PAPER NUMBER 5

PERFORMANCE CRITERIA AND TESTING FOR WIND AND FIRE RESISTANCE

R. L. Fricklas
Roofing Industry Educational Institute

Performance tests for fire and wind-uplift resistance of built-up roof assemblies evolve through experience and reaction to serious loss. Tests for three types of fire resistance—external, internal and time-rated fire endurance—have followed this pattern, with the catastrophic 1953 General Motors plant fire in Livonia, Michigan, sparking the most drastic changes in testing procedures and roof construction.

A similar process characterizes the development of tests and standards for wind-uplift resistance. The rising incidence of blowoffs during the 1960s paralleled the advent of lighter gage, flexible steel decks. New design criteria based on uplift tests and wind-tunnel tests, plus bad field experience with adhered (as opposed to mechanically fastened systems), have toughened wind-uplift standards for conventional bituminous roof systems.

The advantages of two-layered insulation—mechanically fastened bottom layer, hot-mopped top layer—have been documented through research and field experience. Meanwhile, the advent of loose ballasted roof systems, for which no generally recognized wind-uplift test procedures have been developed, poses the latest challenge in wind-uplift resistance.

TESTING FOR FIRE RESISTANCE

Fire testing can be classified into three basic categories:

- External fire exposure from flying brands or burning debris blown over from neighboring buildings on fire
- Internal fire exposure from interior inventory or equipment fires as measured by flame spread along the roof assembly soffit
- Fire endurance testing (time-temperature rating) per ASTM E119 furnace test.

External fire-resistance tests have been designed to simulate wind-blown flaming debris as well as to measure the movement of flames up a roof covering's surface. UL test conditions, known as Class A, B, and C, simulate field conditions very well. They are widely accepted under ASTM E108. The test conditions can be duplicated remarkably well from laboratory to laboratory, and the tests are suitable for evaluating fire resistance of many different types of roof covering system.

Internal (below-deck) fire testing evolved as a reaction to the catastrophic 1953 fire in a General Motors Transmission plant in Livonia, Mich. The Livonia fire exposed the previously unrecognized fire hazard presented by a bituminous roof system applied directly to metal deck. Intense heat from an interior equipment fire reached the underside of the metal deck. Bituminous vapor-retarder materials in direct contact with the hot metal deck melted or vaporized and entered the building, where they accelerated rapid spread of the fire.

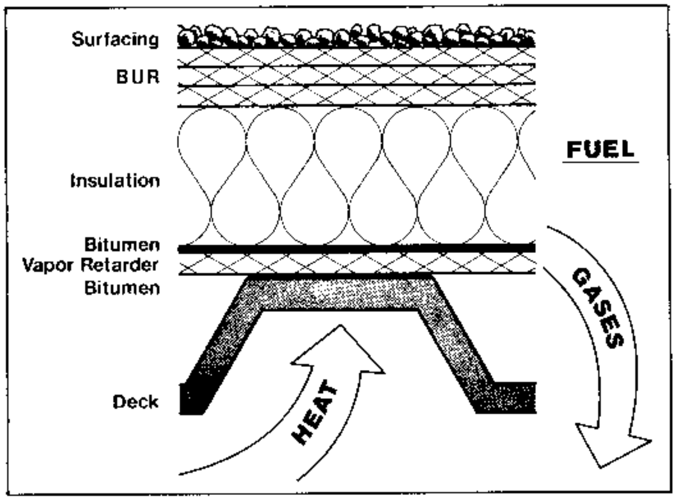

ILLUSTRATION 1
Fire Hazard of Insulated Steel Deck Construction

To establish criteria for fire-safe steel-deck built-up roof assemblies, Factory Mutual (FM) and Underwriters Laboratories (UL) built several large-scale building models to duplicate conditions that caused the intense burning and rapid flame spread in the GM fire. Incremental reductions were made from that level of combustibles until they were reduced to a safe level. The next step was to develop small-scale laboratory tests that duplicated the acceptable conditions determined by the large-scale tests.

As its approach to the problem, FM devised a test procedure featuring heat-release measurements in full-scale fire tests. These heat-release measurements (quantity and maximum rate during 30-minute fire exposure) are correlated with similar data from large-scale test-building fires to determine acceptable quantites of combustibles in the roof assembly. Since the mid-1950s, this FM Building Materials Calorimeter test procedure has been nationally recognized as the most representative acceptance criterion for the roofing and insurance industries, under the designation "Class I." It is applicable to roof assemblies with steel, wood, or structural cement fiber decks.

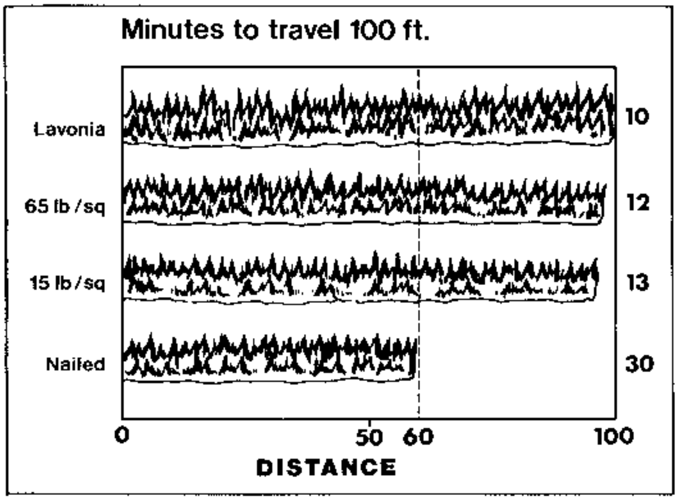

ILLUSTRATION 2
Fire Spread in Large Scale Test Building

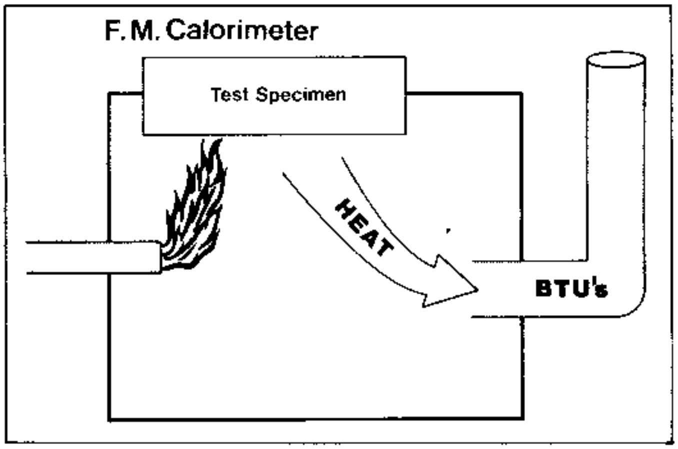

ILLUSTRATION 3
Factory Mutual Calorimeter

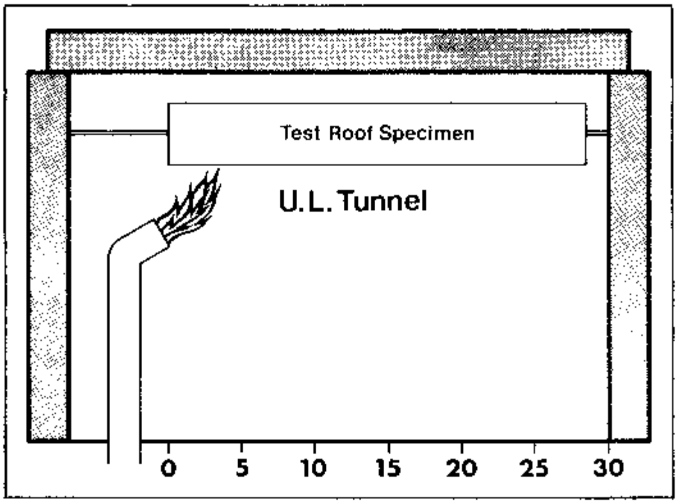

ILLUSTRATION 4
Underwriters Laboratories Tunnel

UL took a different approach, featuring its already developed test device, the Steiner tunnel, which measures flame spread and smoke density of building materials in a 10-minute test using red oak as the basis for comparison. To fire-test steel deck roof assemblies, UL modified the Steiner tunnel and installed in it a metal deck system, with all components from deck through surfacing aggregate. By comparing results with the large-scale tests, UL determined that a satisfactory assembly would not spread flame more than 10 ft. down the tunnel in 10 minutes, 14 ft. or less in 30 minutes. The 100-plus different insulated steel deck constructions that have passed this widely accepted test are listed in the current edition of the ***UL Building Materials Directory.***

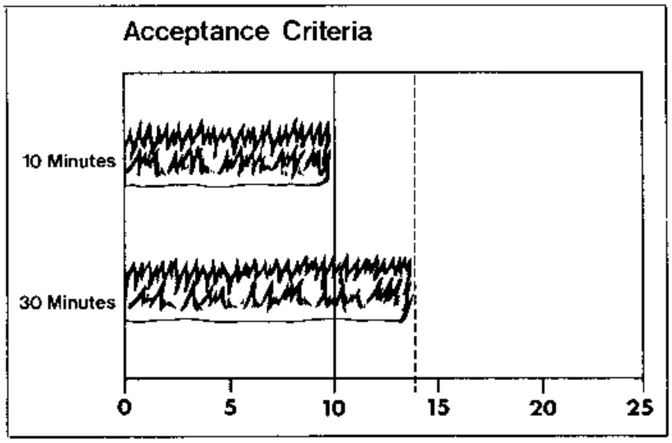

ILLUSTRATION 5
Acceptance Criteria of U.L. Procedure

Fire-endurance testing, using ASTM method E119, the third basic type of testing, exposes the bottom side of a roof-ceiling assembly to a specific temperature. Representing the fire load to which a building might be exposed, ASTM E119 is an index of its resistance to collapse. ASTM E119 does, however, pose a dilemma: as the system's thermal efficiency increases, the thermal load on the structural elements may increase, resulting in earlier failure. UL engineers have discovered that massive roof deck systems are not affected by increasing the R value from 22 or 3 to 20 or 30. There is more effect in the lighter constructions, such as

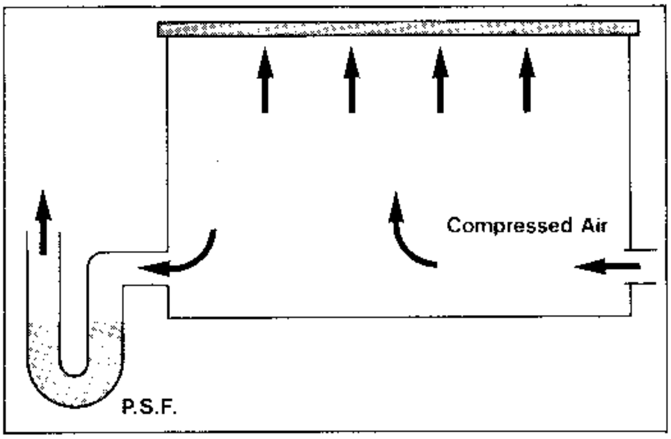

ILLUSTRATION 6
Fire Endurance (Time-Temperature) Testing

metal decks with hung ceilings. Nonetheless, several of these systems have been successfully tested and represented in UL's Fire Resistance Directory.

RECENT AND FURTHER DEVELOPMENTS IN FIRE RESISTANCE

In contrast with the successful fire tests described above, some small-scale fire tests, notably ASTM D1692, failed to exhibit the hazards of plastic foam insulation products when they were first used as construction materials. Some bad construction fires were unpredictable from the results of these small, unrealistic fire tests. Fortunately, when these same plastic foams were tested by the roof system tests previously discussed, these tests were found to be perfectly adequate, undoubtedly because the entire roof system was tested rather than single components. Polyurethane boards failed both the FM and UL criteria not merely because of their burning characteristics, but also because in melting they lost their ability to isolate the bituminous built-up roofing system from the fire. Acceptance of these materials was achieved by interposing perlite board, fibrous glass, or gypsum board between the polyurethane and the deck. Even if the plastic foam melted, the other product would remain in place as a barrier to fuel and combustible gasses. By having valid fire tests available to conduct development tests, the plastics industry was able to develop polyurethane foams with an isocyanurate "back-bone." In a fire, these will char in place, maintaining enough structure to hold back any bitumen. Several of these systems are now listed by FM and UL for direct application to metal roof decks.

Another recent related development has been the application of urethane foam sprayed directly to the topside of metal buildings. In this case, Underwriters Laboratories conducted a series of full-scale fire tests rather than laboratory tests, because of the complicated nature of the burning process. Some raised-seam roof decks, with appropriate combinations of foam and roof coating, are now classified.

WIND RESISTANCE

For about 10 years following the Livonia fire, field performance of these fire-rated steel roof deck assemblies was extremely good, with few problems reported. But then in the mid-1960s came thinner gage steel decks spanning longer distances with less securement at the ends, no fastening at sidelaps, stiffener grooves in the top flanges and narrower (3-in.) top flanges. These deck economies created their own set of problems: flange dishing and inadequate flat contact surface to receive adhesive and insulation. Under foot traffic, these thin-gage decks produced excessive dynamic deflections, causing failure of the adhesive bond. As a result of these compromises by the steel deck industry, steel deck roofs began to experience more frequent and larger-scale wind blowoffs.

The lack of attachment attributable to these economizing steel deck manufacturing practices remains a contributing factor in most wind losses. Just as the strength of a building depends on its foundation, the integrity of a roof system depends on the deck's rigidity.

Of the several small-scale laboratory tests available to evaluate steel roof deck systems for acceptable attachment, the FM method, developed in 1954, is probably the most widely recognized. It comprises a dynamic pressure test, with compressed air introduced between deck and roofing system in incremental steps until the roofing system fails. Roof assemblies that resist 60-psf uplift pressure for at least 60 seconds and meet the Class I fire condition are rated by FM as Class I-60 systems; those that resist 90-psf uplift for at least 60 seconds are rated I-90. This method has been satisfactory for testing the adhered roofing systems of the last 30 years. Critics point out that this FM test does not evaluate the effects of vibrations, oscillations and dynamic construction deflections that occur on a real building. There is, however, no available test programmed to duplicate these variables, especially construction traffic.

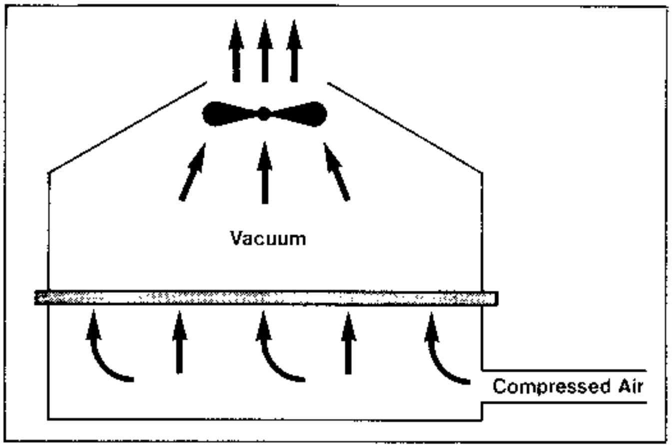

ILLUSTRATION 7
F.M. Uplift Pressure Test

UL uses a less well-known wind-pressure device. The lower chamber applies positive pressure like the FM method, but there is also an upper chamber cycled between atmospheric and negative pressure. This combination results in flexing of the roofing assembly thereby possibly correcting some deficiencies of the smaller scale FM test. UL classification levels are currently designated as Class 30, 60, and 90 with a Class 15 to be added when ANSI A58.1 is revised.

The roofing industry has been very slow to accept these standards, perhaps because of the severity of the UL tests, the cost, or both. The first conventional insulated metal deck

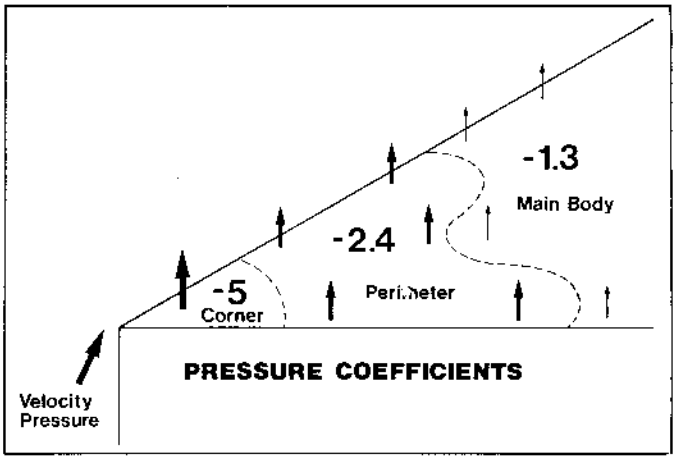

ILLUSTRATION 8
U.L. Uplift Pressure Test

system appeared in the UL directory in 1980.

In addition to progress in testing procedures, wind-uplift design pressures are periodically refined. When the American National Standards Institute published ANSI standard A58.1 in 1972, designers were able to mathematically estimate wind-uplift forces for a building under study. The ANSI standard recognizes such variables as terrain surrounding the building, building height average wind velocity from weather bureau studies, etc. By using published pressure coefficient data, wind-uplift pressures can be calculated for three different roof areas:

- corner areas where pressure coefficients are extremely high
- perimeter areas with moderate pressure coefficients, and
- interior portions where up-lift pressures are expected to be considerably less.

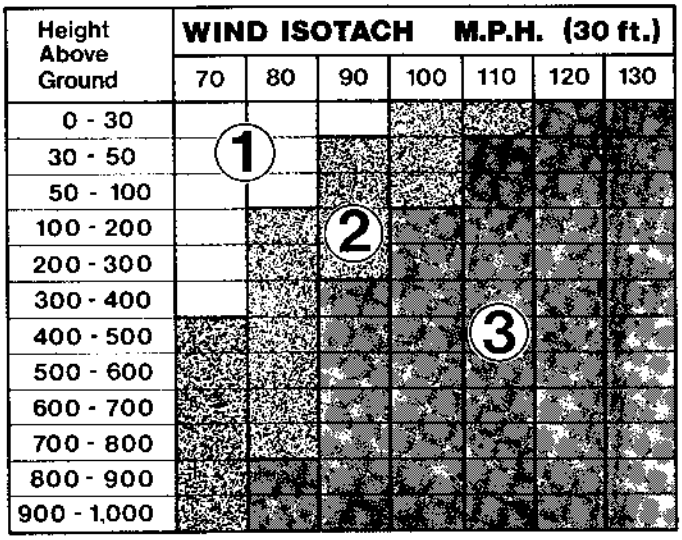

ILLUSTRATION 9
Pressure Coefficients for Various Roof Areas

This basic ANSI approach is incorprated in FM's Loss Data Sheet 1-7, which defines three wind zones.

Wind zone 1, for roofing systems with calculated wind-uplift pressure = 30 psf or less. This is related to the FM static pressure test by assuming that those systems passing their Class I approval standard (60) (safety factor = 2) are suitable for application on roofs in Zone 1.

Zone 2, where wind-uplift pressures are between 30 psf and 45 psf. In zone 2, roofing assemblies must be approved by FM through its I-90 listings.

Zone 3, for roofing systems with calculated wind-uplift pressures exceeding 45 psf where metal roof decks may be inadequate and special design precautions required.

The ANSI method provides the numerical uplift pressures in pounds per square foot, leaving it up to the designer to develop sufficient information to select an appropriate roof system. FM lists systems that meet its zone requirements. In the perimeter and corner areas subject to higher pressure coefficients, FM requires use of approved mechanical fasteners to supplement the basic method of attachment. Mechanical fasteners are more reliable than any adhesive system.

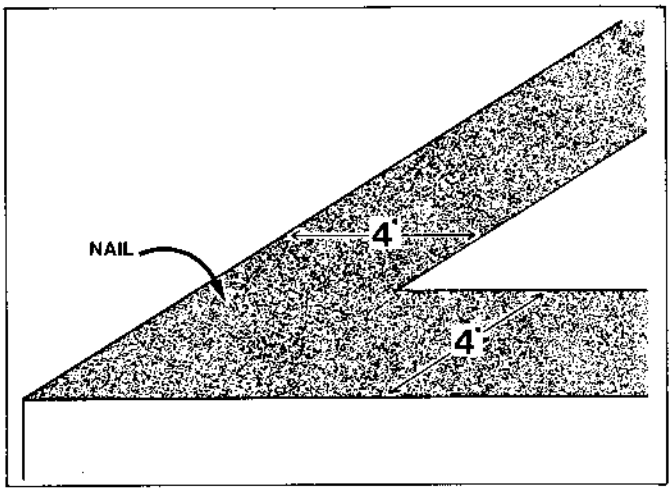

ILLUSTRATION 10
F.M. Zone Chart for Wind Resistance

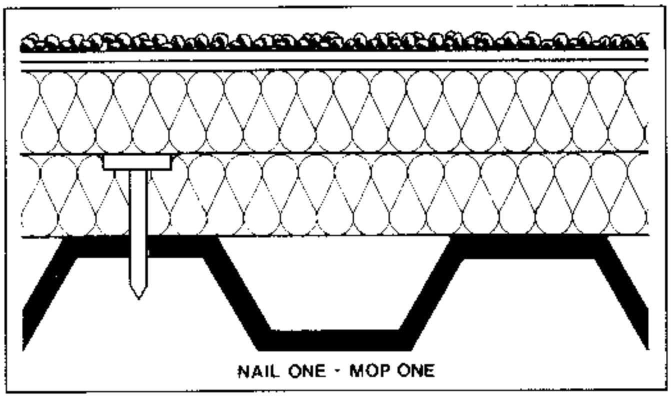

ILLUSTRATION 11
F.M. Perimeter Nailing Requirements

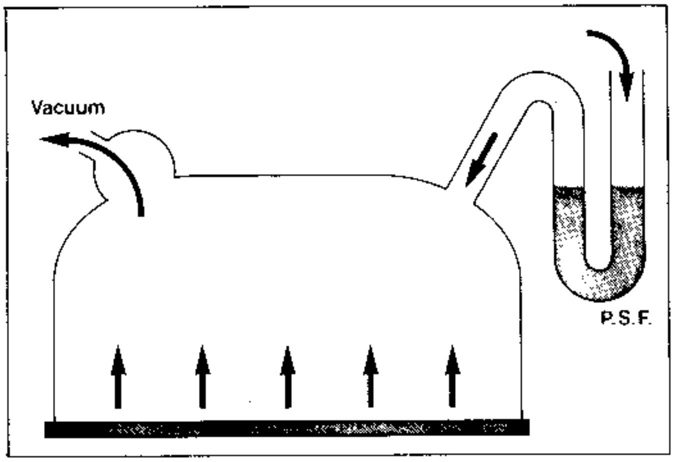

ILLUSTRATION 12
First Layer of Insulation Mechanically Fastened

The difficulties in accomplishing reliable field attachment of roofing systems with both cold adhesives and hot bitumens have led to the "nail-one, mop-one" technique. Here, the bottom layer of roof insulation is mechanically fastened throughout the entire roof area, not merely at the perimeter. The top insulation layer is adhered to the bottom layer by a solid asphalt mopping. Joints between the two insulation layers are staggered. Two-layered insulation has several advantages:

1. Improved insulation anchorage (since adhesion is less dependent on substrate temperature) and consequently improved resistance to construction loads and wind-induced oscillations
2. Improved thermal efficiency (through elimination of "thermal bridges" at single-layered insulation joints)
3. Reduced stress concentrations at insulation joints (improved continuity of the insulation "plate" reduces low-temperature thermal contraction stress in the membrane by about 10%, according to Owens-Corning research).

Introduction of these two-layer systems also allows a combination of two different insulating materials, exploiting the special advantages of each. For one example, the bottom layer can serve as fire barrier for the top layer. For another, the top layer might act as a heat sink to prevent gas pressure from forming between a bottom layer of plastic foam and an impermeable roof membrane.

Judged by FM's loss experience, secure anchorage of perimeter flashing is vital to roof-system wind resistance. If metal flashing is lost in a severe wind storm, wind peeling action is likely to destroy even a securely fastened roofing system. FM Loss Data Sheet 1-49 includes recommendations for anchorage of perimeter wood members as well as fascia metal. The latest version of the 1-49 data sheet is now also designed to satisfy requirements of the various wind zones.

A revision to ANSI standard A58.1, currently underway, includes such things as hurricane factors, importance factors and other adjustments to the basic method of calculating the potential wind-uplift forces. After its publication, FM will update Loss Data Sheet 1-7 to reflect these changes. Basic concepts will however, remain unchanged.

One criticism made of laboratory tests for wind-uplift resistance is that while these tests adequately establish discrete levels of performance for various roofing materials and systems, they do not simulate installation abuses and localized overloads.

Through the pioneering work of the Midwest Roofing Contractors Association and more recently an ASTM committee on wind tests, a field uplift test has been designed to test actual roofing in the field. This test is intended to be non-destructive,—i.e. an acceptable roof membrane would require no repair after the test is run. The obvious advantage of a non-destructive method is its testing of the actual roof assembly, not a sample assembly applied by experienced technicians under ideal weather conditions on a clean, warm, metal deck in a laboratory.

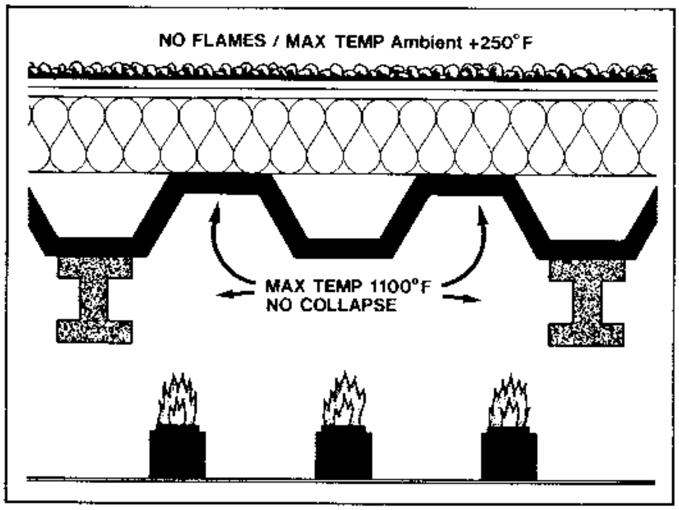

ILLUSTRATION 13
Uplift Test Device Designed for Field Testing

As the only compromise normally required for this field test, it is normally conducted before the flood coat and aggregate are applied. This timing is necessary to achieve an air-tight seal between the up-lift device and the roof membrane.

One drawback to running the negative pressure test prior to the graveling operation is that application of roofing aggregate normally involves heavy mechanized equipment. If the deck is not rigid enough to withstand the deflections and vibrations of this equipment traffic, the roofing system anchorage just judged acceptable could be ruined.

Work is continuing on the development of this test method. FM Data Sheet 1-52 on field uplift tests now includes this negative pressure test as a method of evaluating wind damaged roofing systems.

The entry of loose-laid roof systems into the roofing markets presents the latest problem in wind-uplift testing. Loose-laid roof systems, with their unanchored insulation and membrane, rely on ballast to keep them in place. It is impracticable to load a structure with ballast weighing 30 psf or more. More commonly, the dead weight of the ballast is around 10-15 psf. While this weight is probably insufficient to meet the design criteria of 30-40 psf normally required for attached systems, field experience suggests that an entirely different failure mechanism takes place in a ballasted roof. In the adhered system, any area that disbonds no longer contributes to the wind resistance of the roof system. These small unbonded areas can expand rapidly due to the low peeling resistance of the remaining attached section. An adhered roof system can thus experience a blowoff from local failure, much like the failure of the weakest link in a chain.

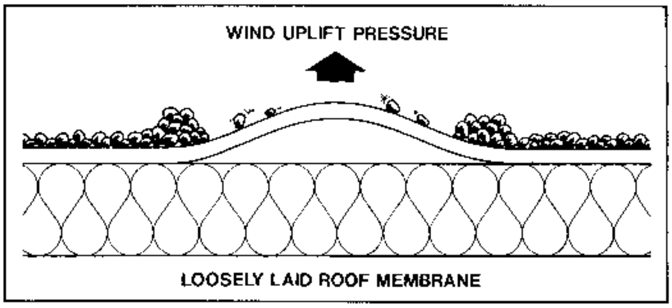

ILLUSTRATION 14
Wind Uplift Force on Loosely Laid, Ballasted Membrane

In ballasted systems, any area that does lift up transfers the ballast by rolling or dislodgement to nearby areas. Thus while a small section of the membrane might lose its ballast cover and be lifted up, the surrounding area would have the weight of the dislodged ballast as well as the original ballast and this should prevent further spreading of the damage.

Since we know that perimeters and corners are most vulnerable to wind-uplift, loosely laid systems are frequently protected by adding additional ballast at these locations. Sometimes concrete pavers weighing 20-25 psf are used instead of gravel in these areas. This provides a neat appearance to the roof structure and helps prevent roofing gravel from being blown off the roof, where it might break windows or hit pedestrians. These pavers are also used to delineate traffic walkways and to provide traffic platforms around rooftop HVAC units and other locations where workmen perform maintenance services.

Though we currently lack a valid wind-uplift test for loose-laid roof systems, the industry's successful development of performance tests for adhered systems points to a similar evolution of loose system testing of comparable reliability.