LAP ATTACHMENT OF MECHANICALLY FASTENED ROOF MEMBRANE SYSTEMS

COLIN MURPHY
Trinity Group Fastening Systems, Inc.
East Hanover, N.J.

The purpose of this paper is to identify and describe specific types of deterioration of mechanically attached roofing systems that may occur due to prolonged exposure to severe wind, and to substitute different assembly components or designs for comparative data.

Mechanically attached flexible-sheet roofing has become a standard roof system utilizing a variety of elastomeric sheets as a waterproofing membrane. Although there are a variety of designs, the predominant usage is the tab- or lap-attached system, whereby the sheet is attached to the substrate with a mechanical device and compression (stress) plate. The spacing of the mechanical devices ranges from one every 5 to 10 square feet, depending on sheet widths and code requirements.

A recent paper by Professor H.J. Gerhardt,[1] has questioned the need for the quantity of fixings in a mechanically fastened system, as well as the generally accepted design criteria established under ANSI standards. Although the conclusions drawn by Gerhardt are not contested on a theoretical basis, consideration must be given to a realistic deterioration factor as well as standard safety factors. Once types of deterioration have been identified, new components can be designed to resist deterioration. Further, safety factors can be devised in severe wind areas to take into account degrees of deterioration.

A paper by Kuno Hoher[2] discusses the results of testing linear or bar-attached systems with tab- or lap-attached systems. The purpose of the tests was to better understand the mechanics and stress conditions occurring in the two types of fastening systems. Additionally, Hoher tested the performance of the roofing membrane, mechanical attachment and insulation board under simulated conditions.

Hoher's testing demonstrates the superior performance and even stress characteristics of the "bar over the top" attachment system and brings to light a number of significant deficiencies of the tab-attached system, such as insulation fatigue, loss of compression between stress plate and membrane, and deformation of certain configurations of stress plates.

The cyclic testing detailed in this paper accentuates these deficiencies. Components were substituted and compared in an attempt to find those that would best resist deterioration. Minor design changes were tested to further increase the performance of the roof system.

A variety of laboratory and field testing has been undertaken to help understand the effects of wind on low-slope roofs. This testing has resulted in a number of wind-uplift procedures that examine, for the most part, ideal conditions of a roof assembly. Assemblies are constructed in the laboratory utilizing new materials. The test assembly is subjected to continually increasing wind-uplift pressure until the assembly fails or reaches the specified test load. However, roof systems begin to deteriorate from the moment they are subjected to weathering, wind and corrosion. If older roof systems were to be examined, the results could differ greatly.

As a comparative example, crash testing of new motor vehicles provides data for minimum safety standards. A 10-year-old vehicle that has been subjected to corrosion and vibration may not pass the test it easily passed when new. It is difficult to compare data when roof systems are subjected to varying external conditions as well as differing degrees of corrosion. To control the variables, the deterioration must be simulated. Test methods were developed to simulate deterioration created by wind and vibration. No test method has been generally accepted that will effectively accelerate the deterioration of the mechanical attachment of a roof assembly over its projected life. New methods of testing, such as the Brerwolf testing at the Building Research Establishment in England, which is running 50-year wind-stress tests, and cycling machines such as those used by Hoher, provide a basis for new cyclic test methods that may become part of basic system analysis in the United States in the future. Identifying and re-creating results of deterioration is the most effective way of realizing comparative data.

THE EFFECTS OF WIND ON MECHANICALLY FASTENED SINGLE-PLY LOW-SLOPE ROOFS

In general, mechanically attached single-ply roof systems can withstand significant wind-uplift pressures due to the inherent flexibility of sheet membranes. Single-ply sheets can absorb the effects of uplift forces and dissipate the stresses over a large area. The basic uplift pressure on a roof system is explained by the Bernoulli principle. This states that as the velocity increases in a fluid stream, the pressure decreases and vice versa. With stagnant air in the building and moving air outside the building, there is a pressure drop across the roof structure. The upwind edge of the roof magnifies the uplift force due to the forces that form along the roof edge when the airstream is compressed as it moves up over the building. The worst case is generated when the wind is 45 degrees at the corner.

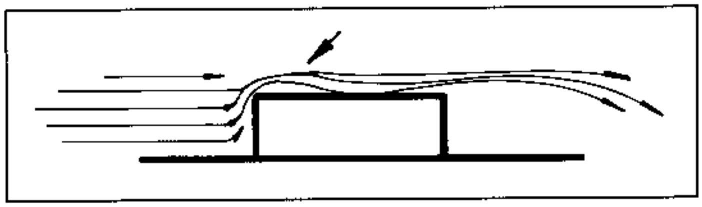

Figure 1 Wind over a building.

The effects of the negative pressure can be magnified by internal pressure. This may be the result of open windows or doors on the windward side, which increase the internal positive air pressure. The high permeability of certain deck types, combined with large open interior areas, can greatly increase the internal pressure underneath the roof membrane.

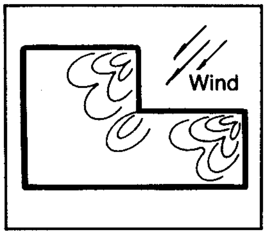

Figure 2 Pressure distribution of wind at 45 degrees on the corner of a building.

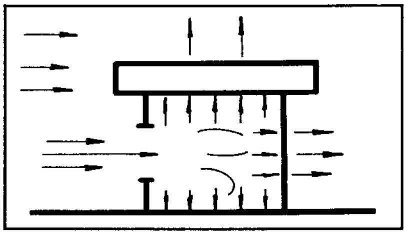

Figure 3 Combined pressure of wind striking a building through windward openings causing pressure differentials.

In recent years, roof system design has taken these factors into account, increasing the number of fasteners and decreasing the widths of perimeter sheets. Factory Mutual Research (FM) has addressed the condition in Loss Prevention Data Sheet 1-7 (April 1983), 1-28 (May 1983) and 1-29S (June 1986). The American National Standards Institute (ANSI) has also developed standards for various wind-load conditions, published in ANSI Publication A58.1-1982.

TESTING OF TAB-ATTACHED SYSTEMS

At present, wind-uplift testing is carried out by Factory Mutual Research utilizing a 5-by-9-foot positive wind-uplift chamber. A larger chamber (12½ by 24 feet) has been installed at the FM facility and is used when manufacturers have systems that exceed a 7-foot fastener spacing. The smaller test chamber at FM is a shallow rectangular pressure vessel. When testing, sections of deck material are cut to size and attached to the lower section of the chamber. Insulation is then mechanically fixed to the deck. A roofing cover is fixed to the deck or adhered to the insulation. The upper section of the vessel is then lowered and clamped to the bottom section. The clamping action forms a seal around the edges. Compressed air enters the assembly slowly in increments of 15 pounds per square foot (0.72 kPa). Once 30 pounds per square foot is achieved, pressure is maintained for a period of one minute. The pressure is increased in increments of 15 pounds per square foot over one minute periods until the assembly fails or it reaches the specified test load.

Failure takes place when:

- the membrane tears;
- the membrane and a mechanical assembly disengage; or
- a mechanical fastener pulls from the deck.

FM classifies roof systems as I-60 or I-90—resisting 60 pounds per square foot (2.87 kPa) and 90 pounds per square foot (4.31 kPa) respectively. A safety factor of two is calculated into the design pressure.

Therefore, when tested, the membrane system must withstand pressure twice the design criteria. For example, when pressure reaches 60 pounds per square foot (2.88 kPa) and holds for one minute without loss of pressure or failure of mechanical components, the assembly is windstorm rated Class I-60. Roof perimeters and corners are always exposed to higher uplift forces than the roof field. FM addresses the design of additional mechanical attachment in these areas

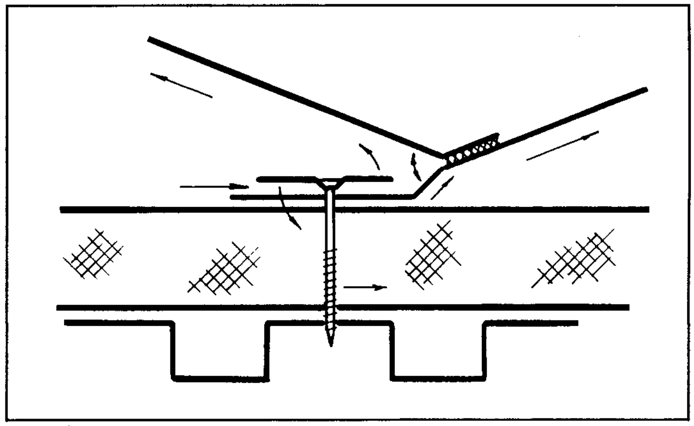

Figure 4 Directions of force on membrane, stress plate and fastener.

in FM Loss Prevention Data Sheets 1-7, 1-28, and 1-29S. As an example, fasteners at perimeters and corners for an I-90 rated system are increased by 50 percent. The fastening pattern within the chamber is calculated as the roof membrane would be fastened in the field of the roof. For example, a roof membrane 65 inches wide fastened 18 inches OC at the lap with a 4.5-inch tab would be calculated as follows:

sheet width	64 inches
less: tab width	4.5 inches
	59.5 inches
Multiply by fastener spacing ×	18 inches OC
Total number of square inches	1,071
÷ 144 = one fastener every 7.4 square feet	

When FM lays a system out on the uplift test table, it attempts to isolate a "system panel" in the center of the deck. In the example given above, the assembly would be tested as shown in Figures 5 or 5A. This is to assure a complete section representing the system is subjected to full pressure.

The load on each fastener can be calculated as follows when the assembly is inflated from 30 to 90 pounds per square foot:

30 lb/sq ft		= 222 lbs.
60 lb/sq ft	× 7.4 sq. ft.	= 444 lbs.
90 lb/sq ft		= 666 lbs.

Alternative or similar testing equipment is utilized by other test laboratories, such as United States Testing and Southwest Testing. Underwriters Laboratories (UL) utilizes a chamber, which, in addition to applying positive pressure to the underside of the assembly, has an upper chamber that cycles between atmospheric and negative pressure. The combination flexes the membrane, creating a somewhat more realistic wind condition compared to the positive wind-uplift chamber.

PRELIMINARY TESTING

Since all roof membrane systems tested had extensive FM positive wind-uplift testing, preliminary testing of each system was carried out in a 5-by-9 foot positive chamber. The data was recorded for comparison.

ACCELERATED DETERIORATION TESTING

A test device was developed to simulate extreme wind-uplift conditions. The test device, known as a COG machine, was developed to load the membrane at a predetermined angle

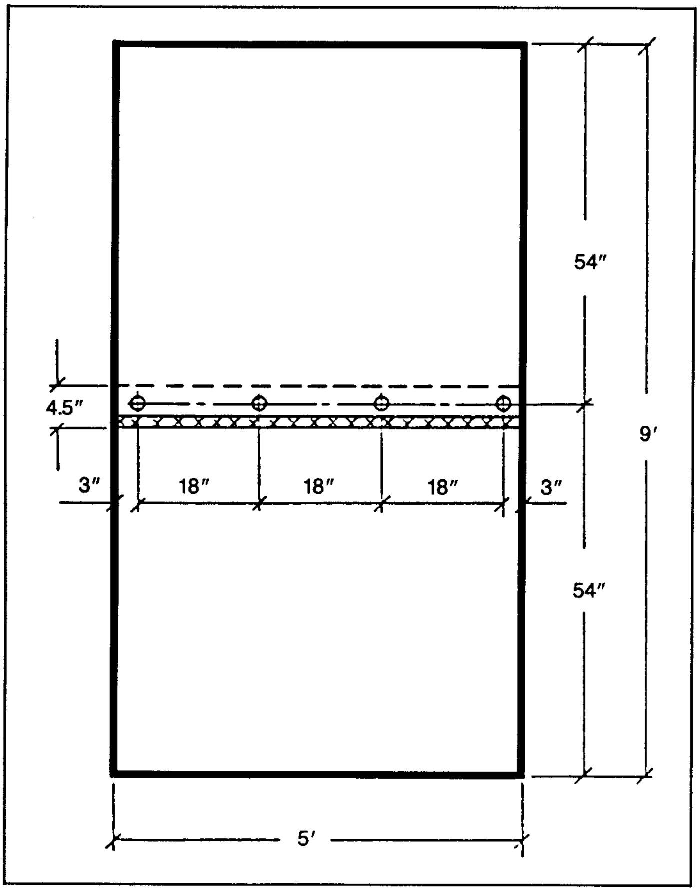

Figure 5

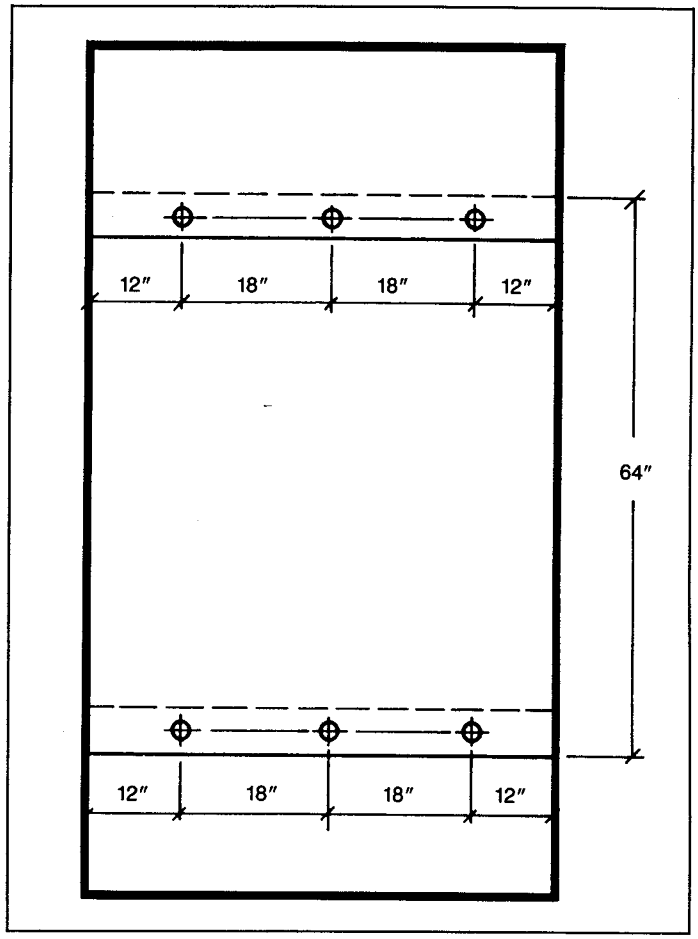

Figure 5A

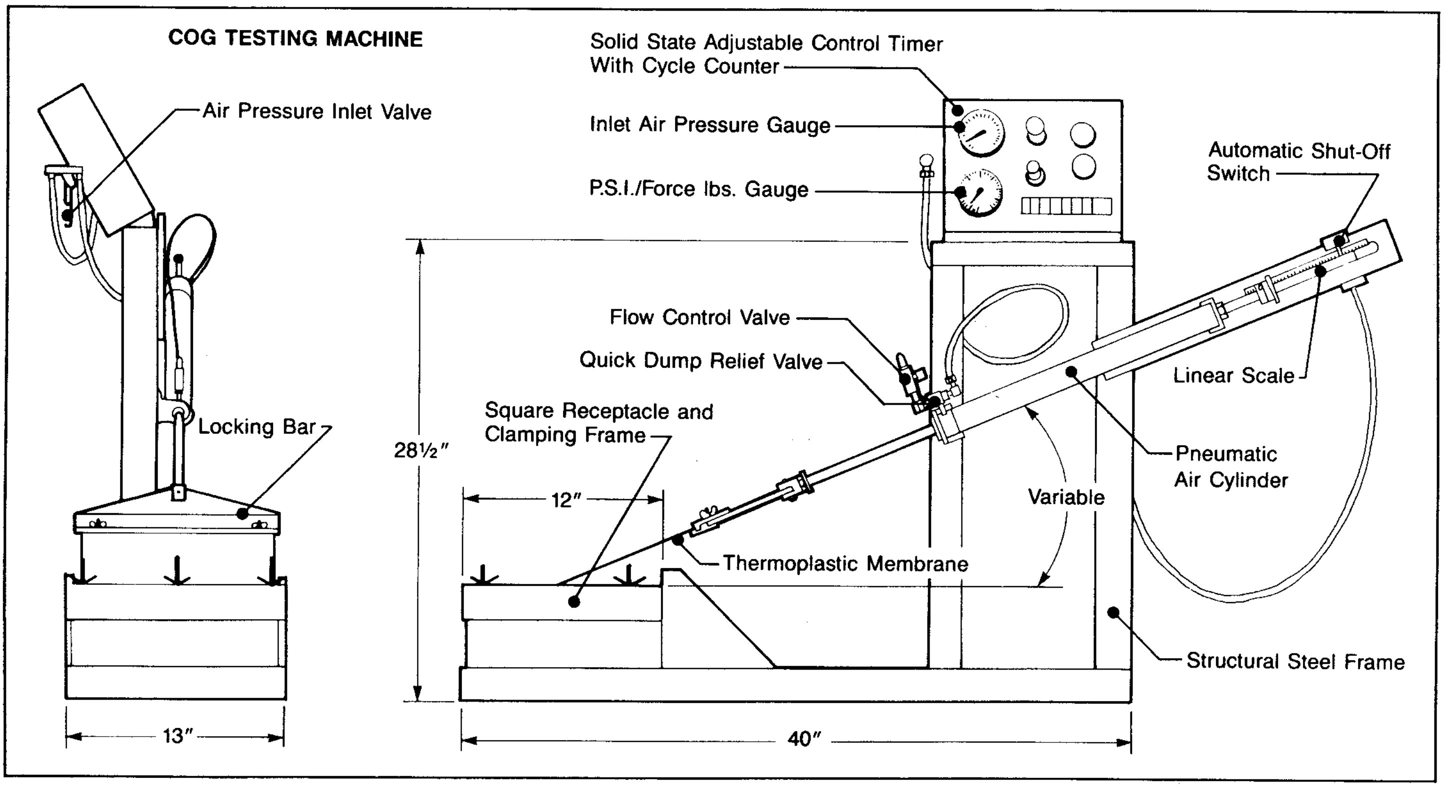

Figure 6 *COG machine.*

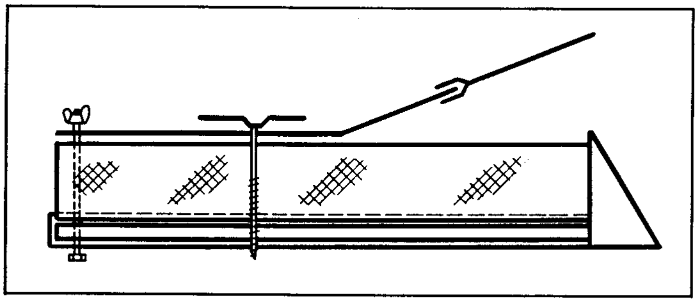

Figure 6A detail

to the assembly surface and to load the fastener assembly from zero to a peak of 140 pounds in one complete cycle. Testing was carried out at 35 cycles per minute. The test equipment was designed to simulate the effects of sheet flutter and wind-uplift forces on mechanically attached assemblies. The COG machine accelerated conditions of deterioration similar to those found in actual roof assemblies.

Seven roof systems installed at airport facilities on the east coast of the United States were examined for mechanical deterioration. Random samples at the perimeter, corners and in the field were examined and recorded to compare with COG test results. The deterioration accelerated by the COG machine was recorded and compared with the samples from actual roof systems. The deterioration was re-created in the positive wind-uplift chamber to compare with results from original FM testing and confirmed in subsequent positive wind-uplift tests.

EFFECTS OF WIND UPLIFT ON A TAB-ATTACHED SYSTEM

A tab- or lap-attached system is usually secured to a substrate with a metal or plastic stress plate in combination with a fastener. Fasteners and stress plates are spaced along one edge of the membrane at varying intervals depending on sheet width and code requirements. The overlapping membrane is fused to the adjoining sheet by solvent, hot air or adhesive. This set of tests utilized only heat-weldable membranes in order to maintain a greater degree of control. Negative pressure lifts the membrane from the substrate, leaving only the securement tab under the mechanical attachment static. Failure in the wind-uplift chamber takes place by one or a combination of the following:

- seam failure;
- stress plate deformation;
- membrane tears around stress plate;
- membrane tears out from under mechanical assembly; or
- fastener pulls from the substrate.

Five heat-weldable membranes were chosen for testing, representing a wide variety of thermoplastics.

Each membrane was tested over the following insulations:

- 2 pound-per-cubic-foot density polyisocyanurate, 1.2 inches thick;
- high-density fiberboard, 1 inch thick; and
- 1.25 pound-per-cubic-foot density expanded polystyrene, 1 inch thick.

Each membrane was tested with three types of fasteners:

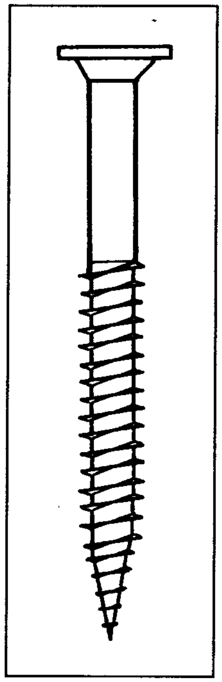

Figure 7 #12 diameter/11 threads per inch, gimlet point fastener

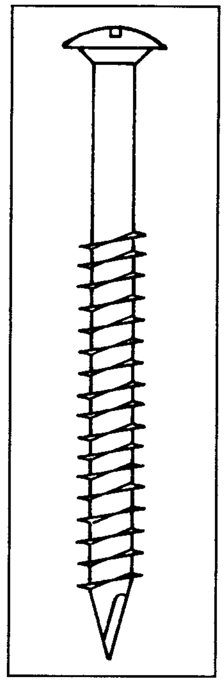

Figure 8 #14 diameter/10 threads per inch, slab point fastener

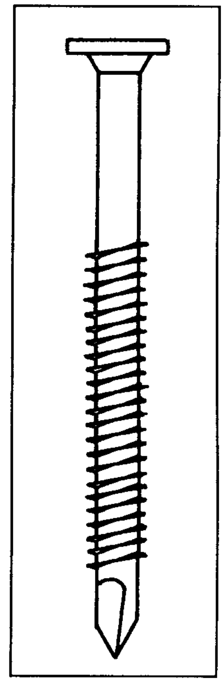

Figure 9 #14 diameter/14 threads per inch, reduced drill point fastener

In all tests noted in Table 2, all three fasteners were tested with identical results. Each membrane system achieved or exceeded the FM I-90 wind-uplift test results detailed in the 1988 FM Approval Guide over all three insulation boards over 22 gauge metal decking.

MEMBRANE	Type 1 REINFORCED PVC	Type 2 HYPALON	Type 3 REINFORCED EIP	Type 4 UNREINFORCED PVC	Type 5 REINFORCED PVC
Thickness	1.2mm (48 mil)	1.0mm (45 mil)	0.8mm (30 mil)	1.5mm (60 mil)	0.9mm (35 mil)
Roll Width	81″	64.5″	57″	49.25″	62″
Fastening for FM I-90	12″ OC	18″ OC	18″ OC	18″ OC	18″OC
Lap Width	4″	4.5″	4″	5.25″	5″
Fastener Spacing per Square Foot to Meet FM I-90	6.426	7.5	6.625	5.5	7.125
Type of Stress Plate	2″ round metal	2″ round metal	2″ round metal, barbed	1½″ x 2¾″ oval metal	2″ round plastic

Table 1

All fasteners penetrated the decks a minimum one-half inch. The fastener was located in the center of the 9-inch dimension of the sheet. Prior to setting the fastener, three test fasteners were installed in the deck material and pulled with a dynamometer for comparative data. An additional two fasteners were installed in the same manner. These fasteners were tested for breakaway and backout torque. The fastener head and stress plate were marked with a carbide stylus with a comparative mark on the membrane in order to record any movement.

The opposite end of the membrane was clamped to the locking bar at the air piston of the COG machine to pull the membrane at various angles. The angle of the pull was calculated by the angle measured in the positive wind-uplift chamber during the control tests. The COG machine pulled a load to 140 pounds at 35 cycles per minute. For the initial cycles, the quick dump valve was adjusted to provide a short stroke length. Afterward, the stroke length was adjusted to ¾ inch for the duration of cycling. Once the fastener had "broken away," reducing the compression of the stress plate on the membrane, the maximum load was reduced to 80 pounds. The reduction in load was necessary to achieve the maximum number of cycles before the membrane or fastener failed. The test ran for 50,000 cycles or until failure. An average test duration was 23 hours. The following data was recorded:

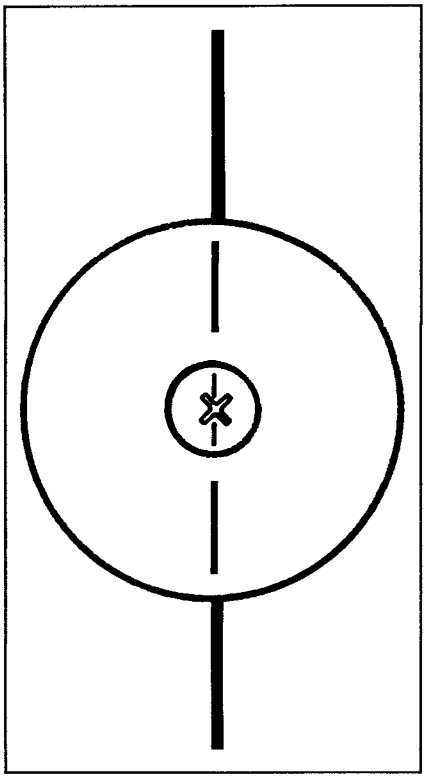

Figure 10 *Stylus and marking lines on fastener head, stress plate and membrane.*

- distance from the outer edge of the stress plate to the edge of the membrane (tab tear);
- number of cycles at which initial movement of the fastener took place (within 100);
- rotation of the fastener;
- rotation of the stress plate;
- depth of depression of the insulation on the pressure side of the stress plate; and
- tensile pull-out values before and after testing.

The following is a sample of the data noted on each test.

Membrane #1
with 2″ Round Stress Plate
Angle of pull: 20°
Deck type: 22 ga metal

Initial tensile pull-out values: (average of 3)

12–11	490 lbs.
14–10	575 lbs.
14–14	590 lbs.

Initial breakaway: (average of 3)

12–11	31 in/lbs.
14–10	28 in/lbs.
14–14	32 in/lbs.

Back-out torque:

12–11	6.3 in/lbs.
14–10	3.4 in/lbs.
14–14	6.7 in/lbs.

Cycle testing: (COG)
Initial breakway to nearest 100 cycles

12–11	15,100
14–10	13,800
14–14	20,400

Number of samples to run 50,000 cycles: 3
2 fiberboard samples
1 polyisocyanurate

Tab tear:

fiberboard	.475″
	.630″
polyisocyanurate	1.05″

All other samples tore out from under stress plate:

polyisocyanurate	(sample 1)	41,237
polyisocyanurate	(sample 3)	39,776
EPS	(sample 1)	28,134
EPS	(sample 2)	33,281
EPS	(sample 3)	33,474
fiberboard	(sample 2)	46,644

Insulation depressions: (average of 3 samples)
1. polyisocyanurate .240″
2. fiberboard .130″
3. EPS .290″

Fastener that rotated least:
14–14 over polyisocyanurate
90° after 50,000 cycles

Fastener that rotated most:
14–10 over fiberboard
140° after 46,644 cycles

Stress plate rotation was on average 12 percent greater than fastener rotation.

Stress plate deformation:
polyisocyanurate—all samples
fiberboard—all samples
EPS—none

Membrane	Insulations Polyisocy-anurate	Fiber-board	EPS	Comments
Type 1 2″ round metal	A	A	A	Minor stress plate deformation. Failure in all cases at 120 lb/sq ft.
Type 2 2″ round metal	A	A	A	Minor stress plate deformation in fiber board. Failure in all cases at 120 lb/sq ft.
Type 3 2″ round barbed metal	A	B	A	Minor stress plate deformation in fiber-board. Failure of 1 and 3 at 120 lb/sq ft. Failure of fiberboard at 135 lb/sq ft.
Type 4 1½″x2¾″ oval metal	B	B	A	Stress plate deformation. Failure in all cases at 105 lb/sq ft.
Type 5 2″ round plastic	A	A	A	No stress plate deformation. Failure in all cases at 105 lb/sq ft.

A = Tab tears out from under stress plate
B = Tab tears around stress plate

Table 2 *Positive wind-uplift testing.*

18 ga metal deck	45 inch lbs.
22 ga metal deck	34 inch lbs.
28 ga metal deck	25 inch lbs.
15/32″ plywood	30 inch lbs.
15/32″ oriented strand board	25 inch lbs.

Table 3 *Drive torque of insulation fastener.*

DISCUSSION OF RESULTS

Substrates for the tests were randomly selected from materials purchased over the counter. Due to variations in materials, properties and the limited number of tests, some results may not be representative of actual relative performance. In all cases, the fastener and the stress plate rotated in a counterclockwise direction. When the oval stress plate used in membrane 4 rotated, the next cycle would either turn the stress plate to its original position or deform one side of the plate. The barbed stress plate used in membrane sample 3 reduced tab slippage over all types of insulation and reduced or eliminated counterclockwise movement. The plastic stress plate utilized with membrane sample 5 absorbed some of the sheet load, reduced counterclockwise movement of the fastener and reduced depressions in the insulation. The rocking of the stress plate under cyclic conditions causes pressure on the outer tab side of the plate. The degree of deformation of the insulation is dependent on the stress plate and the density of the insulation. Since the fastening function is derived from the compression of the stress plate over the membrane, the loss of compression reduces the holding capabilities of the mechanical attachment. This was demonstrated in Hoher's tests with 40/80mm and 70/70mm stress plates.

As noted above, the most evident depressions were measured in polystyrene, the least evident in fiberboard. Although there was no decrease in insulation depression in membrane 3, the barbed stress plate reduced tab slippage and held samples for the full 50,000 cycles, more than any other stress plate. The plastic stress plate created the least depressions in the insulation. However, there was no increase in holding capability. The compression and fatigue of insulation recorded in the cycle testing was confirmed in field measurement on the seven jobs listed. In all cases, the depth of depressions were as deep, if not deeper, in actual jobsite conditions. The loss of compression reduced the load on the fastener. Jobsite visits confirmed fasteners backed out significantly in high wind conditions. In some cases, fasteners had backed out as much as 22 revolutions, the fastener head protruding through the membrane.

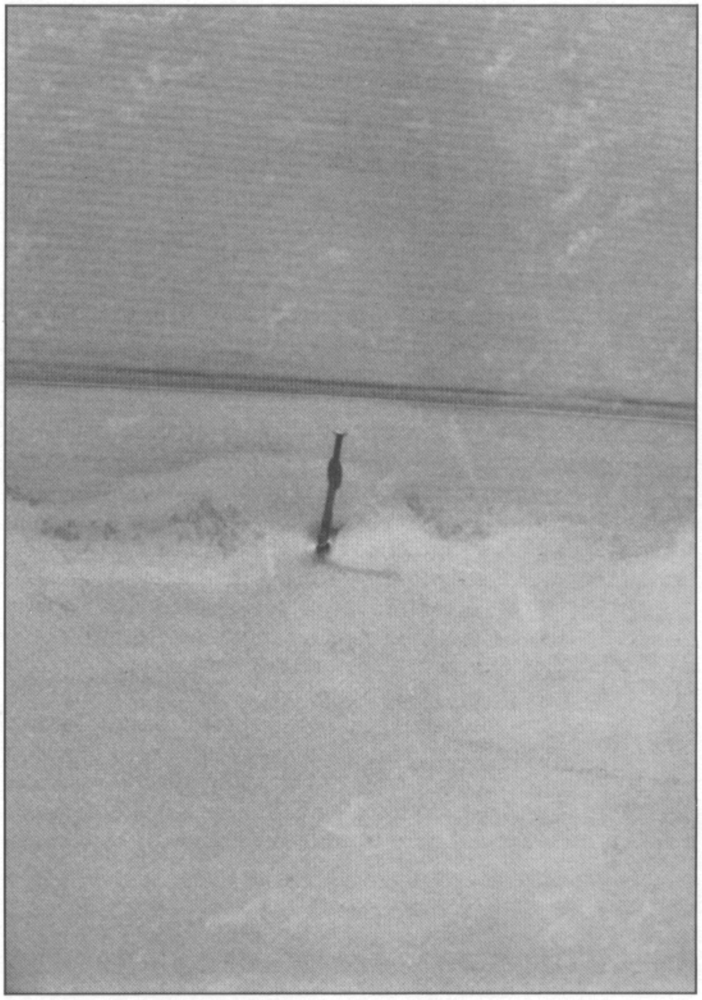

Photo 1 *Protruding fastener head.*

Although the cyclic testing confirmed a loss of compression, all potential causes of fastener backout have not been addressed. The COG machine is a very severe test which may, or may not, recreate actual conditions. In all seven roofs examined similar or worse conditions were recorded. All seven roofs have been subjected to higher than average wind conditions.

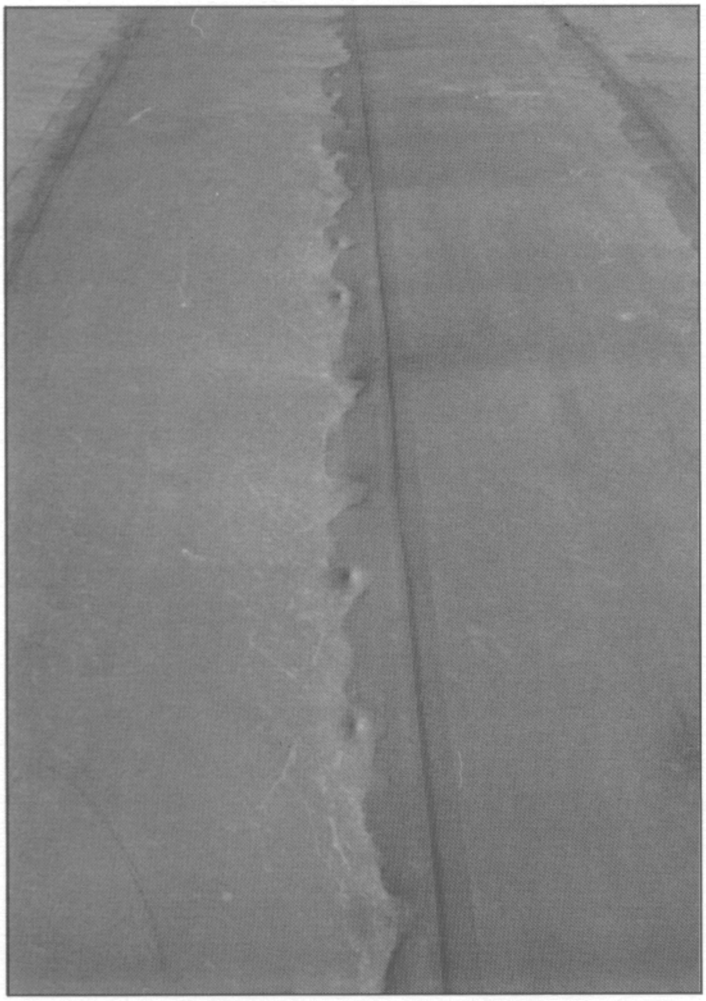

Photo 2

The breakaway of the three different types of fasteners is proportionately consistent with breakaway torque tests carried out prior to cyclic testing. The point and thread configurations play a major role in breakaway torque in different deck types. Since the load on the fastener is in an oblique direction, a vertical tensile pull-out test will not provide accurate design data. Reinforced membranes are capable of resisting tearout more than unreinforced membranes. With only a minor loss of compression, membrane 4 tore out from under the stress plate. Minor fastener movement of less than half a revolution of a 14–10 fastener was sufficient to allow the membrane to tear out from under the stress plate. The loss of compression was caused by:

- counterclockwise turning of the fastener; and
- compression and fatigue of the insulation board.

The oval plate utilized with membrane 4 had a tendency to turn once there was a loss of compression. If the stress plate turned during cycling, the stress plate would be deformed. This condition would be unlikely in a tab system since the overlap weld would hold the plate in position.

All threaded fasteners performed poorly in 15⁄32-inch plywood and oriented strand board. Threaded fasteners achieved limited success in 28 gauge composite deck. Membrane tear was evident in all samples. The least amount of tear was recorded with fiberboard samples; the greatest degree of tearout was recorded with EPS. The barbed stress plate utilized with membrane 3 recorded the least tear over all insulation and deck types. The knitted weave of membrane 3 has a very high tear strength that could have assisted in the reduction of tear.

CONCLUSIONS

As concluded by Hoher, the fastening function of a tab-attached system is highly dependent on the compressibility and fatigue factor of the insulation material. These tests recorded different degrees of compressibility and fatigue depending on the type of stress plate. The least compression was recorded with a plastic stress plate.

Although a metal barbed stress plate created a similar amount of compression as a metal non-barbed stress plate, it reduced membrane tearout.

When load from the membrane to the stress plate and fastener assembly is in an oblique direction, the fastener and stress plate will turn. The degree of rotation is dependent on:

- configuration of the stress plate;
- stress plate material;
- diameter point and thread pattern of the fastener (breakaway); and
- deck type.

The stress plate that turned least was the metal barbed stress plate followed by the plastic stress plate.

Reinforced membranes have a greater capability to resist tearout than unreinforced membranes. Only a minor loss of compression with an unreinforced membrane will result in tearout.

Threaded fasteners performed poorly in the 15⁄32-inch plywood and oriented strand boards. Fasteners in 28 gauge composite deck broke away early, especially over high density fiberboard.

Re-Creating of "Cycled" Samples

To re-create the conditions measured in the cycled testing, the deck assemblies were produced utilizing the summary of results obtained from the COG wind-uplift tests. Stress plates were placed on the attached sheet and marked for position. Fasteners were installed using a torque adjusted electric screwdriver to the drive torque noted in Table 3. The stress plate, membrane and insulation assembly were compressed with a hydraulic piston with an adjustable foot to re-create the insulation depression. The fastener was backed off ten revolutions in order to measure the insulation depression. In all cases, the simulated depressions were approximate. Fasteners were driven into place and then backed off to re-create the results obtained from the earlier COG tests. Fastener heads, stress plates and membranes were marked in order to record any movement.

Summary of Results

All test panels demonstrated significantly reduced wind-uplift resistance when subjected to the positive wind-uplift chamber except membrane 3. Membrane 3 recorded only a minor drop in results. The most significant drop in results was recorded with membrane 4, which tore out from under stress plates before one full minute of pressure at 60 pounds per square foot.

Conclusions

- Insulation compression and fatigue will cause a loss of compression of the stress plate over the membrane, the result of which is a loss of positive wind-uplift capabilities with most stress plate configurations.
- The barbed stress plate, after compression and fatigue of the insulation, had the most consistent results of any plate configuration.
- Due to the low tear strength of unreinforced membrane, loss of compression can result in a greater loss of wind-uplift capabilities.
- Cyclic testing and jobsite visits have confirmed backout of fasteners in tab attached systems.
- Accelerated testing, causing an uneven stress on a tab-attached stress plate and fastener cause the fastener and stress plate to turn in a counterclockwise direction. Such movement reduces the compression of the stress plate on the membrane, allowing the membrane to tear out from under the stress plate.
- Positive and wind-uplift testing recorded significant decreases in test results after cyclic testing of all samples. Samples with barbed plates recorded less of a decrease.

Further Testing

Cyclic testing with the COG machine highlighted the advantages of certain components. To confirm the advantages of these components, another series of tests was conducted substituting these components with all membranes. Additionally, non-threaded fasteners were tested in the lighter decks in an attempt to increase the results.

Testing was limited to two deck types:

- 22 gauge metal deck; and
- 28 gauge composite deck.

Both deck types were overlaid with the three insulations utilized in prior testing.

22 GAUGE METAL DECK

All five membrane systems were tested with a 2-inch round metal barbed stress plate and a 2″ round plastic barbed stress plate in combination with a 14-14 fastener.

All membranes were tested in a 5-by-9-foot positive wind-uplift chamber with the results recorded in Table 4.

In all cases where pressure exceeded 105 pounds per square foot, metal stress plate deformation was recorded over fiberboard. No deformation of plastic stress plates was recorded.

Membrane	Type 1 Polyisocyanurate	Type 2 Fiberboard	Type 3 EPS	Comments
Membrane #1				
Metal barbed plate	A	A	A	1, 2 & 3 at 135 lb/sq ft
Plastic barbed plate	A	A	A	1, 2 & 3 at 135 lb/sq ft (no sample held for 1 minute)
Membrane #2				
Metal barbed plate	A	A	A	1, 2 & 3 at 120 lb/sq ft
Plastic barbed plate	A	A	A	1 & 3 at 135 lb/sq ft 2 at 120 lb/sq ft
Membrane #3				
Metal barbed plate	A	B	A	1 & 3 at 135 lb/sq ft 2 at 120 lb/sq ft
Plastic barbed plate	A	A	A	1, 2 & 3 at 105 lb/sq ft
Membrane #4				
Metal barbed plate	B	B	B	1, 2 & 3 at 105 lb/sq ft
Plastic barbed plate	A	B	A	1, 2, & 3 at 105 lb/sq ft
Membrane #5				
Metal barbed plate	A	B	A	1, 2 & 3 at 105 lb/sq ft
Plastic barbed plate	A	A	A	1 & 2 at 105 lb/sq ft 3 at 105 lb/sq ft

A = Tab tears out from under stress plate B = Tab tears around stress plate

Table 4

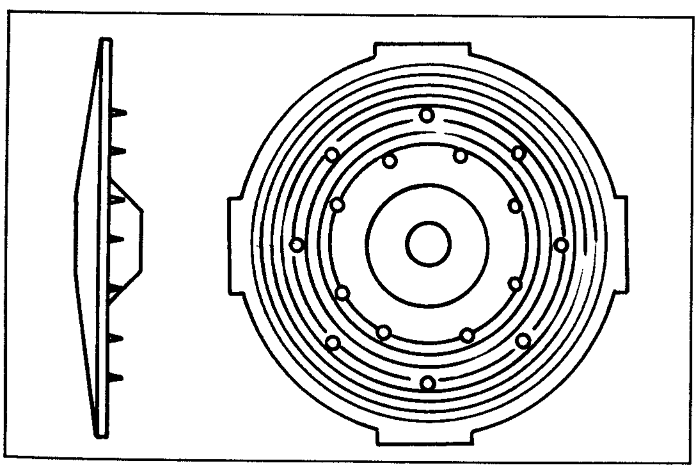

Figure 11 *Plastic stress plate.*

Discussion of Results

All samples achieved similar or better results than those noted in Table 2 except membrane 3 with a plastic barbed plate. Membrane 5 had a mode of failure change from Table 3.

COG TESTING

All membranes were tested over 22 gauge metal deck in combination with a metal and plastic barbed stress plate and a 14-14 fastener. The test methods were identical to the prior tests with the following results:

	Tab Tear	Insulation Depression on Pressure Side	Rotation of Fastener After 50,000 Cycles	Rotation of Stress Plate After 50,000 Cycles
MEMBRANE #1				
w/metal barbed stress plate				
polyisocyanurate	.127″	.210″	<10°	0°
fiberboard	.102″	.110″	<10°	0°
EPS	.187″	.280″	15°	<10°
w/plastic barbed stress plate				
polyisocyanurate	.114″	.110″	0°	0°
fiberboard	.092″	.060″	0°	0°
EPS	.138″	.140″	<10°	0°
MEMBRANE #2				
w/metal barbed stress plate				
polisocyanurate	.114″	.210″	<10°	0°
fiberboard	.085″	.110″	<10°	0°
EPS	.125″	.260″	<10°	20°
w/plastic barbed stress plate				
polyisocyanurate	.131″	.130″	0°	0°
fiberboard	.095″	.110″	0°	0°
EPS	.128″	.130″	<10°	<10°
MEMBRANE #3				
w/metal barbed stress plate				
polyisocyanurate	.143″	.250″	<10°	0°
fiberboard	.104″	.120″	<10°	0°
EPS	.180″	.270″	10°	2°
w/plastic barbed stress plate				
polyisocyanurate	tore out	not measurable	*1	*2
fiberboard	.112″	.074″	0°	0°
EPS	tore out	.138″	*1	*2
MEMBRANE #4				
w/metal barbed stress plate				
polyisocyanurate	.215″	.230″	0°	0°
fiberboard	.175″	.110″	0°	0°
EPS	.205″	.270″	0°	0°
w/plastic barbed stress plate				
polyisocyanurate	.178″	.200″	0°	0°
fiberboard	.183″	.090″	0°	0°
EPS	.225″	.120″	0°	0°
MEMBRANE #5				
w/metal barbed stress plate				
polyisocyanurate	.142″	.220″	<10°	0°
fiberboard	.100″	.070″	<10°	0°
EPS	.95″	.260″	<10°	<10°
w/plastic barbed stress plate				
polyisocyanurate	.134″	.130″	0°	0°
fiberboard	.085″	.090″	0°	0°
EPS	.155″	.150″	<10°	0°

*1. The plastic barbs did not penetrate the membrane; therefore, the stress plate sat up off the membrane.
*2. Results not valuable since the plate did not properly seat.

Table 5

Summary of Results

All metal plate samples recorded less tear and counterclockwise movement than in earlier tests except membrane 3, which recorded similar results. The plastic barbed stress plate recorded less movement of fastener and stress plate than the metal based stress plate and fastener. The plastic barbs were unable to puncture membrane 3 over low-density insulation.

Conclusions

- Both plastic and metal barbed plates recorded a greater reduction in tab tear than non-barbed stress plates.
- In conjunction with a 14–14 fastener, anti-rotational movement of the stress plate and fastener was reduced in a 22 gauge deck.
- A more significant reduction in anti-rotational move-

ment was recorded with plastic barbed stress plates than metal barbed stress plates.

- If the barbs do not set in or through the membrane, the plastic stress plate will not function.
- Insulation depressions in all three types of insulations were smaller with the use of plastic barbed stress plates.
- Plastic stress plates recorded no deformation.

28 GAUGE COMPOSITE DECK

Tests were carried out utilizing membranes 1 and 4 over 28 gauge composite deck with all three insulation boards. The loading of the membrane was reduced to 60 pounds to increase the number of cycles prior to failure. All samples were tested with a 12-11 gimlet point fastener with the following results:

An unreinforced sheet will tear out more quickly than a reinforced sheet.

- The rocking of the metal stress plate causes a loss of compression, reducing the load on the fastener.
- Once initial breakaway takes place, the fastener accelerates its rotational movement. However, no distinct pattern was recorded.
- The plastic stress plate did not rotate in any test. The flexibility of the plastic stress plate reduced insulation depression and "flexed" with the upward movement of the membrane.

NON-THREADED FASTENERS

Non-threaded peel rivet-type fasteners were substituted for threaded fasteners. Peel rivets were used in conjunction with

	Tab Tear	Insulation Depression on Pressure Site	Rotation of Fastener at Failure	Rotation of Stress Plate at Failure
MEMBRANE #1				
w/metal barbed stress plate				
polyisocyanurate	tore out 28,866 cycles	.170″	355°	<10°
fiberboard	tore out 17,935 cycles	.100″	930°	<10°
EPS	tore out 31,365 cycles	.200″	188°	<10°
w/plastic barbed stress plate				
polyisocyanurate	tore out 39,935 cycles	.130″	185°	0°
fiberboard	tore out 40,885 cycles	.080″	260°	0°
EPS	tore out 33,111 cycles	.180″	110°	0°
MEMBRANE #4				
w/metal barbed stress plate				
polyisocyanurate	tore out 16,355 cycles	.170″	120°	10°
fiberboard	tore out 9,840 cycles	.100″	390°	<10°
EPS	tore out 15,835 cycles	.200″	165°	<10°
w/plastic barbed stress plate				
polyisocyanurate	tore out 26,133 cycles	.140″	120°	0°
fiberboard	tore out 28,105 cycles	.090″	245°	0°
EPS	tore out 21,765 cycles	.160″	145°	0°

Table 6

Discussion of Results

The results cannot be compared with previous data due to the reduced load on the assembly. In all cases, fasteners with metal plates broke away earlier than plastic plates. Metal plates in combination with fiberboard recorded the earliest initial breakaway and the greatest fastener rotation. The lower density insulation board in combination with the plastic plate recorded the least amount of fastener movement. Tearout of the unreinforced membrane took place well before the reinforced membrane.

Conclusions

- Initial fastener breakaway takes place more quickly in lighter gauge metal decks.
- A metal stress plate over a dense insulation board acts as a lever, applying uneven stress on the head of the fastener, pulling the fastener from the deck.
- The rocking of the metal stress plate creates a deeper depression than the plastic stress plate.
- The rocking of the metal stress plate causes a loss of compression of the stress plate on the membrane, allowing the membrane to tear out from under the stress plate.

plastic and metal barbed stress plates and metal non-barbed 2-inch-round stress plates.

Assemblies were constructed with the identical substrates, insulation and membrane types enumerated in the three previous tests. In addition, samples were tested with 2-inch cement/wood fiber deck utilizing all insulations and membranes.

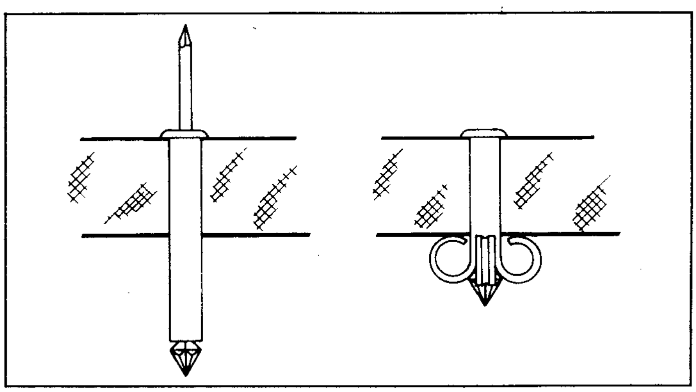

Figure 12

Each assembly was tested in the positive wind-uplift chamber and the COG machine. All fasteners were set with a hand-riveting tool 1½ inches below the underside of the decking in a pre-drilled 9/32-inch hole.

Procedure
Testing was conducted on all assemblies in the same manner as previously noted. The cement-wood fiber sample was subjected to 50,000 cycles of the COG machine at 75 pounds of load for the initial 3,000 cycles and 50 pounds of load for the remaining cycles.

Discussion of Results
Since the rivet-type fastener is non-threaded, no initial turning (breakaway) could take place. In all cases, there was no significant movement of any stress plates. Minimal loss of tensile pull-out values were recorded, with the exception of the cement/wood fiber samples. These samples averaged a 22percent loss in tensile pull values after COG testing. Membrane tear was recorded in all non-barbed plate samples. No tear was recorded with either plastic or metal barbed stress plates.

Summary of Results
- The use of a non-threaded fastener resulted in no counterclockwise movement of the stress plate or fastener.
- No membrane tearing was recorded with the use of plastic barbed stress plates. Minimal tearing was recorded with metal barbed stress plates.
- Deformation of stress plates was evident only with metal plates over fiberboard.

Conclusions
- A non-threaded fastener eliminates the possibility of any counterclockwise movement of the stress plate and fastener.
- A non-threaded fastener in combination with a barbed plastic stress plate produced best results in all membrane types except membrane 3, due to the inability of the plastic barbs to penetrate the membrane.
- Compression and fatigue of insulation boards was still recorded, especially when in combination with metal stress plates.
- Metal barbed stress plates deformed over fiberboard.
- There was no deformation of plastic stress plates.

DOUBLE-WELDED MEMBRANE

Identical samples of all five membranes over all three insulations were assembled with non-barbed 2-inch-round 22 gauge metal plates, in combination with a 14-10 fastener, positioned 2 inches from the outside tab. Fasteners were spaced in the identical spacing pattern as in previous tests. The membrane was seamed with a 2-inch weld on the outside edge and a 1-inch weld on the inside edge.

The outside weld was probed to insure a homogeneous bond. The inner weld was checked by flipping the membrane over to probe the inner seam. In all cases, the inside seam was found to have some voids as well as areas of reduced width. These seams were examined but not repaired. The membranes were tested in the positive wind-uplift chamber for comparative results. Identical samples were cycled in a 5-by-9-foot negative wind-uplift chamber for 50,000 cycles to record any fastener or stress plate movement.

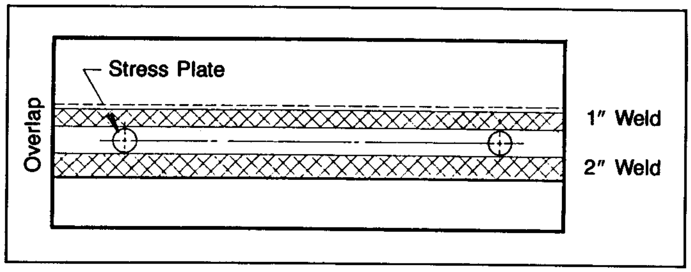

Figure 13 Double-welded membrane

Discussion of Results
All samples were assembled in laboratory conditions. The double weld encapsulated the stress plate within the tab, rendering tearing from under- the plate impossible. Fifty-thousand cycles of negative-wind testing produced insignificant counterclockwise movement of the stress plate and fastener. Failure of the test assemblies occurred when a fastener pulled out of the substrate or the membrane pulled over the stress plate. At no time did failure occur from a membrane slipping out from under a mechanical assembly. In all cases, the sample assemblies withstood greater wind-uplift pressure than with similar "open-tab" samples tested earlier. Minimal insulation depressions on the pressure side were recorded in all samples.

Summary of Results
- The double weld creates a more even loading of the mechanical assembly during wind-uplift conditions.
- The even loading virtually eliminates the counterclockwise movement of the stress plate or fastener.
- Assemblies with identical spacing withstood greater wind-uplift pressure than with an open tab.

Summary of Findings
As concluded by Hoher, there are a number of deficiencies in a tab-attached system as compared to a linear attached system. The cyclic testing of assemblies does generate deterioration of the assemblies in the following ways:
- loss of compression between the stress plate and membrane due to compression of the insulation;
- loss of compression between the stress plate and membrane due to counterclockwise movement of the fastener;
- deformation of stress plates; and
- premature tensile pull-out of the fastener caused by loading in an oblique direction.

Five membrane systems were tested utilizing a variety of components in conjunction with three fasteners. The following findings were recorded:
- Two-inch metal stress plates of ⅛ hard material deformed over fiberboard and polyisocyanurate. Two-inch metal stress plates of ¼ hard material deformed over fiberboard. Plastic stress plates did not deform.
- Metal stress plates caused deeper depressions in insulation than plastic stress plates.
- A plastic or metal barbed stress plate reduces membrane tear.
- Plastic stress plates absorb load transferred to them from the membrane and reduce the load transferred to the insulation.
- All fasteners in combination with metal stress plates were caused to turn in a counterclockwise direction dur-

ing the cyclic testing. Less fastener movement was recorded in combination with a plastic stress plate. Even less movement was recorded with a barbed plastic stress plate.

- Unreinforced membrane will tear out from under a stress plate more easily than reinforced membrane.
- Diameter, thread and point configurations of a fastener bear a direct relation to its ability to withstand counterclockwise movement. Each fastener had varying success depending on the other variables. The worst combination in all decks with all membranes was the 14-10 fastener with a non-barbed metal plate. The 14-10 recorded less counterclockwise movement with plastic or metal barbed plates and non-barbed plastic plates.
- The higher the insulation density, the lower the depression recorded after cycling. Higher density insulation in combination with metal plates recorded the greatest amount of counterclockwise movement of a fastener. This was most evident with the 14-10 fastener. Compression of the EPS insulation resulted in a greater proportion of tearout failures.
- Plastic barbed stress plates (in the configuration tested) do not penetrate all membrane types.
- Pulling of the fastener in an oblique direction in lower density thin decks (plywood and OSB) caused premature pull-out.
- When a non-threaded fastener was cycle tested, there was no anti-rotational movement. Further, there was no significant loss of tensile pull in all decks tested except cement/wood fiber. When the bottom tab is welded to the upper membrane, encapsulating the stress plate, the membrane can not tear out from under the stress plate. Additionally, the double weld places a more even load on the stress plate, transferring a more vertical pull to the fastener. An insignificant amount of counterclockwise movement was recorded in all samples.

Conclusions

- Cycling of the sample assemblies in the COG machine does generate deterioration due to counterclockwise movement of the stress plates and fasteners. Moreover, loss of compression of the stress plate on the membrane is caused by the rocking of the stress plate, especially over low-density insulation.
- The membrane, when loaded at an angle, places an uneven load on the stress plate. The uneven load on the stress plate is transferred to the fastener. The cycled testing recorded fastener backout at a wide variation of cycles depending on stress plate type, insulation density and fastener configuration. The worst configuration recorded was a 14-10 fastener in combination with a metal non-barbed stress plate over fiberboard. In general, the lighter the deck type, the faster the initial breakaway.

  Plastic stress plates absorbed a proportion of membrane loading and reduced the load transferred to the insulation creating smaller depressions. A plastic barbed plate, in combination with a variety of fasteners, recorded the least membrane tear, least fastener backout and the least insulation depressions.
- Insulation density plays a vital role in the performance of tab attached systems. Assemblies with EPS demonstrated the deepest insulation depressions and the greatest number of membrane tearouts. Fiberboard, being the most dense of insulation boards, causes metal stress plate deformation. Additionally, the added density assisted the stress plate by placing greater uneven stress under the fastener head.
- When the deterioration generated in the cycled tests was reproduced for positive wind-uplift testing, the results were significantly reduced.
- Testing of all membranes with both metal and plastic barbed stress plates recorded improved results, including reduced membrane tear, reduced rotation of stress plate and fastener, and greater resistance to positive wind-uplift forces after cycling of the sample assembly.

  Testing demonstrated the plastic barbed stress plate had the least counterclockwise movement and achieved the highest wind-uplift results, even after cyclic testing.
- The use of non-threaded fasteners will eliminate backout potential and will maintain a relatively constant pull-out value even when the fastener is loaded at an oblique angle. Optimum results were achieved in all deck types, membranes (excluding membrane 3) and insulation boards using a non-threaded fastener in combination with a plastic barbed stress plate. Cyclic testing recorded no significant deterioration of the assemblies.
- When a double weld was utilized with both barbed and non-barbed stress plates, the results were similar. The double weld reduced membrane tear; loaded the stress plate more evenly; increased wind-uplift resistance; and recorded insignificant deterioration in cyclic testing. Failure of the double-welded samples took place by either fastener pull-out, or pull-over of the membrane over the stress plate.

Present tab attached systems can be improved by:

- choosing the most appropriate fastener for the deck type;
- utilizing a plastic barbed stress plate that will pierce the membrane surface;
- utilizing insulation with sufficient density to minimize depressions; or
- double welding membrane to reduce membrane tear and more evenly load stress plates and fasteners.

The combination of these changes will result in greater resistance to deterioration caused by severe wind cycling.

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