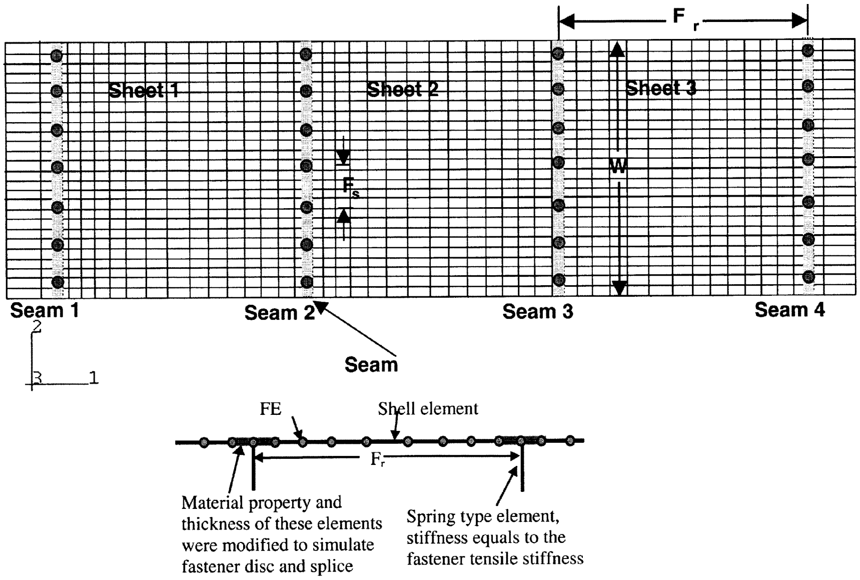

Fig. 3 Typical roofing system layout and seam details for the numerical modelling

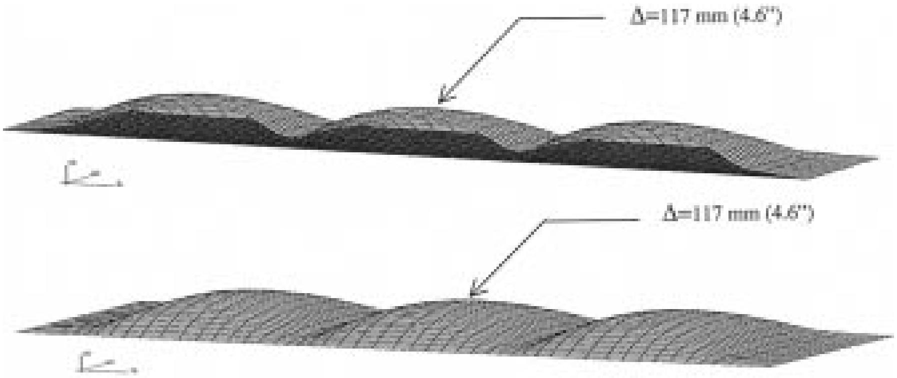

Fig. 4 Computed membrane deflected shape for the 67''/12'' configuration

the input pressure, the model assumed a uniform static uplift pressure on the membrane.

The membrane displacements and fastener forces were printed in the output file after each successful convergence step. Maximum fastener load and nodal displacement in the three orthogonal planes were also calculated in each step. A typical computed membrane deflected shape is shown in Fig. 4 where the membrane ballooning occurs between fastener rows and table edges. A full model of the configuration is also shown to reveal the existence of symmetry. As shown, the modelled 67/12 configuration had a maximum deflection of 117 mm (4.6''). This maximum deflection was noticed at the middle of the membrane and was caused by a pressure of 1436 Pa (30 psf).

To investigate the table width effect, two existing tables (SIGDERS and UEAtc) were selected from Table 1. Both tables have the same length of 6100 mm (240'') and difference in widths 2200 mm (86'') for SIGDERS versus 1500 mm (60'') for UEAtc. A static pressure of 1436 Pa (30 psf) was applied on a system with 48/6 configuration. Resulting fastener force variations along a seam

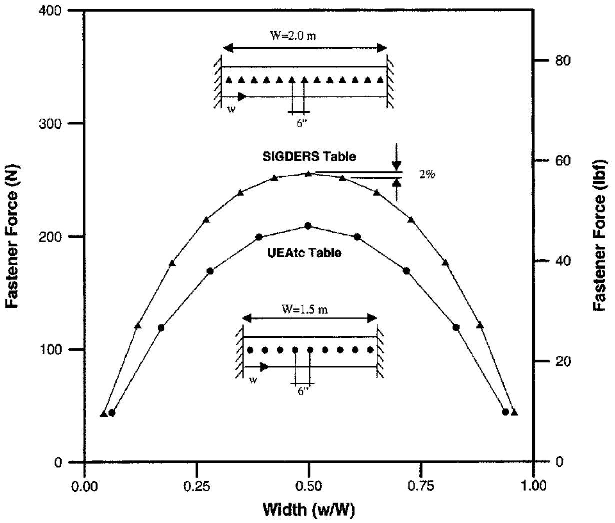

Fig. 5 Computed fastener force variation along the seam for SIGDERS and UEAtc tables

are presented in Fig. 5 with respect to the normalised table width. Computed results indicated a maximum fastener force at the middle of the seam and minimum at the end of the seam. This reveals the edge influence on the fastener forces as the slope of the curve shows a diminishing edge effect on the fastener forces from edge to the middle. An ideal condition is one where edge effects are minimal and most of the fasteners have equal forces since they are subjected to the same wind uplift pressure. However, during the laboratory experiments, the edge will always offer some resistance. In the case of SIGDERS' table which is 2200 mm (86'') wide, three fasteners at the centre (mid-width) will have equal or similar forces to confirm they are not influenced by the edges. Data showed about two percentage of variation from the centre fastener to the adjacent ones. This confirms that the edge influence is negligible. Moreover, decreasing the table width to 1500 mm (60'') decreases the overall magnitude of the fastener force. More details on the effect of table width will be discussed in section 4.

3. Benchmarking the selected model

As discussed in Section 2.2, experimental data obtained from DRF was used to benchmark the developed model. Average values of two characteristic parameters, i.e., fastener loads and membrane deflections measured from the DRF experiments were compared with the output of the FEA (Finite Element Analyses). The fastener force measured at the centre location L1 on the seam and deflection at the mid-span location D1 of the membrane, as indicated in Fig. 2, were selected.

Comparisons of fastener forces between the experimental and FEA modelling are shown in Fig. 6, in which the horizontal axis represents the applied suctions on the roof assembly and the vertical axis represents the fastener forces of the roofing system's response for the applied pressure. In the experiments, depending on the test protocols (FM or SIGDERS) the required pressures are applied and maintained for a specific duration. During the numerical simulation the pressure was increased by increment of 718 Pa (15 psf).

To establish deviations between the two data sets (experiments versus numerical model), the following expression was used:

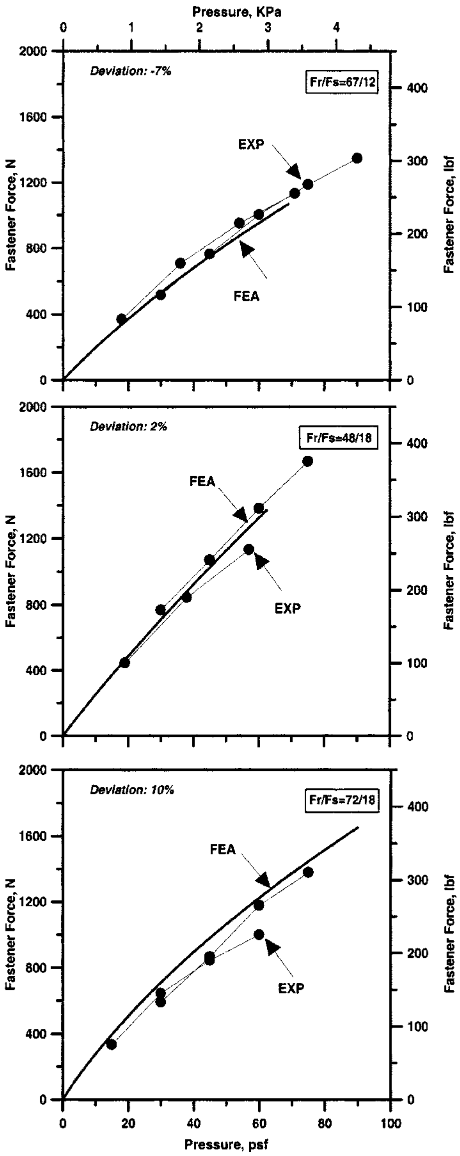

Fig. 6 Model validation for fastener forces

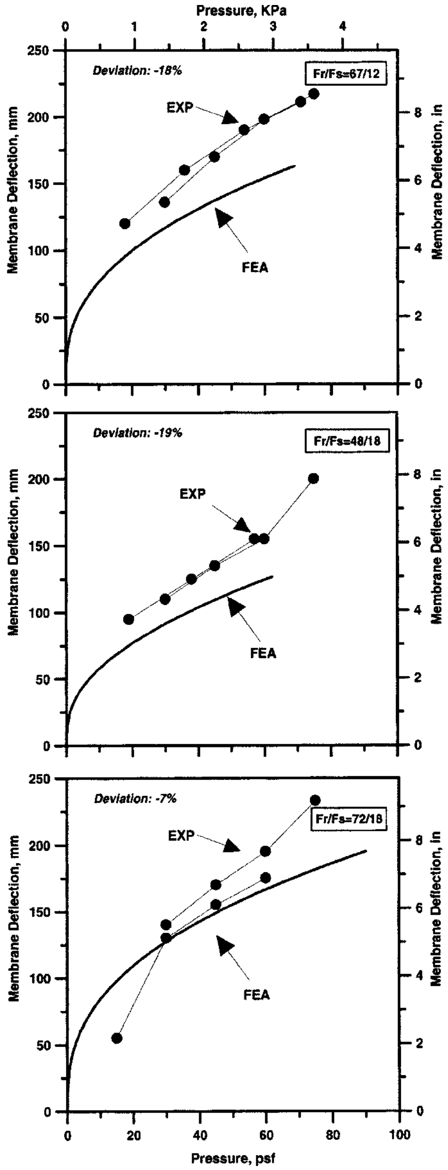

Fig. 7 Model validation for membrane deflections

$$\Delta F = \sum_{i=1}^{N}\left(\frac{F_{FE} - F_{EXP}}{F_{EXP}}\right) \times 100 \qquad (1)$$

Where:

F_{FE} is the fastener force obtained from the FEA model,
F_{EXP} is the fastener force measured at the experimental,
N is the number of cases (pressure levels) considered for each configuration, and

ΔF is the fastener force deviation between F_{FE}, and $F_{EXP.}$ ΔF with a negative sign (-) means that the numerical model underestimates the roofing system response compared to the experimental approach and vice versa.

Using Eq. (1), for the case of $F_r / F_s = 67/12$, an under-estimation of 7% by the FEA model was found. Similar comparisons for the 48/18 and 72/18 configurations respectively revealed 2% and 10% deviations (over-estimations) of the analytical model from the measured fastener loads. These comparisons demonstrated that the FEA model is a viable tool that can be used to predict the fastener forces of test specimens at any uniform static pressure level.

Fig. 7 presents the model validation for the prediction of the membrane deflection. Using deflection instead of forces in the Eq. (1), deviations for the 67/12, 48/18 and 72/18 configurations are 18%, 19% and 7% respectively. Irrespective of the roofing system configurations, the membrane deflections are always underestimated by the numerical model. One of the reasons for the difference between the data set is due to difference in the edge conditions of the model. In the numerical model, all four edges are restrained from any movements, whereas membrane slippage from the edges of the test frame may happen during the lab experiments. Therefore, the measured deflection in the lab is the summation of the true membrane uplift and membrane slippage where as the numerical model computes only membrane uplift.

4. Investigating the effect of table size

4.1. Required table width

This section focuses on the determination of ideal table size. All three dimensions (i.e., length, width and depth) - as shown in Fig. 1 - constitutes the table size. Components used in the lab experiments are similar to those used in the field. In other words, there is no variation in the thickness of components such as the insulation and membrane. Therefore, the depth was not considered in the analysis. The effect of the table length is minimal because during the system installation, membrane width forms parallel to the table width. Therefore, the present investigation focuses to isolate the effect of table width effect on the system response using the validated FE model. With all other parameters maintained constant, the Required Table Width (RTW) is one that will provide roofing system response in the lab similar to that of the field. Moreover, the development of RTW 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. The present study has the luxury of receiving input from all parties concerned with roofing, including researchers, manufacturers, roofing associations representing the contractors, and building owners. (Refer to the acknowledgment section for the consortium participants.) Based on the numerical investigation and the practical inputs the following criteria was established to identify the RTW:

"The table with RTW should provide no change in the maximum fastener forces or change in the maximum fastener force should be within 5% compared to those obtained while decreasing the table width by 305 mm (12'')".

To identify the RTW for the TPO roofing systems, simulations were performed for various table widths. The modelled table width ranged from 781 to 5048 mm (31'' to 199''). This range covered the different tables that are existing for the roofing system evaluation (Table 1). For illustrating the above criteria and involved calculations, a typical example is shown in Table 2. It presents the computed maximum fastener forces for the TPO system with a 1220 mm (48'') fastener row spacing (F_r)

Table 2 Example to illustrate the RTW criteria

Simulation No.	Table Width mm (in)	48"/18"	
		Force N (Ibf)	Change(%)
1	5048(199)	800(180)	0
2	4743(187)	800(180)	0
3	4438(175)	800(180)	0
4	4134(163)	800(180)	0
5	3829(151)	799(179)	0.1
6	3524(139)	795(178)	0.5
7	3219(127)	788(177)	0.9
8	2914(115)	773(173)	1.9
9	2610(103)	748(168)	3.2
10	2305 (91)	708(159)	5.3
11	2000 (79)	650(146)	8.2
12	1695 (67)	572(128)	12.0
13	1390 (55)	470(105)	18.0
14	1086 (43)	341 (77)	27.4
15	781 (31)	207 (47)	39.2

and a 305 mm (12'') fastener spacing (F_s). A suction pressure of 1436 Pa (30 psf), was applied on this system. A computed fastener force of 800 N (180 lbf) was calculated for a table width of 5048 mm (199''). By decreasing, the width to 4134 mm (163'') there was no change on the fastener force. Further reductions of the width reduced the fastener force. For a table width of 2000 mm (79''), the computed fastener force was only 650 N (146 lbf). This reduction from 800 N to 650 N (180 lbf to 146 lbf) is due to the edge effect. By applying the established criteria, a table width of 2610 mm (103'') can be selected as the RTW for this configuration where the variation of fastener force is less than 5%.

4.2. Investigation of parameters influencing the RTW

Number of parameters can influence the RTW. Three critical parameters, namely, variations in the thermoplastic membrane properties, fastener spacing (F_s) and fastener row spacing (F_r) are investigated and discussed below.

1) *Variation in the thermoplastic membrane*: As mentioned before, there are mainly two varieties of thermoplastic membranes in industrial roofing, namely, TPO and PVC. A roofing system, with PVC membrane instead of TPO, was modelled to investigate the effect on the RTW for membrane variations in the thermoplastic group. Same finite element model was used with the exception of different input parameters. A typical configuration 67/12 has been selected with appropriate moduli of elasticity, and details are documented in Zahrai and Baskaran (1999). Computed fastener forces for different table width ranging from 781 to 5048 mm (31'' to 199'') are shown in Fig. 8. Comparison shows minimum variations in fastener forces between the PVC and TPO roof systems. It has been decided, therefore, to use one set of RTW for the evaluation of roofs with thermoplastic membrane.
2) *Fastener row spacing (F_r)*: To quantify the impact of F_r on the RTW, two configurations were selected. The layouts are 48/18 and 114/18, and all other parameters such as fastener spacing and applied pressure were maintained constant. The selected fastener row spacing of 1220 and 2900 mm (48'' and 114'') can cover systems with minimum and maximum fastener row spacing

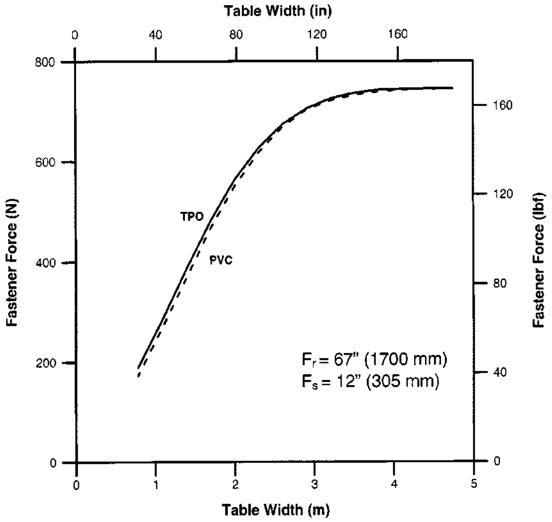

Fig. 8 Effect of membrane on the computed fastener force for a typical configuration

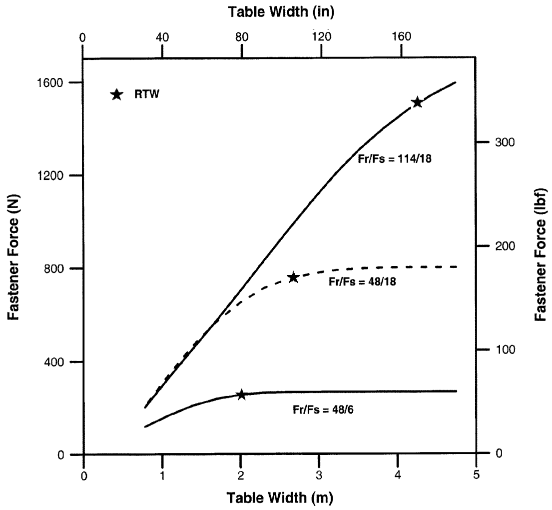

Fig. 9 Impact of roofing system layout on the computed fastener force

available in the roofing industry. Computed fastener loads for both configurations and for different table widths are presented in Fig. 9. Fastener forces were calculated for a 1436 Pa (30 psf) uplift pressure. For the system with a 2900 mm (114'') fastener row spacing, the RTW is 4130 mm (163''), whereas for a system with a F_r of 1220 mm (48'') the RTW is 2610 mm (103''). This reveals that F_r has a direct influence on the RTW and that its dependency is not linear.

3) *Fastener spacing (F_s)*: In order to investigate the influence of fastener spacing on the RTW, computed fastener forces for 48/6 layout are added in to Fig. 9. It is evident that decreasing fastener space from 460 to 152 mm (18'' to 6'') caused a decrease in the computed fastener force. This has been the case for all simulated table width. For the system with 152 mm (6'')

fastener spacing the RTW is 2000 mm (79''). Comparison of RTW between 460 and 152 mm (18'' and 6'') fastener spacing, ranged from 2610 to 2000 mm (103'' to 79''), indicate a small influence. Overall, Fig. 9 data confirms that one should consider effect of fastener row spacing (F_r) and fastener spacing (F_s) in determining the RTW. One can assign higher importance factor for F_r than F_s when generalising the RTW. This will be further explained in the following section in which RTW is used to develop correction factors.

5. Developing correction factor

One objective of the study was to develop correction factors (F_c) for the tables having width smaller than the established RTW. This section develops F_c for various test configurations with thermoplastic waterproofing membranes. Development of correction factors for assemblies with thermoset and modified bituminous membranes are in progress. Generalization of the correction factors and its usage for wind uplift rating of roofs will be the focus of a future paper.

The correction factors can be calculated by dividing the fastener force obtained from the RTW table with that of the narrow ones. Tables having larger widths than RTW have correction factors equal to one. For instance, in Table 2, the width of 2610 mm (103'') was identified as the RTW with

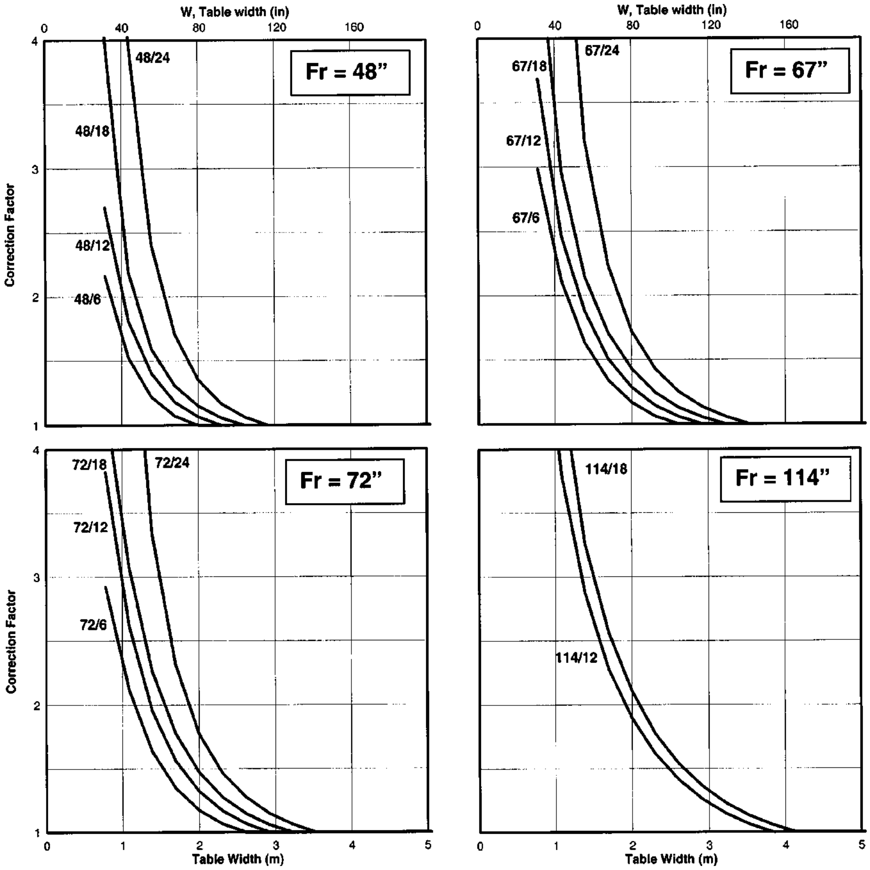

Fig. 10 Developed correction factors for thermoplastic systems

748 N (168 lbf) as fastener force. Using a 2000 mm (79'') table would reduce the fastener force to 650 N (146 lbf). To correct this situation, the fastener force obtained from the table that has a width of 2000 mm (79'') need a multiplication factor of 1.15 (748/650).

More than 200 simulations were performed for the variations of the two influencing factors discussed in the previous section, namely, fastener row spacing (F_r) and fastener spacing (F_s). Four F_r configurations 2900, 1830, 1700 and 1220 mm (114'', 72'', 67'' and 48'') with four F_s configurations 152, 305, 460 and 610 mm (24'', 18'', 12'' and 6'') were considered. These (F_r / F_s) combinations represent most of the thermoplastic systems currently available in the roofing industry. For each configuration, correction factors were developed, and the curves of correction factors for different fastener row spacing and fastener spacing are presented in Fig. 10. The intent is to achieve characteristic curves such that generalised guidelines can be developed for F_c. The comparison of these curves revealed the following based on which generalised correction factors can be developed in a later stage.

- The RTW for different roofing layouts ranged from 2000 mm (79'') to 4000 mm (157''). For instance, using a table width 3000 mm (118''), one can evaluate all layouts for F_r equal to 1220 mm (48). On the other hand, a minimum table width of 4000 mm (157'') is necessary if one wants to evaluate all F_r / F_s combinations without applying any correction factor.
- Increasing F_s from 460 mm (18'') to 610 mm (24'') increased F_c more than any other changes in F_s. This is found true irrespective of F_r.
- In experimental set up, at least three fasteners along the each seam are required to provide sufficient roofing system response. To investigate a system with F_s as 610 mm (24''), table width should be greater than 1400 mm (55''). Then, in general, application of F_c for tables less than 1400 mm (55'') wide is not appropriate. Therefore, only table widths more than 1400 mm (55'') can be used with correction factors. The required correction factors for all F_r / F_s combinations can be obtained from Fig. 10.

6. Conclusions

Various mechanically fastened thermoplastic roofing systems were numerically simulated by applying a finite element based model. Experimental data obtained using the Dynamic Roofing Facility was used for benchmarking the developed model. Numerical results for various system configurations compared well with those obtained from the experimental studies.

The validated model was further used to investigate the effect of table size on the roofing system performance. Attempts were made to identify the required table width. It was found that an increase in the table width beyond a certain level did not significantly change the system response and found that the specific limit depends mainly on two system parameters, namely, fastener row spacing and fastener spacing. Influences of these two parameters on the required table width were also investigated. Based on such modelling efforts, correction factors were established for various test configurations with thermoplastic waterproofing membranes.

Development of correction factors for assemblies with thermoset and modified bituminous membranes are progress. Generalization of the correction factors and its usage for wind uplift rating of roofs will be the focus of a future paper.

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· ***Manufacturers***: Canadian General Tower Ltd., Carlisle SynTec Inc, GAF Materials Cooperation, Firestone Building Products Co., IKO industries Canada, Stevens Roofing Systems, Soprema Canada, Vicwest Steel
· ***Building owners***: Canada Post Corporation, Department of National Defense, Public Works and Government Services Canada and
· ***Associations***: Canadian Roofing Contractors Association, Industrial Risk Insurers, National Roofing Contractors Association and Roof Consultants Institute.

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