Design of Mechanically-Attached Base Sheets In Built-Up and Modified Bitumen Roofing

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Roof systems are subjected to a wide variety of environmentally-driven forces that designers of components and systems must consider when specifying a roof system. One of the most important considerations is the wind-induced pressure fluctuations that a roof system must withstand over its life. Test methods have been developed over the years to quantify roof system wind-uplift performance, leading to industry-recognized performance criteria. While these test methods and criteria have certainly provided designers with some tools for specifying an "appropriate" roof system attachment, some areas in the test methodology and criteria are lacking. Often, this results in the under-design of a roof assembly, leading to the potential for roof system blow-off; or to over-design of a roof assembly, leading to the potential for excessive cost and improperly serving the customer's needs. This article serves to document existing, nationally-recognized test methods and performance criteria, discuss areas where these methods and criteria are lacking, consider why these areas are lacking, examine existing tools developed to address these issues and their inherent flaws, and suggest alternate design methods presently utilized in Europe and certain areas of the United States.

Existing Test Methods

Factory Mutual is a research and engineering entity owned and operated by a small group of commercial insurance carriers whose objective is to reduce losses through research, testing, and analysis of building components and systems. In 1986, Factory Mutual Research Corporation (FMRC) published its Approval Standard 4470[1], a document containing a number of tests designed to quantify roof system performance under a variety of simulated environmental conditions. Successfully meeting the Standard 4470 requirements constitutes "FM Approval" of a component or system and subsequent publication in the Factory Mutual Approval Guide. The Standard 4470 and associated Approval listings have since become the most widely utilized performance-based specification tool in the U. S.

Uplift pressure (the upward pressure roof systems experience when subjected to wind) is one of the conditions the Standard 4470 examines. Examination of mechanically-attached roof systems is accomplished through one of two test methods, dependent on the distance between fasteners and the target uplift rating.

Appendix C of Standard 4470 is required for testing of mechanically-attached roof systems having fastener row spacing less than or equal to 4 feet or a contributory fastener area less than or equal to 8 ft^2. A 5-ft x 9-ft roof specimen is pressurized from below in predetermined pressure increments until specimen failure. The maximum obtainable uplift rating is 90 psf. (See *Figure 1*.)

Appendix K of Standard 4470 is required for testing of mechanically-attached roof systems having fastener row spacing greater than four feet or a contributory fastener area greater than 8 ft^2. A 12-ft x 24-ft roof specimen is pressurized from below in predetermined pressure increments until specimen failure. There is no limit to the obtainable uplift rating. (See *Figure 2*.)

FM Approval of roof systems per Standard 4470 requirements is limited to installations over FM Approved deck types. This limitation stems mainly from the desire to limit losses from fire, whereby FM Approved decks are categorized as either "Noncombustible" or "Class 1 Fire Rated." Presently, these deck types are limited to:

- Cementitious wood fiber
- Fiber reinforced cement
- Gypsum concrete (recover applications only)
- Lightweight insulating concrete (having met the requirements of Approval Standard 4450)
- Fiber reinforced plastic
- Steel (minimum 22 ga. with narrow, intermediate, or wide rib)
- Structural concrete (minimum 2,500 psi compressive strength, poured or precast)
- Treated wood (minimum nominal 2-inch thick lumber or 3/4-inch plywood, impregnated fire-retardant)

While other simulated uplift test standards and roof system approvals/classifications do exist, none are as widely utilized and specified as those set forth in Standard 4470.

Areas of Lacking

While it is important to hold building components and systems to a certain level of performance, it is equally important to recognize any limitations associated with the performance criteria being specified. The increasing use of FM Approved roof sys-

Figure 1 (above): View of 5-ft x 9-ft Pressure Chamber.

Figure 2 (left): View of 12-ft x 24-ft Pressure Chamber.

tems, coupled with the inherent limitations associated with test method and deck type, lend to potential misuse of the Approval Standard 4470 intent.

The roof system uplift ratings resulting from simulated uplift testing provide users with a performance benchmark; however, that benchmark may not be truly applicable to the specific needs of a project. An example of this fallacy is use of a "1-90 Windstorm Classification" as a rule-of-thumb, while not examining the actual design pressures for the project being specified. While methods of determining the design pressures for a particular building exist, they are not always utilized. Rather, specifiers rely on FM Approval to "fail-proof" the roof system—a practice that often leads to under-design or over-design of the roof system. As more designers blindly specify FM Approved roof systems, the roof system manufacturers have become more active in educating their customer base. The following excerpt is taken from a major built-up and modified bitumen roofing manufacturer's guide specification manual.

"Be advised that FMRC Approvals are often specified on installations not to be insured by FMRC Underwriters, and actual needs may be misinterpreted. Discussing such situations...may serve to clarify actual job requirements."

Another example, which appears regularly on West Coast projects, is use of a "1-90 Windstorm Classification" for a roof system over plywood decking, when the plywood installed is not FM Approved (i.e., impregnated fire-retardant plywood of minimum 3/4 inch thickness).

Wood Deck Uplift Resistance Limitations

Again, fire resistance is the major objective in the limiting of FM Approved roof decks. This is particularly limiting to use of wood and wood-based products. However, an additional, more subtle reason for limiting wood decks is the repeatability of uplift performance testing. The fastener holding performance of wood and wood based products varies significantly from region to region, from lot to lot, from project to project. In fact, nail withdrawal data indicate significant variation from installation to installation. Consider the test data in the table below, published by the American Plywood Association in their APA Report T92-8[2].

While the number of tests performed provides a perfectly viable data set for statistical analysis, and, with an appropriate margin of safety, data could be used as design values, the large performance variation remains. Because uplift performance under Standard 4470 is based on system testing, it is nearly impossible to correlate one test to another for applications over such a variable deck type. On the other hand, fastener performance in steel and concrete decks has proven very consistent, allowing for comparison of test results and, to a certain degree, extension of test results to alternate systems.

Notwithstanding the reasons for lack of FM Approved roof systems over wood decks, this void has led to specifications and requirements that often conflict with actual field conditions and could be misconstrued. Consider the following excerpts from a major built-up and modified bitumen roofing manufacturer's guide specification manual.

> "Plywood sheathing shall be exterior-grade, minimum 4-ply, not less than 1/2 inch thick."
>
> "Nail the base sheet through flat metal caps or use nails with attached 1-inch square or round metal caps that have a minimum withdrawal resistance of 40 pounds each."
>
> "Nail along the side lap of the base ply at intervals not to exceed nine inches and stagger-nail down the center of sheet in two rows with nails spaced at intervals not to exceed 18 inches in each row with each row 12-13 inches from the edges of the sheet."

While guide specifications are loaded with disclaimers, such prescriptive statements lend to the potential for unknowingly specifying an inferior base sheet attachment. What do these statements truly mean? How will the system perform in uplift conditions when installed in this manner? Will performance be affected by a change from one base sheet to another? The answers to these questions remain to be seen in the next windstorm.

Other manufacturers have taken the "safer" route, delegating attachment design to the design professional:

"It shall be the responsibility of the designer to consider geographical wind conditions and provide protection against wind uplift."

Existing U.S. Design Tools for Non-FM Approved Decks

Factory Mutual Engineering Corporation (FME) publishes reference documents known as Loss Prevention Data Sheets (LPDS) to record field observations of past losses and provide recommendations based thereon. As more losses occur, more data are gathered, and more recommendations are published. Data Sheets are also published to provide guidance when faced with conditions prohibiting use of a completely FM Approved roof assembly, from deck to roof covering.

One such document is the LPDS 1-29[3], which provides recommendations for the proper design and installation of above-deck roof components. Recognizing the lack of FM Approved built-up and modified bitumen systems over wood decks, Section 2.1.1 of the 1-29 sets forth a method for determining an appro-

Table 1: Test Results - Nail Withdrawn from 19/32" Plywood (lbf)

Nail Type➡	10 ga. ring shank	11 ga. screw shank	11 ga. plain shank	11 ga. ring shank
Average Result*	214	115	72	180
Minimum	145	53	47	99
Maximum	326	174	134	247

*Average of 20 tests.

Figure 3: View of Field Withdrawal Resistance Testing.

priate base sheet attachment pattern based on:

1) the building's wind exposure (determined through use of LPDS 1-28[4]), and
2) the proposed fastener's withdrawal resistance (determined through field pull-out testing).

These variables are utilized to cross-reference an appropriate fastener coverage/spacing and minimum fastener head or disc diameter.

While Section 2.1.1 of the 1-29 (formerly published in LPDS 1-48, 1991) provides a tool for base sheet attachment design over non-FM Approved decks, the methodology is lacking in certain areas that should be considered.

1. The methodology includes no procedure for determining fastener withdrawal performance. Different test procedures produce different results, particularly in an inherently variable substrate. Moreover, the total number of withdrawal resistance tests to be performed is not stated, lending to the potential for a statistically unreliable data set.

   The most comprehensive field withdrawal resistance test protocol in the U.S. is Metro-Dade Protocol PA 105[5]. (See *Figure 3*, above.) Protocol PA 105 clearly establishes the apparatus to be used and procedures to be followed (including the number of tests based on roof size) in determining fastener withdrawal performance. Moreover, the protocol establishes a statistical analysis of recorded data resulting in a Minimum Characteristic Resistance Force (MCRF) for the particular fastener in the particular deck. The analysis includes reduction of the average withdrawal value by the product of the sample standard deviation and an "estimator." The estimator is a function of the desired probability (95%) and the number of tests performed. Therefore, the MCRF reflects the fastener performance while accounting for performance variations encountered through the entire roof deck (spread of data).

   Alternatively, fastener performance quantification could take place in the laboratory, where consistent, repeatable procedures are easily maintained. Moreover, use of laboratory equipment allows for more accurate simulation of fastener loading conditions. (Laboratory procedures are discussed later in this article.)

2. The methodology utilizes tabulated data to determine fastener spacing assuming a 36-inch wide base sheet and provides no allowances for alternate base sheet widths.

   While the consequences of this assumption could be considered negligible with the 2-to-1 margin of safety built into the 1-29 methodology, it is an assumption and should be recognized as such.

3. The methodology utilizes tabulated data to determine minimum fastener head/disc diameter, assuming the rupture value of the head/disc through the base sheet exceeds the fastener strength.

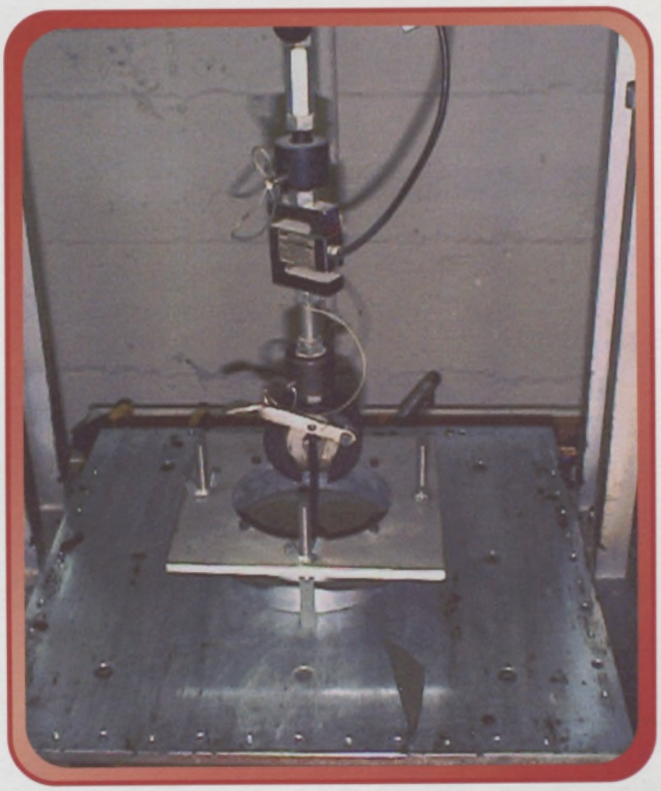


Figure 4: View of FM Rupture Test Apparatus.

The tabulated data, which correlate fastener strength to minimum head/disc diameter, utilize "user-friendly" methods; however, as illustrated later in this article, fastener rupture performance may not always exceed fastener withdrawal performance. There is presently no industry-accepted, consistent, repeatable test procedure for determination of representative base sheet rupture performance.

Factory Mutual Research Corporation does examine base sheet rupture when multiple base sheets are desired for FM Approved roof systems under Standard 4470. However, the data are used strictly for comparative purposes in determining a worst-case or critical base sheet for use in full scale uplift testing. The test procedure consists of clamping a single base sheet specimen in a seven-inch diameter clamping-ring, placing the subject fastener/plate through the center of the base sheet specimen, and applying load at two inches per minute until specimen failure. The maximum load required to rupture the base sheet is recorded. (See *Figure 4*.)

While the Factory Mutual test method allows for determining the "weakest" base sheet and designation of that sheet as "worst case" for simulated uplift testing of the roof system, the test procedure does not produce data representative of actual rupture performance.

- Values are generally higher than actual base sheet performance in a roof system due to the relatively small contributory area inherent to the test apparatus. For example, the seven-inch diameter clamping ring provides an area of 0.267 ft^2 per fastener, and a base sheet attachment pattern of 9 inches o.c. in a 4-inch lap and 18 inches o.c. in two staggered rows provides an area of 1.0 ft^2 per fastener. A contributory area difference of this magnitude drastically affects rupture performance as illustrated later in this article.
- Testing of a single base sheet with no overlying membrane does not represent base sheet performance when installed in a roof system. Inclusion of an asphalt- or torch-applied membrane over the base sheet increases rupture performance as some load is transferred to the adhesive bond to the fastener head or disc. Rupture resistance is further assisted when the fastener head or disc is equipped with holes that allow for adhesive flow-through. The type of roof cover installed over the base sheet is equally important as the base sheet itself, particularly as modified bitumen systems become lighter and less rigid, often including merely a torch-applied cap over a mechanically-attached base sheet.

4. Use of the LPDS 1-29 is limited to buildings having a field area design pressure not greater than 45 psf, the maximum Wind Exposure category set forth in the tabulated data. No direction is provided for field area design pressures in excess of 45 psf. This limitation ties in with what once was the maximum obtainable Windstorm Classification under Standard 4470.

Existing Studies of Wood and Wood-Based Deck Materials

As noted above, FME LPDS 1-29 provides a tool for base sheet attachment design over wood decks; however, the document does not provide fixed procedures to gather necessary fastener strength data. Whether determined in the field or in the laboratory, fastener strength is a vital component to system performance, and, therefore, should be quantified using consistent, repeatable procedures that ensure performance variation is taken into account.

Consistency in the testing of fastener performance in wood and wood-based products is something not seen in recent studies of the subject. Following are a number of studies published between 1990 and 1993 which examine general nail performance in new and wet/dry-conditioned plywood and OSB sheathing.

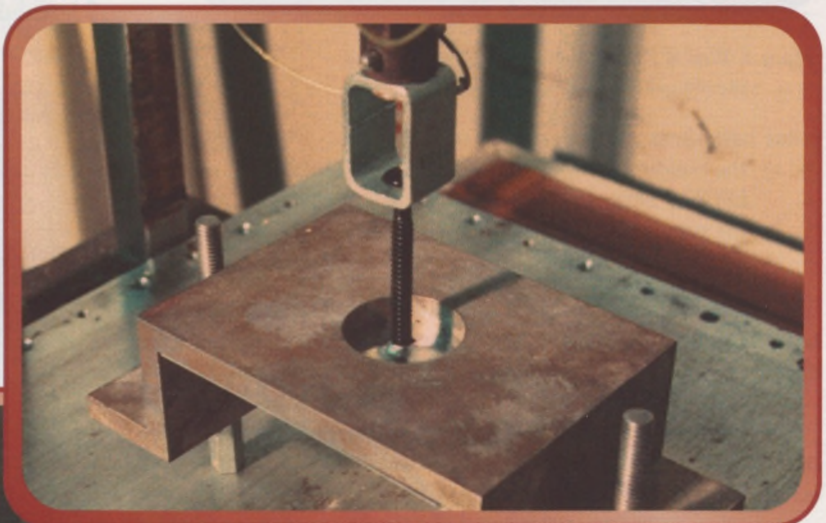
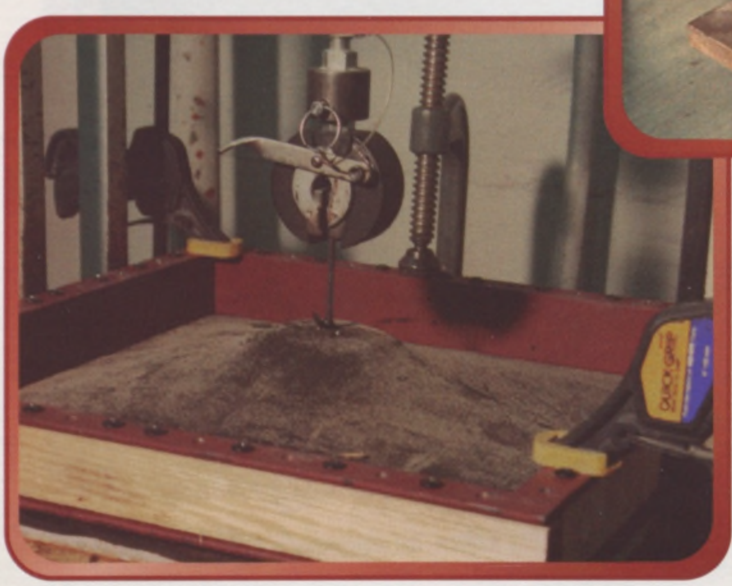


Figure 5 (above): View of NBI 129/83 Withdrawal Test.

Figure 6 (below): View of NBI 163/91 Rupture Test.



APA Report T92-8

This report publishes results of nail withdrawal testing following the procedures published in ASTM D-1761[6]. The author states the objective: "to determine if the 1/32" difference in nominal panel thickness had an appreciable effect on nail withdrawal capacities" and "to determine if deformed shank roofing nails provide increased withdrawal capacities relative to conventional smooth shank roofing nails." The report examines the performance of four nail types of a similar gage in two thicknesses of dry plywood. Test results document comparable performance regardless of plywood thickness and increased performance for deformed shank nails when compared to smooth shank nails. Results also document a large variance within each data set.

OSB vs. Plywood[7]

This report publishes results of nail and staple withdrawal testing following a procedure designed by the authors. The authors state the objective: "to simulate field conditions commonly encountered by the roofing contractor in fastening built-up roofing membranes to wood decks and to compare the withdrawal strength of standard BUR fasteners in OSB and in plywood decks." The authors continue, "Under various conditions, tests were performed to quantify fastener withdrawal strengths and to correlate the test results with industry standards for wind uplift." The report examines the performance of "standard roofing nails and standard staples" in various types of OSB and plywood under various wet/dry conditions. Test results document a performance reduction for nails and staples under increasing substrate soaking (wetting) conditions and comparable performance between OSB and plywood. In addition, the authors set forth the minimum nail or staple performance required to achieve a 60 psf and 90 psf uplift resistance when installed at patterns "recommended by roofing materials manufacturers." The authors go so far as to state: "...for the test conditions, both OSB and plywood have adequate average nail withdrawal strengths to obtain an uplift resistance equal to 60 psf or 90 psf."

Figure 8 (top left): View of 1" Diameter Cap Nail.

Figure 9 (top right): View of NBI 163/91 Rupture Test.

Figure 10 (left): View of FMRC Rupture Test (7" diameter).

Direct Withdrawal and Head Pull-Through Performance of Nails and Staples in Structural Wood-Based Panel Materials[8]

This report publishes results of nail withdrawal testing, among other tests, following the procedures published in Sections 47-53 of ASTM D 1037[9]. Referring to increased use of nail and staple guns in new types of wood-based panels, the authors state the objective: "New information on the performance of staples in these new sheathing and siding products is needed for comparative purposes." Among other variables, the report examines the performance of a roof sheathing nail and a power-driven staple in four wood-based sheathing materials under various wet/dry conditions. Test results document greater withdrawal performance of the power driven staple than the nail in all substrates when dry and after a 24-hour soak condition and greater withdrawal performance of the nail than the power-driven staple after the most severe weathering condition (6-cycle aged). In addition, test results document a performance reduction for nails and staples under increasing substrate weathering conditions.

Each of these studies provides valuable information; however, the value is limited to the scope and objective of the particular study. The lack of a common element between each study disallows any comparative analysis of data or further analysis of base sheet attachment over wood decks. Of the three studies, only OSB vs. Plywood specifically includes base sheet attachment and roof system performance in its scope. However, because base sheet rupture performance is not examined (or even considered), statements made regarding roof system uplift performance must be viewed within the context of the study—limited to nail withdrawal performance.

While studies have been performed and fastener performance data exist, review of these and other studies clearly emphasizes the need for consistent, industry-recognized, repeatable test procedures to generate comparable data with which to examine base sheet attachment and roof system uplift performance. The procedures must not only consider fastener withdrawal strength but must also consider base sheet rupture strength. A better reference within the scope of base sheet attachment analysis could be "Attachment Point Strength."

Existing European Design Tools

As noted above, the critical variable in the analysis and design of mechanically-attached base sheets is Attachment Point Strength. The objective is to examine both fastener withdrawal performance and base sheet rupture performance, and balance the two to establish a cost-effective method of base sheet attachment that will secure the roof system against wind-induced uplift pressures.

Field withdrawal resistance testing is a suitable means of obtaining fastener performance values. In addition, the laboratory is a valuable asset in this determination. Naturally, the value of either is subject to use of a consistent, repeatable procedure with provisions to account for variability in results. While testing in the field takes into account field conditions, use of laboratory equipment allows for more accurate simulation of fastener loading conditions.

Scandinavian countries have a 30-year history in the design and installation of mechanically-attached base sheets for use with built-up and modified bitumen roof systems. Over the years, these countries have developed, through the Norwegian Building Research Institute, test procedures designed to properly evaluate attachment point performance (examining both fastener withdrawal and membrane rupture) and system performance.

NBI 129/83 (NT Build 306[10])

This test procedure examines the withdrawal resistance performance of roofing fasteners. While the various procedures used in the U.S. examine fastener performance under a static, continuous load application, NBI 129/83 also examines performance under pulsating or cyclic loading conditions. This procedure incorporates fatigue into the examination. The procedure first establishes the average fastener performance under static load, then subjects the fastener to one interval of pulsating load consisting of one-fifth of the static load applied for 200 cycles. Upon completion of the first interval, the applied pulsating load is increased to two-fifths of the average static load result and additional interval of 200 cycles. This process continues until specimen failure or until the final interval is completed. (See *Figure 5*.) This laboratory test allows for accurate simulation of fastener loading conditions.

NBI 163/91[11]

This test procedure examines the membrane pull-through (rupture) performance of membranes with fastener heads, discs, or stress plates. As noted previously, various published studies

Figure 7: View of "Informs No. 5" Publication


No. 5

Information pamphlet no. 5-1990
(Substitute no. 2-1980)
Norwegian Roofing Research Group

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TPF INFORMS

MECHANICAL FASTENING OF ROOFING MEMBRANES

Design and construction

Authors: Arnold Askeland and Einar M.Paulsen

INTRODUCTION

This pamphlet is published by the Norwegian Roofing Research Group (TPF) and the Norwegian Building Research Institute (NBI).

The pamphlet describes mechanical fastening of roofing membranes and insulation with plugs, screws, nails and staples.

WHAT IS TPF?

The Norwegian Roofing Research Group is an amalgamation (on a voluntary basis) of firms working with roofing in the form of production and delivery of materials or carrying out roofing work.

The aim of TPF is to cover the need of the members, for research, when developing insulation- and roofing systems, and to publish information regarding the correct use of these.

Firms connected to TPF

Producers of insulating materials:
Elkem-Rockwool, OSLO
Siporex Elementbygg A/S, HOKKSUND
Norsk Leca A/S, OSLO

Producers of roofing materials and who have roofing departments:
Fjeldhammer Brug A/S, FJELLHAMAR
Isola as, EIDANGER
Protan A/S, DRAMMEN

Roofing companies:
Hesselbergtak A/S, OSLO
Ing. Per E.Jørnsen A/S, DRAMMEN
Arne Sande A/S, BERGEN
Scanditak A/S, TILLER
Tak og Fasader A/S, BERGEN
Takservice A/S, SPJELKAVIK
Karstein B.Vågenes A/S, BERGEN
RV-Tak, GJERDRUM
Eurotak Oslo A/S, RUD
Fagmann A/S, GJESÅSEN
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Montasjeutstyr A/S, SKÅRER
K-Plast AB, STRÄNGNÄS
Markt & Co A/S, SKÅRER
Sjong Fasteners A/S, OSLO
Jan Rube AB, HELSINGBORG
Tingstad A/S, OSLO

and presently-used design methods do not address this critical performance variable. Similar to the FMRC procedure, the NBI 163/91 procedure consists of clamping a specimen in a test frame, placing the subject fastener/plate through the center of the specimen, and applying load at a constant rate of deflection until specimen failure. However, the specimen size is 18 in. x 18 in. for a close representation of contributory area, and the specimen can include an asphalt or torch-applied cover sheet for accurate simulation of roof system installations. (See *Figure 6*.)

NBI 92/85 (NT Build 307[12])

This test procedure examines the uplift resistance performance of roof systems when subjected to static and pulsating simulated wind pressures. The test procedure, which is similar to Underwriters Laboratories' UL 580[13], positions a constructed deck and roof system specimen between two sealed chambers and subjects the specimen to predetermined intervals of positive pressure from below and negative pressure from above. The pressure intervals are continued at various, predetermined magnitudes until specimen failure.

Results from these component and system tests are utilized to design base sheet attachment on a project-by-project basis following the methodology outlined in Informs No. 5[14] and No. 5B[15]. (See *Figure 7*.)

Having generated a large database for component and system performance, following the same, consistent, repeatable test procedures, Scandinavian countries have a valuable design tool that the industry in the U.S. is lacking.

It should be noted that these procedures and methods were incorporated into The South Florida Building Code in the early 1990s. While FM Approved systems and systems tested in full scale uplift chambers remain the primary focus of design, the database that exists within the South Florida Building Code jurisdiction allows for proper evaluation of attachment point performance and system design for each project, particularly those having non-Approved deck types.

Data and Data Analysis

As noted earlier, base sheet rupture performance is a variable virtually non-existent in U.S. design procedures for base sheet attachment. While FME LPDS 1-29 addresses minimum fastener head/disc diameter, it does so qualitatively, assuming performance exceeding that of fastener withdrawal. While FMRC does examine base sheet rupture performance, the test procedure utilized results in data for comparative purposes only, yielding no design values. Scandinavian countries also examine rupture performance through NBI 163/91, but test procedures and specimens are designed to yield usable design values.

To illustrate this point, three ASTM D 4601 base sheets widely used in the U.S. market today were tested for rupture performance using one-inch diameter, standard, metal cap nails. Testing included use of both the FMRC and NBI 163/91 test procedures. (See *Figures 8* through *10*.)

Consider *Table 2*, below, which lists the resulting rupture values.

Table 2: Base Sheet Rupture Test Results (lbf)

Test Procedure	Base Sheet		
	A	B	C
FMRC	69.1	89.3	93.1
NBI 163/91	32.9	55.8	56.3

Note: Specimens tested per the FMRC procedure consisted solely of the base sheet. Those tested per the NBI 163/91 procedure included an asphalt applied sheet over the base sheet.

Review of these results indicates the following:

- Base sheets in the U.S. market, while compliant with ASTM D-4601 specifications, vary significantly in rupture performance.
- Test procedure has a significant impact on test results. Results generated using the FMRC procedure range from 60% to 110% greater than those generated using the NBI 163/91 procedure.
- Results for all base sheets under the FMRC procedure indicate all products could achieve a 45 psf uplift resistance if attached at a pattern of 9 inches o.c. in a 4-inch lap and 18 inches o.c. in two staggered rows in the center of the sheet (1 fastener per 1 sq. ft.). However, results under the NBI 163/91 procedure (a more representative procedure) indicate only sheets "B" and "C" could achieve this uplift resistance.
- The FME LPDS 1-29 specifies a minimum one-inch diameter fastener-head/disc for fastener performance less than 45 lbf, assuming base sheet rupture performance at 45 lbf or greater. Clearly, sheet "A" would not meet this assumption.

As noted earlier, base sheet rupture performance is significantly enhanced by the type of roof cover installed over the sheet. Consider *Table 3*, below, which lists rupture values recorded for various types of base sheets widely used in the U.S. market today. Base sheets were tested using a 1-5/8 inch diameter, metal cap nail following both the NBI 163/91 test procedures.

Table 3: Base Sheet Rupture Test Results (lbf)

Specimen Construction	Base Sheet		
	ASTM D-4601 Type II	ASTM D-2626	ASTM D-226 Type II
Center of base sheet only	34	35	30
Center of base sheet w/ asphalt-applied cover sheet	91	89	68
Center of 4" wide overlap of base sheet with asphalt-applied cover sheet	127	118	93

Review of these results indicates the following:

- Base sheets in the U.S. market, while compliant with various ASTM specifications, vary significantly in rupture performance.
- Specimen construction has a significant impact on test results. Results for all base sheets tested indicate a performance increase with an asphalt-applied cover sheet and when installed through a typical side lap.

Example Calculation

Scandinavian countries have developed a method for proper evaluation of attachment point performance and system design through Informs No. 5 and 5B, and associated test methods. The methods and procedures have since been incorporated into the South Florida Building Code. While FME LPDS 1-29 provides a tool for use in the rest of the U.S., the methodology does not explicitly consider base sheet rupture performance, a critical variable in roof system performance. The following example calculation serves to document these procedures, highlighting the issues covered by this article.

Consider a building having a 4 ply, 1/2-inch thick plywood deck. The roof design pressures have been calculated following industry recognized procedures, resulting in the following.

- Field Area: -45 psf
- Perimeter Areas: -75 psf
- Corner Areas: -105 psf

The designer would like to specify an ASTM D 4601, Type II base sheet, mechanically attached to the deck with 11 ga. smooth shank nails and 1-5/8 inch diameter tin caps, followed by an asphalt-applied, built-up roof.

Field withdrawal resistance testing has been performed using the 11 ga. smooth shank nail resulting in a Minimum Characteristic Resistance Force of 90.5 lbf. Rupture testing of the base sheet with the 1-5/8" diameter tin caps has resulted in an average value of 91 lbf. Applying a 2 to 1 margin of safety yields a base sheet attachment design value of 45.5 lbf.

Table 4, below, outlines results of analysis based on FME LPDS 1-29 and NBI Informs No. 5.

Table 4: Base Sheet Attachment Analysis Results, Minimum Spacing Requirements

Specimen Construction	FME LPDS 1-29			NBI Informs No. 5		
	Lap Row	Center Rows	Total Fasteners per Square	Lap Row	Two Center Rows	Total Fasteners per Square
Field	8" o.c.	2 @ 16" o.c.	113	9" o.c.	2 @ 18" o.c.	103
Perimeters	5" o.c.	2 @ 11" o.c.	172	5" o.c.	2 @ 12" o.c.	168
Corner	4" o.c.	2 @ 6" o.c.	262	4" o.c. or 6" o.c.	2 @ 7" o.c. or 3 @ 8" o.c.	244
Minimum head/disc diameter	2 inch			1-5/8 inch		

While an initial review of these results may indicate comparable requirements, consider also the following:

- While both procedures inherently include a 2 to 1 margin of safety, the LPDS 1-29 analysis results in more fasteners per square of roofing than are needed to adequately resist design pressures.
- The LPDS 1-29 analysis results in a very "tight" pattern at corner areas, particularly in the lap. However, the NBI Informs No. 5 method allows the designer flexibility to change fastener spacing by adding a row in the center of the sheet.
- Most importantly, the LPDS 1-29 analysis requires use of a minimum 2-inch diameter fastener head or disc, while the Informs No. 5 analysis, having already examined rupture performance, allows for use of the desired 1-5/8" diameter metal disc.
- Use of the Informs No. 5 method and associated test data allows the designer to determine the minimum "Attachment Point Value" to meet his/her design pressure parameters and, based thereon, select an appropriate base sheet, stress plate, and attachment pattern.
- It should be noted that the resultant requirements for field attachment tie-in closely to those set forth in the manufacturer's published literature referred to earlier in this article.

Discussion

One of the many environmental forces roof systems incur is wind-induced uplift pressure. While existing U.S. test procedures and performance criteria provide designers with the tools to specify "wind-resistant" roof systems, the procedures and criteria are extremely limiting in some areas, particularly for installations over wood decks. As the procedures and criteria become more prevalent in the industry, with no other means of performance-based specification, designers tend to use the existing criteria to "fail-proof" the system without adequate knowledge of its applicability to the project.

While tools for the design of "non-approved" roof systems do exist, they often are not used. Moreover, the existing tools fail to adequately examine all of the variables associated with uplift performance (fastener withdrawal, base sheet rupture, and system performance). This is partially due to lack of an industry-recognized, consistent, repeatable test procedure that examines each of these variables. All of these issues lend to the potential for under-design or over-design of the roof system. There are test procedures and design methods utilized in Europe and small areas of the U.S. that examine all variables associated with uplift performance, allowing the designer to properly evaluate attachment point performance and, based thereon, design base sheet attachment.

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Colin Murphy, RRO, RRC, founded Trinity Group Fastening Systems in 1981. In 1986, he established Trinity Engineering, focusing primarily on forensic analysis of roof systems, materials analysis, laboratory testing, and long-term analysis of in-place roof systems. The firm, formally known as Exterior Research & Design, LLC, Trinity Engineering, is based in Seattle, WA. Colin joined RCI in 1986 and became an RRC in 1993. He is currently the Director of Region VII. In 1996, he was honored with the Richard Horowitz Award for Excellence in technical writing for *Interface*. In 1998, RCI granted Colin the Herbert Busching Jr. Award for significant contributions to the general betterment of the roof consulting industry. Murphy and Ian Lurie authored the *Roof Construction Guide for General Contractors*, marketed by RCI.

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