

A Long Term Evaluation of Mechanical Attachment of Thermoplastic Systems



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This paper has been written in response to comments at the Roof Wind Uplift Testing Workshop in November, 1989, held at Oak Ridge, Tennessee. Comments were made in the opening remarks by Richard L. Fricklas, of the Roofing Industries Educational Institute (RIEI), and in the written presentation of the task group of R.L. Alumbaugh addressing research and development, regarding the lack of, and inadequacies of field testing of fastening components and their performance over an extended period of time.

Ongoing research has been carried out and documented detailing the performance of fasteners utilized in mechanically attached systems over an eleven year period in one region of the United States. The data provides an interesting picture in light of the Factory Mutual 4470 requirements for corrosion testing, the Factory Mutual Loss Prevention Data Sheet 1-28, and the proposals for dynamic testing similar to those recently adopted in Europe under the U.E.A. tc., and new discussion papers such as The British Standard draft BS 6399, Part 2.

In recent years the roofing industry has developed new standards for corrosion resistance and has quantified performance of fastening elements in specific roof systems. Data reveals an improvement in performance of the fastening system when corrosion resistance requirements are met (F.M. 4470) and density recommendations (ANSI A58.1, (recently revised as ASCE 7-88) FM 1-7 and FM 1-28) are properly executed. The 43 separate decks making up this survey confirm many roof systems have been installed and warranted with attachment not in compliance with ANSI

A58.1 or Factory Mutual recommendations. It should be noted that virtually all roof membrane manufacturers provide a warranty for wind speed not exceeding 65 m.p.h. Recurring wind speeds on both the 50 and 100 year maps are significantly higher than the maximum warranty wind speeds. This 'gap' should be a concern at the point of system design.

THE DATA SAMPLE, ROOF DECKS

Thirty seven roofing projects situated at facilities owned and/or operated by the Port Authority of New York and New Jersey, were identified prior to the commencement of re-roofing over existing built-up roofs. Buildings were situated at all three New York and New Jersey airports; repair facilities within the New York metropolitan area; and port facilities surrounding New York City and the West Hudson New Jersey piers.

All projects surveyed were re-roofed with mechanically attached PVC roof systems over rigid insulation ranging from 3/8" to 1.7" in thickness. All projects were re-roofs over existing asphalt or coal tar built-up roofs. Only minor removals were specified in saturated areas. In some cases, especially over concrete substrates, new roofs were installed over existing saturated built-up systems. These were identified, where possible, prior to the re-roofing commencement.

In all cases, withdrawal resistance testing was carried out within forty-five days prior to commencement of installation, repeated within three years of the completion date and repeated thereafter in three year intervals. The assistance of Frank Williams and Charles Bolechek of the Port Authority

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of New York and New Jersey Design Department is acknowledged and greatly appreciated by the author. In addition, the assistance of Russell Baker in collecting data is acknowledged.

The oldest project in the survey was installed in July, 1979. The last project was completed in October, 1987.



Photo 1
Hanger project installed in 1979. The manufacturer carried out frequent repairs to perimeter and barrel shoulders for the first four years of the installation.

In addition, data was collected as a broad sampling from 611 field tests carried out in the New York, New Jersey, Pennsylvania area, and subsequent retesting of 186 of the projects to confirm performance.

CHANGES IN APPLICATION

During the twelve year period, major changes have taken place in the installation of mechanically attached systems, as observed in these thirty-seven applications.

- Early installations had no preliminary attachment of insulation. This became a Factory Mutual requirement in 1983 in the Loss Prevention Data Sheet 1-28. Problems such as insulation board movement and curling were evident in pre 1983 applications.
- Early installations utilized electroplated zinc fasteners and first generation coatings, such as endurion. Corrosion was evident at an early stage, even in "moist" environments.

- Installations prior to 1983 utilized narrow membrane rolls (one meter or less) and comparatively dense fastening patterns.
- Few installations prior to 1986 followed the Factory Mutual Loss Prevention Data 1-28 recommendations calling for an increase of fastening elements at perimeters and corners.
- Attachment systems evolved from adhesive dependent "spot attached" systems to solely mechanical "lap attached" systems, creating a more economic application. Moreover, the newer systems were less dependent on good weather for application.

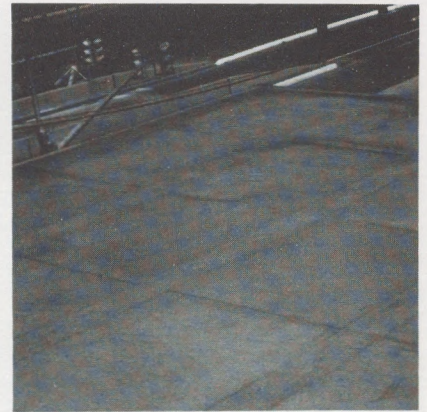


Photo 3
An 'early' 81" wide roll system with spot attached discs in the center of each row. The cross strips are a subsequent repair.



Photo 2
Early installations did not include preliminary insulation attachment. Subsequent attachment and perimeter repairs created an abundance of patches.

- Rigid foam insulation specifications improved over the period. Polystyrene density increased from 1 lb./ft.³ to a minimum of 1.25 lbs./ft.³. Eventually specifications changed to exclude expanded polystyrene, allowing only higher density extruded polystyrene and polyisocyanurate. Phenolic foam was added to the specifications and withdrawn after two years.
- Some applications in the mid 1980's were re-covered with unreinforced nominal 60 mil membrane systems; however, a large majority of systems were reinforced membranes. No unreinforced roofing systems were installed after 1986.

TEST PROCEDURE

Roofs were identified by public bid specifications prepared by the Design Section of the Engineering Department of the Port Authority of NY and NJ. On-site inspection was carried out to confirm existing conditions and to obtain roof samples. Static withdrawal tests at the rate of one test sample per 5,000 sq. ft. were carried out with the specified fastener. A minimum sampling of ten samples per roof deck was taken. Fasteners were installed and tested in the presence of a Port Authority observer in virtually all cases. Fasteners were tested utilizing a hydraulic dynamometer, calibrated quarterly by a recognized testing laboratory. Initial and ultimate failure values were recorded and plotted on a roof plan.



Photo 4
Finding a solid substrate for attachment.

Beginning in 1983, back-out and break-away torque values were added to the test procedure at the time of preliminary testing of metal deck and toggle bolt projects. Although a strict test procedure was maintained, minor variations in test methods during field testing were anticipated. Each project was monitored through the bid award, at which time the proposed fastener was confirmed with the successful bidder. If a change in fastener was declared by the successful bidder, a new set of tests was completed with the approved fastening system.

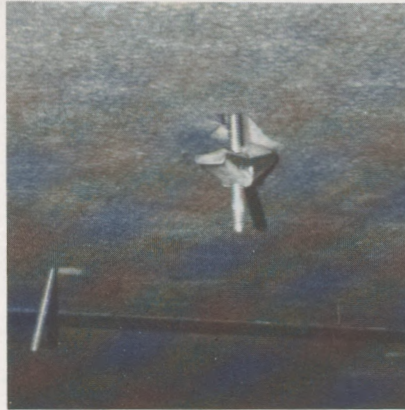


Photo 5
Toggle attachment systems with lost or loose toggle wings.

Within three years of application a re-inspection took place. Five samples from the perimeter and corner areas, and four field samples were identified for testing. The membrane was cut away from the fastener head for visual inspection. The fastener head and top side of the stress plate were inspected for signs of corrosion. Compression of the membrane and insulation were noted. Breakaway and backout torque were recorded in metal deck and toggle bolt applications. Insulation and membrane samples were taken from the area directly under the stress plate. Withdrawal resistance tests of the fastening elements were carried out withdrawing the fasteners in a similar manner to the preliminary testing. All fasteners and stress plates pulled were examined, details recorded and samples retained. Three insulation stress plates and fasteners were removed at the three and six year inspections for pull over tests. A visual examination of the entire attachment system from the top side of the membrane was made. Any deficiencies were noted and photographed. This examination procedure was repeated every three years.

If the roof installation had multiple roof decks, other than mechanical penthouses or canopies, each roof deck was treated as a separate building for the purpose of this survey.

WIND LOAD CALCULATIONS

A worksheet was formulated to calculate the wind pressure coefficients for each roof deck in compliance with the formulas

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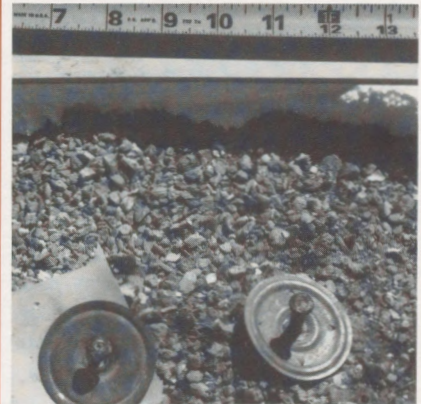


Photo 6
Removal of roof membrane and insulation to test fasteners during re-inspection.

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established in ANSI A58.1 (now ASCE 7-88) and Factory Mutual Loss Prevention Data Sheet 1-7, (revised April, 1983).¹ All data was entered into a computer database. The withdrawal resistance values were compared with 611 projects, in the Middle Atlantic region of the United States, of similar deck types. Although the identical dynamometer was not utilized on all projects, similar unit types were used and calibrated with the same regularity.

DISCUSSION

With the exception of two roof decks, all Port Authority buildings in the sample could be categorized as "exposed" roof decks, designated ground roughness categories "C" and "D" under ANSI defini-

tions.² Use of buildings ranged from pier warehouses and aircraft hangars, usually found to experience high internal pressures, to office buildings with masonry walls and roof decks with fixed window systems, usually found to experience very low internal pressures. A careful examination of the structure and its use was detailed in the preliminary examination sheet, and updated during each visit. Change of use of a building, or a part thereof, did take place during the survey period at three of the samples.

(No change of use altered windload pressure calculations from the original worksheets.)

NUMERICAL DATA (Port Authority Structures)

Deck Types	# of Decks
18-22 ga. metal decks (A,F,N and B types)	11
Poured concrete (2500 psi or greater)	12
Wood plank (1" and greater)	6
1/2" Plywood (varying grades)	2
Poured gypsum over fiberglass or gypsum formboard	8
Lightweight insulating concrete fill over 26 ga. metal pan	2
24 ga. corrugated metal deck	2
Total Number of Roof Decks	43
The 37 roofing projects consisted of 43 separate roof decks.	

Membrane Types	# of Decks
Reinforced PVC	38
Unreinforced PVC	5

Year of Installation	# of Decks
1979	3
1980	8
1981	7
1982	8
1983	8
1984	3
1985	3
1986	2
1987	1

Insulation Types	# of Decks
Expanded polystyrene (density of 1.00 to 1.25 lb/ft ³ [+/- 10%])	14
Extruded polystyrene	6
Polyisocyanurate	16
Phenolic foam	2
Wood fiber board	1
Polyurethane	3
Foamed polyethylene (rolls)	1

Fastener Types	Membrane Only	Insulation Only
#12 diameter threaded fasteners	7	14
#14 diameter threaded fasteners	11	4
Nylon expansion anchors(8mm diameter)	1	1
Aluminum peel rivets(1/4" diameter)	2	2
One piece concrete expansion anchors	7	9
Threaded concrete anchors	11	9
Toggle bolts	4	4

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AVERAGE WITHDRAWAL RESISTANCE IN LBS. (INITIAL FAILURE) BY FASTENER AND DECK TYPE

(All built-up roofing and insulation removed around test area)

#12 Fastener	Port Authority Survey	General Survey of 611 Projects
18 ga. metal	574	557
20 ga. metal	536	518
22 ga. metal	473	449
24 ga. metal	246	238
1/2" plywood	222	212
#14 Fastener		
16 ga. metal	886	793
18 ga. metal	605	608
20 ga. metal	577	546
22 ga. metal	492	472
24 ga. metal	248	262
Nylon Expansion Anchors		
18 ga. metal	362	341
Aluminum Peel Rivets		
Poured gypsum	444	463
Fill over 26 ga. pan	504	472
One Piece Concrete Expansion Anchors Poured concrete 2500 psi or greater		
3/16" diameter	980	874
1/4" diameter	1,132	979
#14 Threaded Concrete Anchors		
2,500 psi or greater poured concrete	781	717
Toggle Bolts		
	327	352

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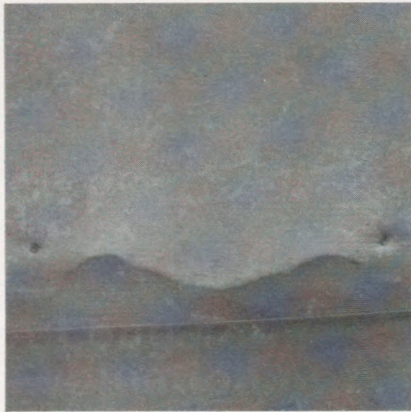


Photo 7

High uplift conditions stressed the weld and the lap plates causing bending of the plates and loss of fastener leads.

COMPARATIVE FASTENER DATA

All membrane fastening systems recorded a loss of withdrawal resistance over the survey period. The most significant decrease in fastener values was recorded after three years in 22 ga. metal decks recording an average drop of 12% for #12 fasteners and 16% for #14 fasteners. The most significant decrease in values, after a six year period, was recorded in concrete decks, recording an average 32% drop for 1/4" one piece expansion anchors and 37% for threaded concrete anchors. The greatest loss of values as an average of all fasteners in one roof deck over a nine year period, by percentage, was threaded fasteners installed in a concrete deck, with an average loss of 58% from the initial values.³

All metal deck fasteners recorded a progressive reduction in breakaway torque, the greatest reduction recorded at perimeter membrane attachment. Lap attached systems recorded the highest percentage of backout, most pronounced in perimeter and corner areas. Fastener head loss was observed in lap attached applications over concrete decks in perimeter and corner areas only.

Fasteners located in the perimeter areas, (perimeters as calculated by the ANSI A58.1 formula) recorded a 9.3% greater loss of withdrawal resistance than field areas in poured concrete decks and 6.8% in 22 ga. metal decks.

All 18 and 20 ga. metal decks recorded less than 1% difference between perimeter and field areas.⁴

All 24 ga. metal, poured gypsum and fill over 26 ga. pan decks recorded reductions of between 10.3 and 13.4%, the greatest being #12 fasteners in 24 ga. metal deck.

Pull-over values of metal deck fasteners and insulation stress plates decreased on average 14.2% over six years. Hammer type expansion anchors used in concrete had widely varying pull-over values caused as much by installation variables as from a deterioration of components. Similar installation variables (over driving) were observed on the threaded concrete anchor applications; however, the condition was not as pronounced as in "hammer in" anchors.⁵ Examination of toggle wings from the underside revealed missing and loose toggle wings as well as cone

shaped voids on the underside where form-board and gypsum were broken away. A greater percentage of toggle wings was missing or loose in perimeter areas than in the field of the roof.⁶

CORROSION

Corrosion of fastener components was most pronounced and most consistent in concrete deck applications. Lightweight insulating fill applications recorded a close second; however, it should be noted, only two roofs of this deck type were surveyed. Where the existing built-up roof and insulation were found to be dry in the initial survey, electro-plated zinc fasteners performed well over the nine year period. The majority of zinc plated fasteners removed for testing after six and nine years revealed no signs of corrosion. Corrosion was evident wherever moist or wet conditions were found in the original built-up roof and insulation system. Where a breach in the new membrane system occurred and was subsequently repaired, water entry caused corrosion in the affected area. No corrosion was evident at other areas of the roof deck. Concrete fasteners removed during the survey were found to have corroded at the roof deck level, and at the existing insulation level. Advanced corrosion was most evident in woodfiber and perlite installations under existing built-up roofing systems. Breakage of lap attached threaded concrete fasteners at the deck level was observed during three and six year examinations. In some cases breakage was observed in continuous rows of as many as sixteen fasteners spaced over thirty-two feet.

Galvanized stress plates and batten bars were observed in various stages of deterioration due to corrosion. Moisture rising as vapor from either the old roof system or from the interior of the building, condensed on the top side of the stress plate, beginning the corrosion process. Corrosion was most evident in the area surrounding the center hole, at the perimeters, and in any depressions of the stress plate. While rust was evident on virtually all samples nine years old and greater, red rust was observed in five samples only three years old. Early corrosion of the stress plates and/or batten bars was always coupled with an elevated moisture level in the existing built-up roof.

AVERAGE REDUCTION IN STATIC WITHDRAWAL RESISTANCE (%) BY DECK AND FASTENER TYPES OVER A SIX YEAR PERIOD (40 DECKS IN SAMPLING)

Metal Decks	22 ga.	20 ga.	18 ga.
#12 fasteners	15%	11%	7%
#14 fasteners	19%	11%	8%

Poured Concrete and Concrete Plank (2,500 psi or greater)	
One piece expansion anchors	32%
Threaded concrete anchors	37%
Wood Plank	
#12 fasteners	6%
#14 fasteners	4%
Plywood	
#12 fasteners	39%
#14 fasteners	42%
(Note: The sampling over 1/2" plywood was too small to be considered statistically significant.)	
Poured Gypsum	
Toggle bolts	19%
Peel rivets	6% ⁷
Lightweight Insulating Fill over 26 ga. pan	
#14 fasteners	32%
Peel rivets	8% ⁸
24 ga. Corrugated Metal Deck	
#12 fasteners	24%
#14 fasteners	31%

REDUCTION IN BREAKAWAY TORQUE OF LAP ATTACHED FASTENERS IN ALL GAGES OF METAL DECKS OVER A SEVEN YEAR PERIOD (6 DECKS IN SAMPLING)

#12 fasteners	26%
#14 fasteners	32%

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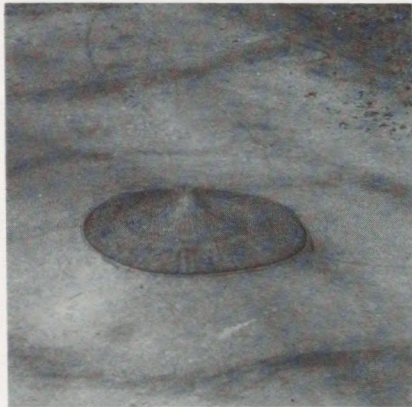


Photo 9
'Tented' fastener under a patch repair.

OBSERVATIONS

- Eighteen roof decks had evidence of fastener repairs at the perimeters and corners as calculated by the ANSI A58.1 formula (seven had evidence of fastener repairs in the field areas.)⁹



Photo 8
Corner repair with strips and individual fastener repairs with round patches.

- Thirty-one roof decks had fasteners "tenting" or puncturing the membrane, twenty seven of which were in the calculated perimeter and corner areas, after six years.

Metal decks (18-22 ga.)	10
Poured concrete or concrete plank	11
Wood plank	1
Plywood	2
Gypsum	4
Lightweight insulating concrete over 26 ga. pan	1
24 ga. metal	2

The eighteen "pure" lap attached systems revealed a higher rate of tented fasteners than any other type of system after six years of service over all deck types.

- Although most roof decks revealed some fasteners with some degree of corrosion, concrete deck applications revealed a higher level of deterioration more quickly and with a higher number of broken or tented fasteners. Coated and non-coated steel fasteners, installed in concrete decks in conjunction with perlite or woodfiber

insulation, under the existing built-up roofing, revealed the highest level of corrosion within the first three years. The same insulation types over wide rib metal deck were second, with insulating concrete fill registering third. It should be noted that all gypsum roof decks were reroofed over a smooth or gravel surface built-up roof with no existing insulation. All but one wood deck and plywood deck were originally roofed with fiberglass and a built-up composition membrane. Where moisture was present in the old insulation layer, corrosion of coated and non-coated parts was evident within three years. Where no moisture was present, coated and noncoated parts appeared to have performed equally. Coated fasteners installed subsequent to 1987 appear to be out performing their predecessors when compared after three years of service in similar roof conditions.

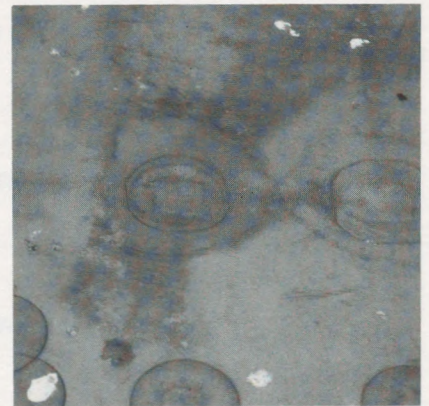


Photo 10
Concrete deck repair due to corroded fasteners.

- The percent of concrete deck fasteners installed over existing BUR and perlite or woodfiber, registering more than 15% red rust within three years of installation:

Coated:	80% of samples
Non-coated:	96% of samples

The percent of metal deck fasteners registering more than 15% red rust within 3 years of installation:

- Through Perlite or woodfiber insulation

Coated	47% of samples
Non-coated	74% of samples
- Through chemical foam insulation

Coated	38% of samples
Non-coated ¹⁰	47% of samples

- Several manufacturers and roof systems were installed utilizing various attachment accessories. The breakdown of system types is as follows:

Spot adhered to coated metal or membrane disc with adhesive or solvent	10
Combination spot adhesive and lap attached	5
Lap attached, disc	18
Lap attached, bar	7
Fastened over top with patch (disc/cap)	3

Although the spot adhered and combination systems were older, backout and breakage problems were observed more often in the more recent lap attached systems.



Photo 11
'Early' spot adhered and lap combination system with increased corner and perimeter attachment densities performing well after nine years.

Systems experiencing the highest number of fastener problems were those installed from 1983 through 1986, utilizing wide perimeter sheets (60" or greater) and no additional perimeter and corner securement.

The large majority of fastener problems were observed in the perimeter and corner areas of these systems.

Systems installed in 1979 through 1982 utilizing the spot attached adhesive system in a 24" X 24" grid are performing well at perimeter and corner areas in comparison to lap attached systems with no additional attachment at perimeters and corners. The nine year inspection revealed few attachment deficiencies at perimeters and corners, except where corrosion was present.¹¹ Additionally, hybrid systems using the adhesive or "over top" disc in the center of a two meter sheet and discs or bars at the lap, 12" o.c. are also performing comparatively well. Early systems were installed at an average spacing of one fastener every four square feet throughout the roof area. Some early fastening patterns systems are as dense as one fastener every 2.5 square feet, throughout.

When lap attached systems utilizing wider sheets with no center fastening were introduced, the roof systems were installed with fastening patterns as wide as one fastener every 9.5 square feet with no additional perimeter and corner fastening. Where additional fastening did take place, it was usually only the width of one sheet. In virtually all cases, the additional fastening was well below the density as calculated under the recommendations established in FM 1-7 and ANSI A58.1. Fewer repairs have been observed in perimeter and corner areas in these later systems than those installed between 1983 and 1986. No specific formula could be determined for the number of narrow rolls and/or closer fastening patterns utilized in the samples. Only five roof decks complied, at original installation, with the Factory Mutual Loss Prevention Data Sheet 1-28 requirement of 50% increase at perimeters

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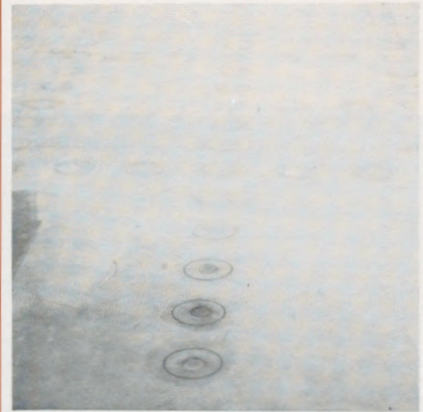


Photo 12
Early 'disc-over' system with no repairs needed over nine years.



Photo 13
A 1986 installation installed in compliance with ANSI A58.1, the perimeter width measuring 40% of the building height. No corner or perimeter repairs were observed.

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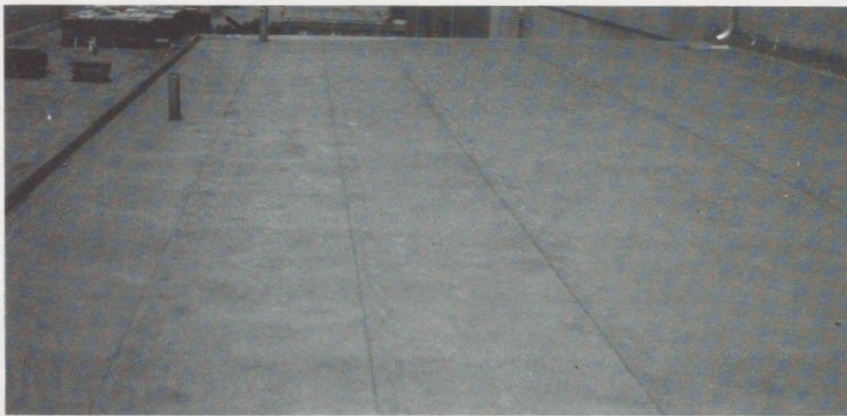


Photo 14
1986 installation of lower roof. Four half sheets, three at outer perimeter and one at the main building. Two full width sheets with fastening pattern at 12" o.c. (1:6 ft.²)



Photo 15
Multiple visits to the same repair area, a prevailing wind corner.

and corners based on the calculation of 40% of the height or 10% of the second largest dimension, whichever was less. Five samples complied with the pressure co-efficient requirements calculated under the ANSI A58.1 formula, utilizing a 3:1 margin of safety for metal and 4:1 margin of safety for concrete and lightweight decks.

Installations subsequent to 1986 revealed wider perimeter areas with a greater density of fastening elements in both the membrane, and in some cases, in the insulation.

The most common repair noted during the sixth year review was replacement of and additional fastening at perimeters and corners. Areas of repair were consistent with the perimeter areas calculated under the ANSI or Factory Mutual formula.

REPAIRS

Although perimeter and corner fastener repairs were the most common repairs of the original application, the most common cause of leakage was identified as punctures caused by the owner during maintenance and subcontractors carrying out non-roofing work from roof deck level.

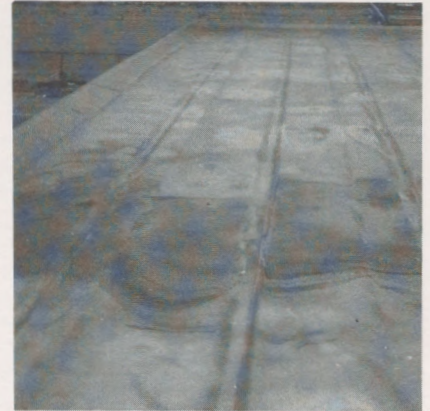


Photo 16
Wind damage to a 1983 installation with one perimeter half sheet.

Damage was caused by the installation of penetrations through the roof, punctures of membrane around HVAC units, contaminants pooling on or covering the membrane, damage to perimeter flashings by ladders or lifting equipment and poor ties to adjoining new construction. Water was able to enter both the new roof system as well as the existing built-up roofing, causing collapse of organic insulations and corroding fasteners.

CONCLUSIONS

- A loss of withdrawal resistance of membrane fasteners can be anticipated over the life cycle of a mechanically attached system. Margins of safety should be calculated after a decrease in the initial withdrawal value. The following reductions are suggested to compensate for anticipated loss of initial withdrawal resistance:

Metal Decks:	15%
Concrete Decks:	25%
Lightweight Decks:	30%

The dynamic load conditions observed over the eleven year period confirm progressive loss of withdrawal resistance separate and apart from failure caused by corrosion of the parts.

Example 1: (Metal Deck) Average initial withdrawal resistance 360 lbs. less 15% = 275/lbs. margin of safety of 3:1 = 91.6 lbs.

Example 2: (Concrete deck) Average initial withdrawal resistance 760 lbs. less 25% = 570/lbs. margin of safety of 4:1 = 142.5 lbs.

Example 3: (Lightweight deck) 450 lbs. less 30% = 315/lbs. margin of safety of 4:1 = 79 lbs.

- Additional fastening of perimeter and corner areas should be calculated according to industry accepted formula established by ANSI A58.1(now ASCE 7-88) or in compliance with Data Sheet 1-28.



Photo 17
Poor maintenance was a common problem on all roofs in the survey.

- While coated fasteners will reduce corrosion, red rust will form during the 10 year life cycle when certain variables are present. When the substrate is dry, zinc plated or “nominally” coated fasteners will perform equally with coated fasteners. The use of coated fasteners is not an acceptable substitute for removal of a wet or moist roof. A breach in a new membrane system can cause saturation of the insulation of an existing roof system, causing a failure of the mechanical attachment system. Coated fasteners will provide greater protection against corrosion in moist conditions and in areas where water has breached the system and is allowed to remain.
- The type of substrate can play a significant role in fastener performance once a fastening system is attacked by corrosion. Standing water on a

deck surface and in an insulation system that retains significant amounts of water can accelerate the corrosion process. Additionally, the oblique uplift load of a lap attached system can load the membrane fasteners in shear causing breakage once cross sectional area is reduced by corrosion. This was most evident in concrete deck applications where the fastener is held rigid at point of entry and may have been weakened during installation. Moreover, water can pond on the deck, increasing the possibility of fastener deterioration at deck level.

- Whether concrete fasteners are hammered or turned into the deck, the coating surface is abraded exposing untreated metal. The coating is removed at the point of attachment (in the deck) and at the deck surface where water is likely to collect and pond. The increased shear load on concrete fasteners makes these types of fastening systems more prone to breakage due to a combination of corrosion and wind load. Where the connection to the deck holds the fastener rigid, greater protection from corrosion is needed.
- Galvanized stress plates and batten bars are subjected to condensation laying on the top surface accelerating the corrosion process. The use of galvalume products tested under FM 4470 procedures has not been in use long enough to obtain significant data.
- Owner care and maintenance of the roof system is a crucial element to the long term performance of the roof system.
- Collapse of the existing built up roof system and/or loss of dimension of the new insulation layer can cause loss of load on the fastening elements. Loss of load can reduce the break away and back out torque of the fasteners, especially in systems where the fastener and stress plate are loaded unevenly.
- Fastener failure was caused by a number of factors. Rarely did failure occur in the field of the roof from combined positive and negative pressure pulling the fastener from the

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deck. Since the wind uplift testing at Factory Mutual Research is intended to simulate such conditions, additional test methods to duplicate other types of fastener failure should be considered for evaluation of mechanically attached roof systems. Reference is made to data prescribed at the wind uplift workshop at Oak Ridge, Tennessee in November 1989.

- Repair of a membrane leak without the removal of all wet roofing material below the leak, especially when an existing built up roof with wood-fiber or perlite is present, could be the cause of rapid deterioration of the fastening system.
- The uneven load on a fastener and plate assembly in a lap attached system will assist in the loss of load by depressing the insulation under the stress plate and by the lift of the head on one side causing counterclockwise movement of the fastener.

With the implementation of windload formulas, the advances in fastening technology and the establishment of a greater range of system testing, many of the fastening deficiencies noted in this survey can be reduced or eliminated.

While there have been substantial improvements in mechanically attached membrane systems over the past eleven years, additional changes are needed to maximize the performance of the fastening system.

- Counterclockwise rotation has been reduced or eliminated by the use of barbed or locking plate systems.

- Uneven load on fastener heads has been reduced by the use of nylon and other engineered plastics in the production of stress plates.
- Even loading of the fastening assembly has been achieved by fastening through the top of the membrane or welding of both sides of the fastening tab.
- Corrosion has been reduced by advancement in coatings and the use of non-ferrous materials.
- Non threaded fasteners, with consistent clamping force are available that will not turn due to vibration.
- Concrete anchors are available that turn into an expanding sleeve reducing loss of coatings.

The gap between maximum wind loads covered by warranties and design pressures calculated under the Factory Mutual Data Sheets or ANSI A58.1 should be resolved at the design stage. Design pressures should be calculated on a simple worksheet and become part of the submittal of job information to the membrane manufacturer. Fastening patterns for field, perimeters and corners should be calculated using the design pressures and a conservative fastener withdrawal resistance value instead of the baseline 'Factory Mutual pattern'. This is standard practice for the United Kingdom, using CP3, Chapter 5 and on Continental Europe, using DIN 1055.



Photo 18
Subsequent corner repair meeting area calculation of ANSI A58.1.

Foot Notes

- ¹ See Appendix A
- ² Exposure definitions can be found in the Data Sheet 1-7, ANSI A58.1 and ASCE 7-88
- ³ Toggle bolts lost wings in all toggle installations (see photo 5). Due to toggle sample size, toggles were not included in the comparison.
- ⁴ Head loss could have been caused by uneven stress on the underside of the head in high wind load conditions or from over torquing the fastener, or a combination of the two.
- ⁵ Overdriving was observed during application.
- ⁶ Although an extensive survey was carried out on the underside, a complete review was not practical due to building usage and high ceilings.
- ⁷ Four year life cycle only
- ⁸ Four year life cycle only.
- ⁹ Repair fasteners were eliminated from the test sampling.
- ¹⁰ Endurion coating, for the purpose of this survey, has been categorized as a non-coated part.
- ¹¹ A large barrel roof with high internal pressure did experience problems requiring extensive repairs at perimeters and at the shoulders of the barrels.

**APPENDIX A
WORKSHEET FOR WIND LOAD CALCULATIONS
FORMULA PER ANSI A58.1**

A copy of ANSI A58.1 or ASCE needed to complete calculation.

I.

A. Building Dimensions

- i. Height of Building:¹ _____ ft [Z]
- ii. Length of Building _____ ft.
- iii. Width or second largest dimension: _____ ft.
- iv. Roof slope:² _____

B. Basic Wind Speed (See wind map at Table 7³ to calculate wind speed.)

- i. _____ [V]

C. Importance Factor

- i. _____ [I]

D. Velocity Pressure

Select velocity pressure co-efficient from Table 6.

- i. _____ [Kz]

E. Exposure Category

Select exposure category from Ground Roughness Chart.⁴ (If mean height is > 60., use category C as minimum.)

- i. _____

Basic Equation: -

$$q_z = \text{Velocity Pressure} = 0.00256 K_z (IV)^2$$

(Substitute values obtained in the equation)

- a. Multiply I x V
- b. Square the sum
- c. Multiply x Kz
- d. Multiply x .00256

$q_z =$ _____

II. External Pressure Co-Efficient (Cpe)

Refer to figures 2, 3 and 4 and to tributary chart for Cpe. (Refer to notes at each figure.)

Note: Area 'a' = 5% of minimum width or second largest dimension or 50% of the mean roof height (h) or height above ground, whichever is less.

If roof slope is greater than 10⁰ but less than 45⁰ the ridge forms additional perimeter area. (See figure 5 of ASCE or ANSI document.)

- Cpe(Corner) _____
- Cpe(Perimeter) _____
- Cpe(Field) _____

III. Internal Pressure Co-Efficient (Cpi)

Refer to Table 9, and notes on ASCE or ANSI document.

Pressure Co-Efficient Calculation

$P = \text{design wind pressure} = q_z (Cpe) - q_z (Cpi)$

- P - Corner _____
- P - Perimeter _____
- P - Field _____

Calculate the design wind force [F]

- F = P.A.
- P = Corner, perimeter, field area
- A - Corner _____
- A - Perimeter _____
- A - Field _____
- F - Corner _____
- F - Perimeter _____
- F - Field _____

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Fastener value:⁵ _____
 No. of fasteners required in corner area _____ (___ per sq.ft.)
 No. of fasteners required in perimeter area _____ (___ per sq. ft.)
 No. of fasteners required in field area _____ (___ per sq. ft.)

¹ If height is over 500 ft., refer to document.

² If roof slope > 450, refer to document.

³ Wind speed map located in ANSI A58.1, or ASCE 7-88, or Factory Mutual Data Sheet 1-7.

⁴ Ground Roughness Chart located in ANSI A58.1, ASCE 2-88, or Factory Mutual Data Sheets 1-7 or 1-28.

⁵ Apply appropriate safety margin.

APPENDIX B

WORKSHEET FOR WIND LOAD CALCULATIONS BASED ON FM LOSS PREVENTION DATA SHEET 1-7

A copy of the 1-7 is needed to complete the calculation.

- Select the basic wind speed [V] _____ (Fig. 6 page 7)
 - Select the velocity pressure (P_h) _____ (Table 2 - Table 4, page 9-10)
 For using Table 2 - Table 4 one should know:
 - Height of building - [h] _____
 - Exposure category - _____
 - Obtain pressure Coeff. [C_p]
 - C_p - Corner _____
 - C_p - Perimeter _____
 - C_p - Field _____ (Tables 5 & 6, page 11, 12)
 - Obtain corner, perimeter & field areas [A]
 - A - Corner _____
 - A - Perimeter _____
 - A - Field _____ (Based on Table 6)
- Calculate:
- Length of building _____
 - Width of building _____
 - Height of building _____
- Substitute values obtained from 2 to 4 into the following equation:

$$F = \text{Wind force} = A \cdot P_h \cdot C_p$$
 - F (Corner) _____
 - F (Perimeter) _____
 - F (Field) _____
 - Obtain the average _____ resistance value of the fasteners and calculate number of fasteners required (F/fastener average pull-out value).
 - Average pull-out value _____
 - Number of fasteners required for
 - (Corner) _____
 - (Perimeter) _____
 - (Field) _____
 - Use factor of safety to recalculate the number of fasteners required.
 - No. of fasteners required for corner _____ = 1 fastener per _____
 - No. of fasteners required for perimeter _____ = 1 fastener per _____
 - No. of fasteners required for field _____ = 1 fastener per _____