APP and SBS Modified Bitumen Membrane Roofs:

A Survey of Field Performance

MIDWEST ROOFING CONTRACTORS ASSOCIATION, INC.

NATIONAL ROOFING CONTRACTORS ASSOCIATION

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1. ABSTRACT

In 1991, the Midwest Roofing Contractors Association (MRCA) and the National Roofing Contractors Association (NRCA) began a joint field survey of APP and SBS modified bitumen roofs in response to several reports of various types of problems with these types of systems. Because modified bitumen roof systems are relatively new in the U.S., and because of very limited published information on their field performance, the research project was undertaken.

The purpose of the project was to evaluate the field performance of polymer modified bituminous systems, recommend procedures and design criteria to minimize observed problems, and recommend repair procedures for existing membranes.

One hunderd nine roofs, up to 13 years old, were inspected in six climatic areas of the U.S. The roofs inspected included both problem and non-problem jobs. A good or excellent rating was assigned to 76 percent of these roofs by the researchers.

This report provides background information on the project, an overview of the use of modified bitumen roof systems in the U.S., documents the roofs inspected and their condition, and provides conclusions and recommendations concerning field performance, design, materials, application, maintenance and repair.

2. KEYWORDS

- APP
- field survey
- low-sloped roofs
- modified bitumen
- performance
- SBS
- SEPS

3. INTRODUCTION

This report presents a joint research project undertaken by the Midwest Roofing Contractors Association (MRCA) and the National Roofing Contractors Association (NRCA) in 1991. One hundred nine polymer modified bitumen roofs (73 APP, 35 SBS and 1 SEPS), ranging from one to 13 years old, were inspected in six climatic areas of the U.S. The roof membranes were constructed from sheets produced by 19 different manufacturers.

This section presents the purpose, limitations and background of the project and describes the use of polymer modified bitumen membranes in the U.S.

3.1 Project Purpose

Because of the widespread use of modified bitumen sheet materials, the limited published information on field performance, and the reports of various problems (as discussed in Section 3.3), this research project was launched. Its purpose is: 1) to investigate the field performance of roofs constructed with factory-fabricated polymer modified bitumen sheets, 2) to recommend procedures and design criteria to minimize problems, and 3) to recommend repair procedures for existing membranes exhibiting various types of problems.

Observations of in-service performance can identify field problems. An understanding of these problems can then lead to improved material standards, guidelines for design, application, maintenance and repair. Unfortunately, prior to publication of this report, very little information had been published on field performance of modified bitumen roofs in the U.S. or other countries. Published reports/papers include:

- A 1985 paper by Hendricks provides information on six APP membrane roofs in the Netherlands.[1]
- A 1991 paper by Duchesne reported on four SBS membrane roofs (two in Europe, and one each in Africa and Florida).[2]
- A 1992 paper by Cogneau reported on a study of 133 APP membrane roofs in Europe.[3] (This study was further reported in 1994.)[4]
- A 1992 report by Bailey gave the findings after three years of exposure of one APP, one SBS and one SEPS membrane roof in Louisiana.[5] (These roofs were further reported in 1994.)[6]
- A 1993 paper by Rossiter gave the results of a field study of 27 APP and 26 SBS membrane roofs located in three areas of the U.S.[7]
- A 1993 paper by Carlson reported on a roof with seven different APP membranes.[8]
- A 1994 report by Hendricks provides information on 18 SBS membrane roofs in Europe.[9] (This study was further reported on by Heimeriks in 1995.)[10]
- Although they were not surveys, Baxter reported on field performance in 1987[11] and Dupuis reported on application concerns in 1989.[12]

Analysis of observations from this project resulted in recommendations (Section 8) related to design, materials, installation, maintenance and repair—all items which affect roof performance.

This report is intended to provide information for contractors, designers and manufacturers involved with modified bitumen roofing. It is also intended for facility mangers who are responsible for the care of their roofs.

3.2 Project Limitations

Although comprehensive, there are a few limitations to the project:

- Very few test cuts were taken to verify and/or determine construction of the roofs system (e.g., the number and type of plies, or the type of membrane substrate).
- Laboratory analysis was not performed.
- Much of the historical information on the roofs (e.g., roof age or membrane manufacturer) was not independently verified, or in some instances, was limited or not available.

- Because of limited sampling and lack of laboratory analysis, the cause(s) of many of the identified problems could not be clearly defined.

3.3 Project Background

As a result of problems reported to MRCA in 1989 regarding lap (seam) separation problems on modified bitumen roof membranes, representatives of the MRCA Technical and Research Committee conducted a preliminary field investigation of lap problems in early 1990. The investigation was conducted in the Chicago, Illinois and Milwaukee, Wisconsin areas.

From this initial investigation, some lap problems were found, but not to the extent expected based on the previous problem job reports. However, other problems involving flashings, blistering, coatings, embrittlement, shrinkage, punctures and tears were found.

The initial problem reports involved lap separation of APP sheets, but later reports also included SBS sheets. A presentation on these problem reports and the findings from the field investigation was presented at the MRCA Annual Convention in October 1990, with the recommendation that further investigations be conducted.

In the meantime, NRCA began to analyze information reported to Project Pinpoint (a database of problem and non-problem jobs, as described in Reference 13). From information obtained from Project Pinpoint, and various problem reports to MRCA and NRCA, both groups decided that a national field survey was necessary to evaluate the performance of modified bitumen roof systems.

Accordingly, representatives of MRCA met with the NRCA Technical Operations Committee in March 1991, to discuss the establishment of a joint research task force to evaluate the performance of APP and SBS modified bitumen membranes.

Consequently, a joint task force was appointed and first met in July 1991. At this meeting, the task force finalized the purpose of the research project (see Section 3.1) and established the following research program outline:

- The project will include APP and SBS modified bitumen sheets manufactured by several different manufacturers.
- The project will include problem and non-problem jobs.
- A total of approximately 100 roofs will be evaluated.
- Roofs will be selected from various climatic regions representative of the U.S. (Further information on job selection is provided in Section 4.)
- At least two people will be on the inspection team, with at least one person inspecting all jobs (to the extent possible).

During 1991, the Task Force developed an inspection form that was used to record information on the inspected roofs (see Appendix B). The task force also began work on the selection of sites and roofs to be inspected. Project Pinpoint problem job reports on modified bitumen roofs, which numbered in excess of 640 jobs through 1990, were also evaluated.

In May 1992, the field inspections began. The last site was inspected in August 1993. Progress reports were presented at MRCA and NRCA conventions in 1993, and the final report was presented at the 1994 NRCA convention. The preliminary conclusions and recommendations were published in the May 1994 issue of *Professional Roofing*.

3.4 Modified Bitumen Use in the U.S.

A modified bitumen membrane roof is defined as a roof covering that is typically composed of a factory-fabricated composite sheet consisting of a copolymer modified bitumen which is typically reinforced and installed in one or more plies. The membrane is commonly surfaced with field-applied coatings, factory-applied granules or metal foil. The roof system may incorporate rigid insulation directly underneath the membrane, or over the membrane in a protected membrane roof (PMR) configuration.

Note: Modified bitumen membrane roofs can also be constructed with polymer modified mopping asphalt (styrene-ethylene-butylene-styrene [SEBS]) field-applied between multiple reinforcing plies. These types of roofs were not included in this research project.

In 1987, Johnson[14] described the history and development of modified bitumen roofs in the U.S. and their European origin. Modified bitumen roofs were first installed in the U.S. in the early 1970s, although it was not until the 1980s that this type of system became widely used. According to NRCA's Annual Market Survey,[15] by 1992, modified bitumen roof membranes were used for 21.7 percent of the reroofing of commercial low-slope roofs, and for 17 percent of the new roofs.

A large number of options are available to the users of modified bitumen roof membranes, including various types of polymer modifiers, reinforcements, surfacings, number and types of plies and attachment methods. The following is an overview of these options:

Note: During 1994 and 1995, modified bitumen sheets made with coal tar were available. However, coal tar modified bitumen roofs were not included in this research project.

Types of Polymers: Prefabricated polymer modified bitumen sheets are typically modified with atactic polypropylene (APP) polymer or styrene-butadiene-styrene (SBS) block copolymers. Self-adhering modified bitumen sheets use styrene-ethylene-propylene-styrene (SEPS) block copolymer.

In 1992, Becker[16] reported on sheets modified with polyalphaolefin (PAO) polymer, however, none of these types of membranes were included in this research project.

Reinforcements: Prefabricated modified bitumen sheets are typically reinforced with woven or non-woven glass fiber, polyester mat, or in some cases with multiple layers of one or both of these types of reinforcements.

Surfacings: When originally introduced, APP modified sheets were promoted by manufacturers as not being susceptible to degradation by ultraviolet (UV) light. Accordingly, until the past few years, APP sheets were typically "unsurfaced" (i.e., the modified bitumen was exposed). However, in 1993, Carlson[8] reported that most manufacturers offer longer warranties if their membranes are field coated, or they require field-applied coatings to obtain a manufacturer's warranty. Types of field-applied coatings include aluminum-pigmented asphalt, asphalt emulsion and latex (acrylic). APP sheets have also been produced with surfacings of factory-applied granules or metal foil. Aggregate has been used for surfacing on APP and SBS bitumen roof membranes, however, this is not a common type of surfacing.

Note: Protective reinforcement near the top of the cap sheet has been used on some APP sheets. Although not classified as a surfacing, this reinforcement acts as a surfacing by protecting the underlying portion of the sheet.

SBS modified bitumen sheets require a surfacing for UV protection. The most common surfacing material is factory-applied granules. Other options include factory-applied metal foils (aluminum, copper or stainless steel), and the coatings listed above. Factory-applied polymeric film has also been used to provide surface protection for SEPS modified bitumen membrane roofs.

Number and Types of Plies: In the early years of use, modified bitumen membranes were commonly composed of only one sheet. Accordingly, they were considered as "single-ply" membranes, although they more resembled built-up roof membranes (BUR). Modified bitumen membranes are now typically composed of a modified bitumen cap sheet (which may or may not be surfaced) and a base sheet (which may or may not be made with modified bitumen).

In addition to the base and cap sheet, many roofs also incorporate one or more fiberglass ply sheets. These systems are sometimes referred to as "hybrid BUR/modified bitumen membranes." Rather than being considered a "single-ply" or BUR, modified bitumen roofs (including hybrids) are now generally considered as a separate category of roof system.

Attachment Methods: APP modified sheets are typically fully-adhered by heat-welding (torching) in the U.S., although in 1992 Buve[17] reported on the use of cold adhesive in Europe. SBS sheets are typically fully-adhered in a continuous mopping of hot asphalt. However, some SBS sheets are capable of being adhered by heat-welding or by the use of cold adhesives. SEPS sheets, which have had limited use as roof membranes in the U.S., are self-adhering. Modified bitumen sheets can be used in PMR configurations, however, none were included in this research project.

Mechanically attached modified bitumen sheets have also been installed (i.e., the sheet is only attached to the substrate at discrete points), however, this is not a common attachment method in the U.S. *(Note: If a base sheet is mechanically attached and a modified bitumen cap sheet is adhered to it, this is considered as a fully-adhered system.)* Another uncommon attachment method in the U.S. is a loose-laid ballasted modified bitumen membrane roof system. Neither of these two system types were included in this research project.

4. INSPECTION SITES

Field inspections were conducted in the following six greater-metropolitan areas:

- Buffalo and Rochester, New York
- Chicago, Illinois
- Kansas City, Missouri
- New Orleans, Louisiana
- Phoenix, Arizona
- Seattle, Washington

These areas were selected to achieve representation of the primary climatic regions of the U.S., and to achieve representation of the different geographical areas (i.e., north, south, east, west), so that differences in regional practices and environments could be observed. To be considered for selection, areas were also required to have a relatively large population of modified bitumen roofs.

Weather data on the six sites are given in Appendix Tables C and D. Summaries follow:

- Buffalo/Rochester: Cold weather, large amount of snowfall, and moderate summer temperature and humidity. This area has the lowest number of clear days per year (of the selected cities).
- Chicago: Cold winters (extreme lows are lower in Chicago than in Buffalo/Rochester, but yearly heating degree days are greater in Buffalo/Rochester), moderate snowfall, warm summers and moderate humidity.
- Kansas City: Moderate winters, limited snowfall, high number of clear days, hot summers and high humidity.
- New Orleans: Mild winters, high number of clear days, very hot summers, very high humidity and the greatest amount of precipitation.
- Phoenix: Very mild winters, the highest number of clear days (nearly double that of Kansas City and New Orleans), the largest percentage of possible sunshine, extremely hot summers (cooling degree days greatly exceed those of New Orleans), extremely low humidity and extremely low precipitation.
- Seattle: Moderate winters, moderate snowfall (although the record amount was very high), relatively few clear days, has the lowest percentage of possible sunshine, very mild summers and low humidity.

It is believed that the selected cities provide a reasonable representation of the climatic regions of the U.S. However, parts of Alaska and several of the other northern states experience cold temperatures substantially below what is experienced in Buffalo, Rochester and Chicago.

Some of the specific buildings to be inspected in each area were selected via the use of Project Pinpoint (baseline and problem job databases). Originally, it was the intent of the task force to select all problem and non-problem jobs from Project Pinpoint, however, for a variety of reasons, too few jobs were found (e.g., some roofs had been replaced, or there were only a few job reports from the area). Accordingly, to augment selection via Project Pinpoint, telephone calls were made to MRCA and NRCA contractor members in the selected cities. Non-problem and problem APP and SBS membrane roofs were solicited.

The task force was primarily interested in inspecting older roofs. However, relatively new roofs were included in the survey. Typically, newer roofs were adjacent to older roofs on the same building, or they exhibited some feature that the inspection team desired to observe.

Selected buildings, including low-rise, mid-rise and high-rise, were located in rural, suburban and urban areas. The roof size varied from being quite small to extremely large. Further information on the inspected roofs is given in Section 5.

Contractors who assisted the inspection team by locating jobs and facilitating access to them are listed in Appendix L. In some cases, the contractor had originally applied the roof being inspected. In other instances, the contractor had not been involved in the original work.

5. INSPECTION OBSERVATIONS

Inspections were performed by walking over the roofs and documenting their construction (in conjunction with historical records) and condition. Numerous photos were taken and information on each roof were recorded on inspection forms. Each roof was inspected for design, material condition, installation and maintenance/abuse in a general sense.

Inspection team members are listed in Appendix L. Except for two roofs in the Chicago area, one team member (Dr. Rene Dupuis) inspected all of the roofs. Every roof was inspected by at least two team members.

Except for two instances (as noted in Appendix Table G), each building was assigned a sequential number, from 1 - 72. If the building had two or more different roofs (i.e., roofs installed in different years, or roofs constructed with different types of modified bitumen sheets, or different manufacturers), these different roofs were assigned sequential letters. For example, Roof 1A and 1B are different roofs on the same building.

Several specialized terms are utilized in the tables and other sections of this report. The ones which are not common, are defined in Appendix A. (*The NRCA Roofing and Waterproofing Manual* includes a glossary of common industry terms.)

Appendix Table G provides data on characteristics of the roofs, and several of the observations are shown in Photos 1 - 51. If a problem was observed, it is so indicated on the table. However, the table does not indicate the number of times that particular problem occurred (e.g., the roof could have one blister or it could have 20). In assigning a rating to the roof (as discussed near the end of this section), the quantity of the various types of problems was taken into consideration. Appendix Table G is summarized in the following tables.

Note: One SEPS modified bitumen membrane roof was inspected. For simplicity, it is considered as an SBS modified bitumen membrane roof in the tables.

City	Number of Buildings	APP Roofs	SBS Roofs	Total Roofs
Buffalo/Rochester	10	9	4	13
Chicago	12	20	3	23
Kansas City	11	16	3	19
New Orleans	14	11	5	16
Phoenix	10	5	11	16
Seattle	17	12	10	22
Total	74	73	36	109
Note: 67% of the roofs have APP roof membranes and 33% have SBS roof membranes.				

Table 1: *Roofs as a function of polymer modifier and city.*

City	Median Age (years)	Range (years)	Unknown Age (# of jobs)
Buffalo/Rochester	6	3-9	
Chicago	3.5	2-9	4
Kansas City	5.5	1-10	1
New Orleans	6.5	1-13	
Phoenix	3	1-8	1
Seattle	4	1-9	1
Total	4.5 (102 jobs)	1-13	7 jobs

Table 2: *Roofs as a function of age and city.*

Surfacing	Buffalo/Rochester		Chicago		Kansas City		New Orleans		Phoenix		Seattle		Total	
	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS
Aggregate			1										1	
Aluminum-pigmented	5		4				5		4		2		20	
Aluminum-pigmented over emulsion							1						1	
Emulsion			4		2		1				4	1	11	1
Granules		4	3	2	2	3		4		7		6	5	26
Latex									1				1	
Metal Foil			1					1		4	2	3	3	8
Polymeric				1										1
Unsurfaced	4		7		12		4				4		31	

Note: 1. 42% of the APP membranes are unsurfaced.
2. All of the APP membranes in Phoenix are surfaced.

Table 3: *Surfacings as a function of polymer modifier and city.*

APP		SBS	
Crazing/Cracking (28)	[38%]	Laps open or loose (14)	[39%]
Blisters (14)	[19%]	Blisters (11)	[31%]
Laps open or loose (13)	[18%]	Crazing/Cracking (11)	[31%]
Loose base flashing (12)	[16%]	Granule Loss (11)	[31%]
Note: The number in parenthesis indicates the number of jobs with a given type of problem. The number in brackets indicates the percentage of jobs of the given polymer type, with a given type of problem (the total percentage exceeds 100% because several roofs had problems in more than one of these categories). See Appendix A for definitions.			

Table 4: *Primary types of problems.*

Rating System: Based upon the field inspections and the judgement of the inspection team, all roofs were given a rating of 1, 2 or 3 (see Table 5). The rating key is as follows:

1. Problems were not observed, or they were judged to be only superficial.

2. Problems were observed, but they were judged to be economically repairable, or they were judged to be unlikely to prevent the roof from achieving the design service life.

Note: In reality, several roofs with a "2" rating will probably not achieve their design service lives because of lack of maintenance or repair.

3. Problems were observed that were judged to be not economically repairable. These roofs were judged to be unlikely to achieve their design service lives.

Rating	Buffalo/Rochester		Chicago		Kansas City		New Orleans		Phoenix		Seattle		Total		
	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS	All
1	2		10	1	2	1	2	1	2	4	2	8	20 (27%)	15 (42%)	35 (32%)
2	3	3	7	2	7	2	7	3	3	5	5	2	32 (43%)	17 (47%)	49 (45%)
3	4	1	3		7		3	1		2	5		22 (30%)	4 (11%)	26 (24%)

Note: One APP roof in New Orleans was rated "2" at the steep-slope areas, and "3" at the low-slope areas.

Table 5: *Rating, as a function of city and polymer modifier.*

6. DISCUSSION

Table 4 presented the primary types of problems that were experienced with APP and SBS membrane roofs. The results of this study are quite different from the reports submitted to NRCA's Project Pinpoint. Through 1992, the leading modified bitumen roof problems reported to Project Pinpoint were: laps (51 percent), flashings (21 percent) and shrinkage (19 percent).[13]

Note: The percentages indicate the number of modified bitumen problem jobs that reported the given problem. Some of these roofs had problems in more than one of these categories. Prior to 1992, separate data on APP and SBS membrane roofs were not collected, hence prior to that time, it is not possible to evaluate the primary problems with respect to the type of polymer modifier.

While this study and Project Pinpoint both identified laps and flashings as primary problems, this study did not identify shrinkage as a primary problem as did Project Pinpoint. Conversely, this study identified crazing/cracking, blistering and granule loss as primary problems while Project Pinpoint did not. Table 6 summarizes these differences.

Problem	Field Study		Project Pinpoint
	APP	SBS	
Blisters	19%	31%	*
Crazing/Cracking	38%	31%	*
Flashing	33%	17%	21%
Granule loss	4%	31%	*
Laps	18%	39%	51%
Shrinkage	1%	11%	19%

*Less than 4%.
Note: The total percentage exceeds 100% because several roofs had problems in more than one of these categories.

Table 6: *Primary types of problems, field study versus Project Pinpoint.*

Twenty-four percent of the roofs in this study were given a rating of "3" (Table 5). These roofs were judged to be not economically repairable and unlikely to achieve their design service lives. Eight-one percent of these roofs had problems related to membrane material, 46 percent had problems related to workmanship and 35 percent had problems related to design. *(Note: The total percentage exceeds 100 percent because several roofs had problems in more than one of these categories.)* One of the roofs was severely damaged by hail and another by wind. Products from nine membrane manufacturers were used on these roofs. One of these manufacturers is no longer producing modified bitumen sheets.

In the following section, design, materials, application, maintenance/abuse and natural phenomenon parameters which may have affected the performance of the roof system are discussed.

6.1 Design

Inadequate or inappropriate design decisions appear to have caused or contributed to impaired performance of many of the roofs. Noteworthy items observed were:

Cant Strips: Many of the early modified bitumen roof systems installed in the U.S. did not use cant strips at parapets or curbs. In this survey it was observed that the lack of cants adversely affected the performance of the membrane on several roofs. Splits and/or cracks were observed in the membrane near the transition from the vertical to horizontal planes. In more severe cases, the entire base flashing had ruptured and was no longer watertight (Photo 1). Small hairline cracks at the 90° intersections were seen to develop quite rapidly on some roofs (e.g., Roof 23A [Phoenix], which was less than one year old).

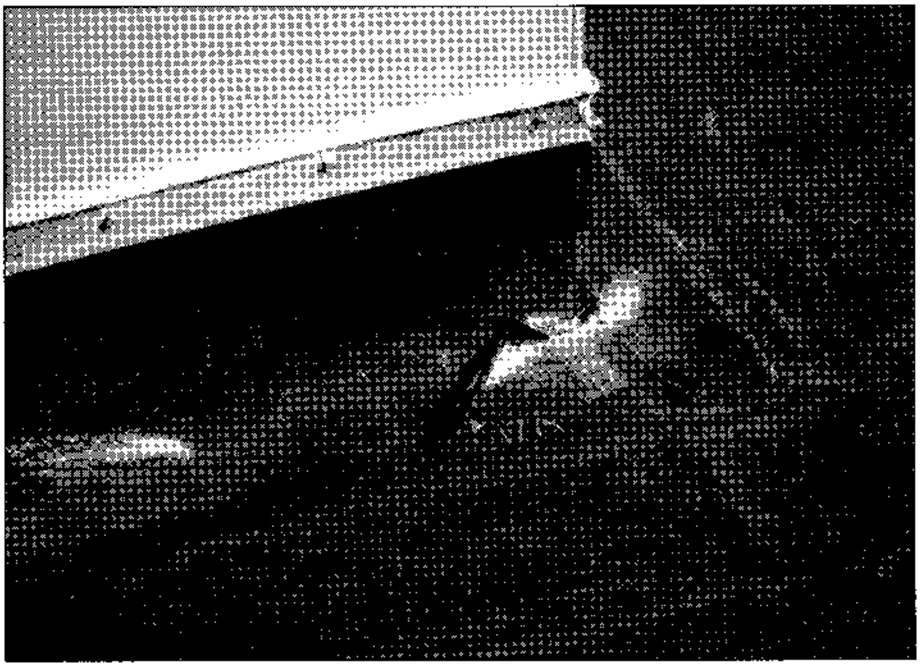

Photo 1. *Roof 17A: Rupture of an APP modified bitumen base flashing at a curb is illustrated. (In this photo, as well as many of the others, an ink pen shows the scale of the photo.) This five-year-old roof in Kansas City did not have cant strips.*

Cant strips provide a gradual transition from the horizontal plane of the membrane to the vertical plane of the parapet or curb, thereby avoiding an abrupt 90° angle change.

Counterflashings: On some jobs, the top of the base flashing was terminated with a metal termination bar, as is commonly used to terminate single-ply membrane base flashings. In a few instances, the base flashing sheet pulled out from underneath the termination bar (Photo 2), thereby allowing rainwater to enter the flashing assembly.

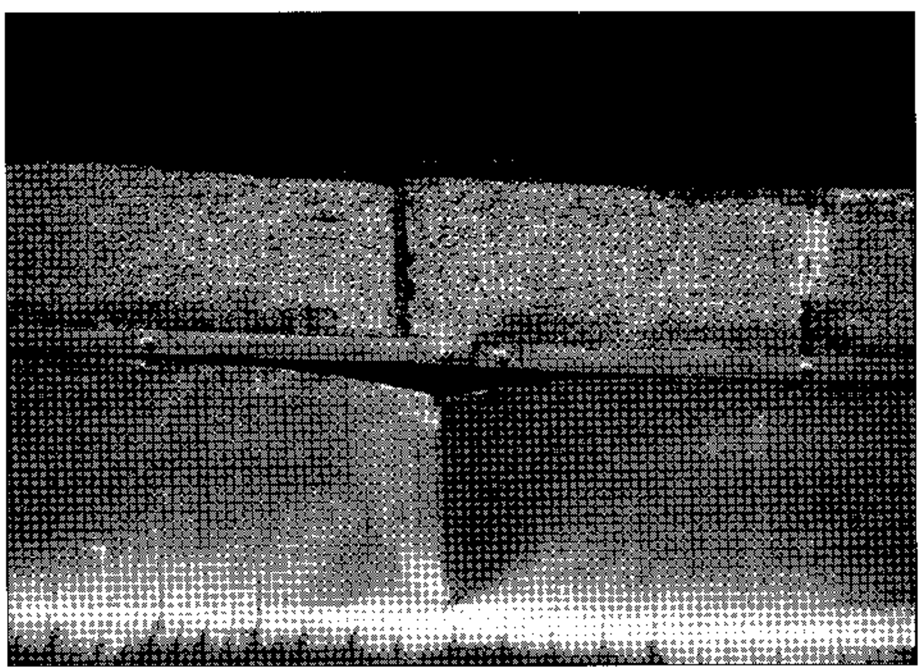

Photo 2. *Roof 7E: The metal foil surfaced APP modified bitumen base flashing pulled out from underneath the metal termination bar. The bar's fasteners were spaced too far apart and placed too close to the top of the sheet. This eight-year-old roof is located in Chicago.*

Because modified bitumen sheet flashings have a greater weight than single-ply sheets, greater securement near the top of modified bitumen flashings is necessary. Additionally, the incorporation of a metal counterflashing to protect the top of the base flashing provides for a more conservative detail (e.g., if the flashing should happen to pull out from the termination bar, the counterflashing usually prevents water from entering the flashing assembly).

Metal Edge Flashings: Membrane splits at metal edge flashing joints were observed on several of the roofs in this survey (Photo 3). This type of problem is also often experienced with built-up roofs. It is typically caused by excessive movement of the metal, which is caused by insufficient nailing of the metal edge flashing (either due to a deficient nailing specification or due to failure to follow the specification).

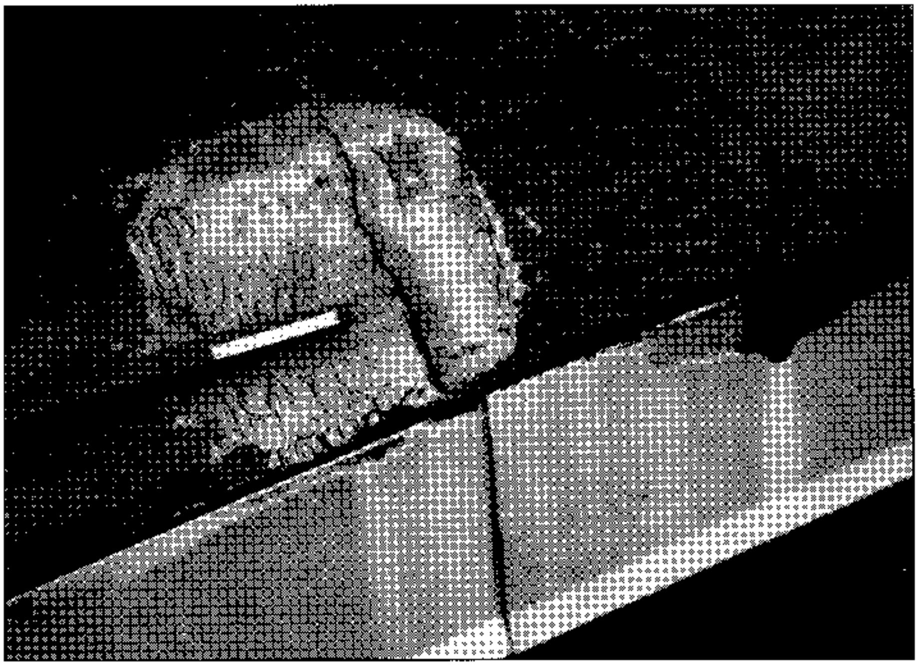

Photo 3. *Roof 54A: The APP modified bitumen membrane split at the metal edge flashing expansion joint. Note that the metal flashing was placed underneath the cap sheet. This eight-year-old roof is located in New Orleans.*

It was observed that the metal edge flashings on several of the roofs were constructed without a stripping ply (i.e., the metal edge flashing was installed prior to the application of the membrane, as shown in Photos 3 and 4). (This condition could be attributable to the design of the detail, or failure to follow the design.) When the metal edge flashing is underneath the membrane, the membrane may be vulnerable to wind blow-off, since the edge of the membrane is not continuously clamped down. If there is a fishmouth at the edge, or if the membrane becomes separated from the metal (Photo 4), the membrane will be susceptible to lifting and peeling, which can lead to a large progressive failure. By detailing the metal over the membrane, followed by a stripping ply (as shown in *The NRCA Roofing and Waterproofing Manual*), in addition to providing enhanced wind-resistance, the roof edge is also less prone to leakage.

Metal edge flashings are also discussed in Section 6.3.

Photo 4. *Roof 3B: The APP modified bitumen cap sheet was placed underneath the cap sheet. In some areas, the sheet had separated from the metal flashing. In this condition, the membrane is susceptible to blow-off, water infiltration and progressive de-bonding. This two-year-old roof is located in Chicago.*

Parapet Base Flashings: Parapets of many different heights and types of construction were observed. Sixteen roofs (15 percent) had loose base flashings. Eight of these roofs had diagonal wrinkling (as defined in Appendix A) and six had cracked base flashings.

Four of the roofs had SBS modified bitumen flashings and 12 of the roofs had APP modified bitumen flashings. Three of the roofs were located in Chicago, three were in Kansas City, one was in Phoenix, three were in Seattle, two were in New Orleans and four were located in New York. The 16 roofs used products from nine different manufacturers (the manufacturer of two jobs is unknown).

Diagonal wrinkling was associated with many of these problems (Photo 5). The cracked base flashings typically occurred at wrinkled areas, as shown in Photo 5. Some of the cracks appeared to extend through the wrinkled sheet.

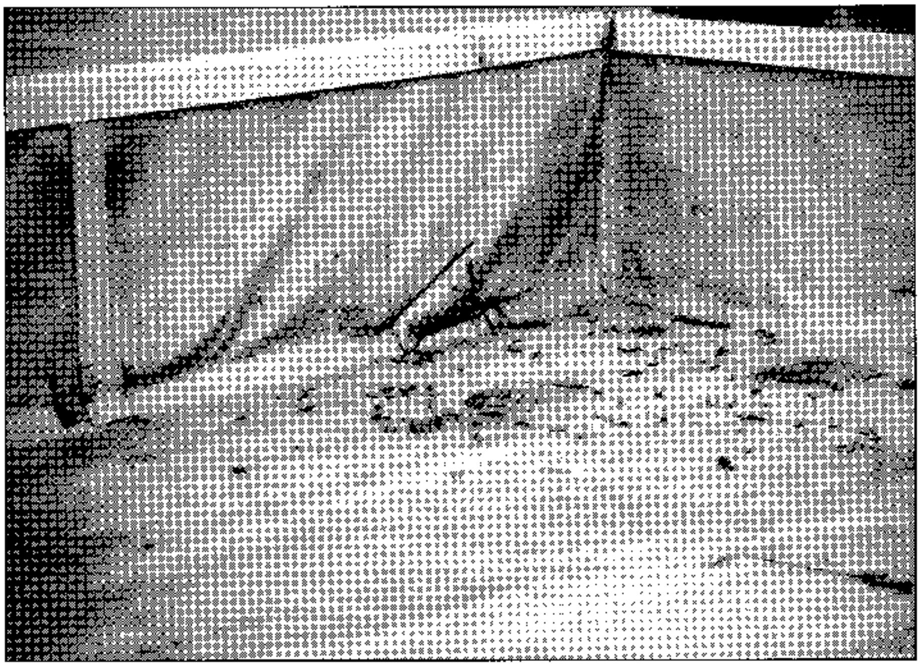

Photo 5. *Roof 61: APP modified bitumen base flashing has separated from the parapet. The diagonal wrinkles are indicative of differential movement between the parapet and the roof deck. In several areas near the ink pen, the flashing is severely cracked. This five-year-old roof is located in New Orleans.*

Diagonal wrinkling is typically associated with differential movement between the parapet and the roof deck.[18] Differential movement can be caused by thermal movements or live loads (e.g., snow). The intersection between the deck and parapet (or wall) needs to be designed and constructed to avoid differential movement, or an expansion joint needs to be designed for this intersection.

Many existing buildings permit differential movement between the roof deck and parapet (or wall), but do not have expansion joints at this intersection. When reroofing is contemplated, if expansion joints do not occur, it is important for the designer to assess the likelihood of differential movement. If movement appears likely, designing an expansion joint is prudent.

Some of the loose base flashing problems may have been related to sealing the wall with the membrane. Henshell describes the reasons for not sealing masonry parapets with membrane materials.[19]

Some of the loose base flashing problems may have been related to deteriorated or unsuitable substrates. When reroofing is contemplated, it is important for the designer to assess base flashing substrate conditions. In some situations, specifying the installation of plywood over the existing parapet may be prudent.

Some of the loose base flashing problems may have been related to parapet height. Several parapets were observed that were several feet (a few meters) high. Some of these exhibited problems, while others did not. Because of their weight, modified bitumen flashing sheets may be vulnerable to slippage (see Section 6.6) when the parapet exceeds approximately two feet (600 mm). To avoid problems, it is important for the designer to pay special attention to securement of flashings that are above this height.

Loose base flashings are also discussed in Section 6.3.

Ponding: *The NRCA Roofing and Waterproofing Manual* recommends that all roofs be designed to ensure positive drainage (i.e., the roof drains within 48 hours of rainfall during ambient drying conditions). However, 20 of the observed roofs (18 percent) had significant ponding. In general, it appeared that the roofs that did not pond were performing better than those that did.

In addition to ponds possibly accelerating deterioration of the membrane, if the membrane in a ponded area is breached (e.g., punctured), a significantly greater amount of water may enter the building than may enter the building in an area that does not pond.

Ponding is also discussed in Section 6.2.

Single-Layer Installations: Some of the observed roof membranes were found to be a true single-layer (single-ply) configuration. On some of these roofs, movement of the rigid insulation board due to thermal loads or dimensional instability apparently caused the membrane to ridge at some of the underlying insulation board joints. At Roof 4B, the membrane was overriding itself and becoming vulnerable to rupturing (Photo 6).

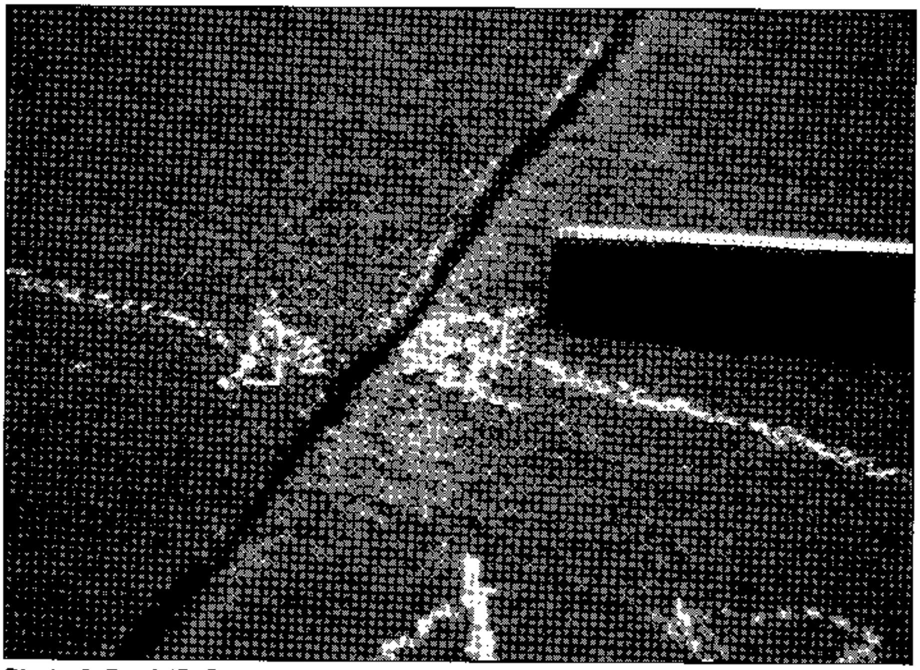

Photo 6. *Roof 4B: Ridging of an APP modified bitumen membrane composed of a single-layer is shown. The membrane on one side of the ridge line is riding up over the membrane on the other side. The ridge line has become vulnerable to rupturing. This seven-year-old roof is located in Chicago.*

In the true single-ply assembly, lap failure of the modified bitumen membrane allows water to penetrate past the membrane directly towards the interior of the building. Membrane systems that incorporate an additional base sheet or base and ply sheets provide additional waterproofing protection in the event of a lap failure. In a paper on APP membranes, Hendricks recommended the use of at least two plies.[1] His recommendation also appears to be valid for SBS membrane roofs.

Surface-Mounted Reglets and Counterflashing: Some of the roofs used surface-mounted reglets and counterflashings on parapets. Photo 7 shows a surfaced-mounted reglet crossing a vertical sealant joint. As this detail ages, it becomes very prone to water infiltration, although the amount of water that can flow in is relatively small. Similarly, infiltration can occur at the intersection of masonry mortar joints and termination bars (Photo 2).

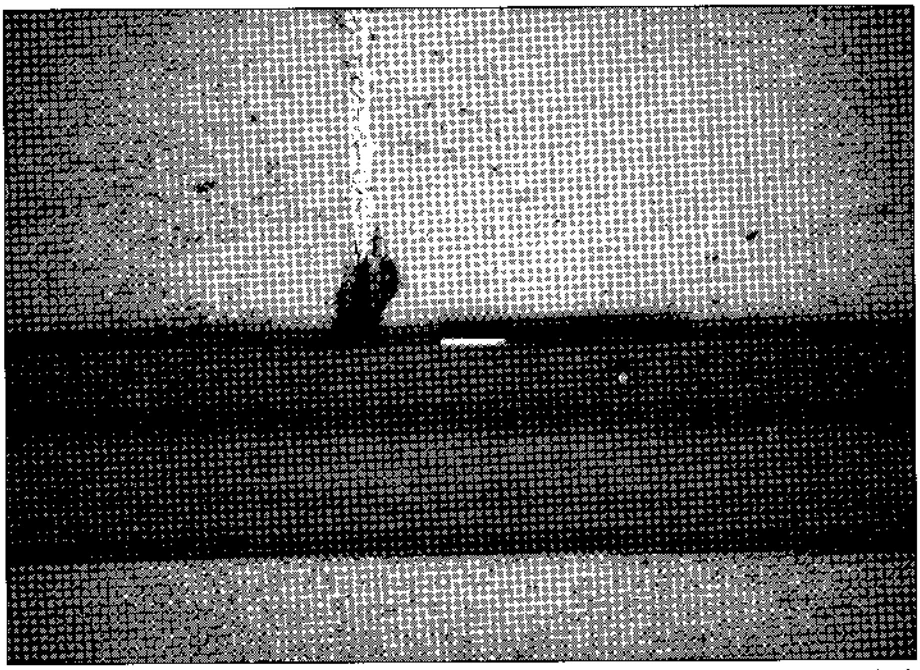

Photo 7. *Roof 15A: A surface-mounted reglet and counterflashing crossing a vertical sealant joint in a parapet wall is shown. The intersection of the vertical and horizontal sealant joints can become vulnerable to water infiltration. Note the cracking of the vertical sealant joint. This two-year-old roof is located in Kansas City.*

When surface-mounted reglets and counterflashings cross vertical sealant or mortar joints, the long-term waterproofing integrity of the detail is questionable. This type of detail should be viewed as one that requires periodic maintenance of the joints.

Thick Insulation Layers: The use of thick individual layers of insulation appeared to affect membrane performance on some of the roofs inspected (e.g., Roofs 14 and 20). Assemblies composed of thick layers of lightweight insulation (i.e., plastic foam or glass fiber board) were believed to be associated with development of small membrane ridges or picture framing. It is thought that systems composed of individual thick layers (e.g., in excess of 4 in. [100 mm]) may not provide sufficient resistance to shear that is induced by thermal movements of the membrane. Conversely, it is believed that systems composed of individual thin layers (e.g., 2 in. [50 mm] or less), provide sufficient shear resistance.

Shear deflection/resistance is discussed in References 20, 21 and 22.

Vent-Through-Roof (VTR): Some VTR (plumbing vent) details were observed wherein the lead flashing flange was placed underneath the cap sheet (Photo 8). To install this detail, the modified bitumen cap sheet usually needs to have cuts radiating out from the hole for the pipe. As the detail ages, it becomes vulnerable to water penetrating past the cap sheet, since the cuts are only sealed by the mopping asphalt, cold adhesive or bitumen that flowed upon heating as the cap sheet was set.

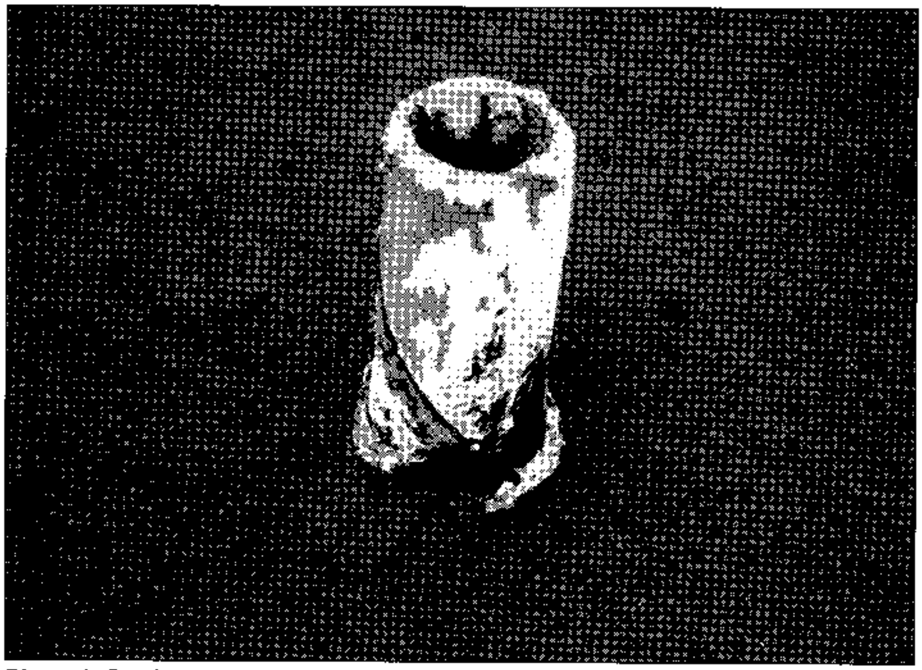

Photo 8. *Roof 56: The lead VTR flashing flange was placed below the SBS modified bitumen cap sheet. The membrane is beginning to lift at one of the radial cuts. This problem can be avoided by placing the metal flange over the cap sheet, followed by a stripping ply. This ten-year-old roof is located in New Orleans.*

By detailing the metal flange over the membrane, followed by a stripping ply (as shown in *The NRCA Roofing and Waterproofing Manual*), the penetration flashing is likely to have greater long-term durability.

Splits at Corners: Some membrane flashing splits were observed at the corner of curbs. It appears that the inside and outside corners of base flashings would benefit from an additional ply of modified bitumen cap sheet material.

Miscellaneous Details: In addition to the above issues, a very large number of poorly designed details were observed (Photos 9 and 10). Many of the deficient details will likely require periodic maintenance, and many of them will probably result in diminished roof service life.

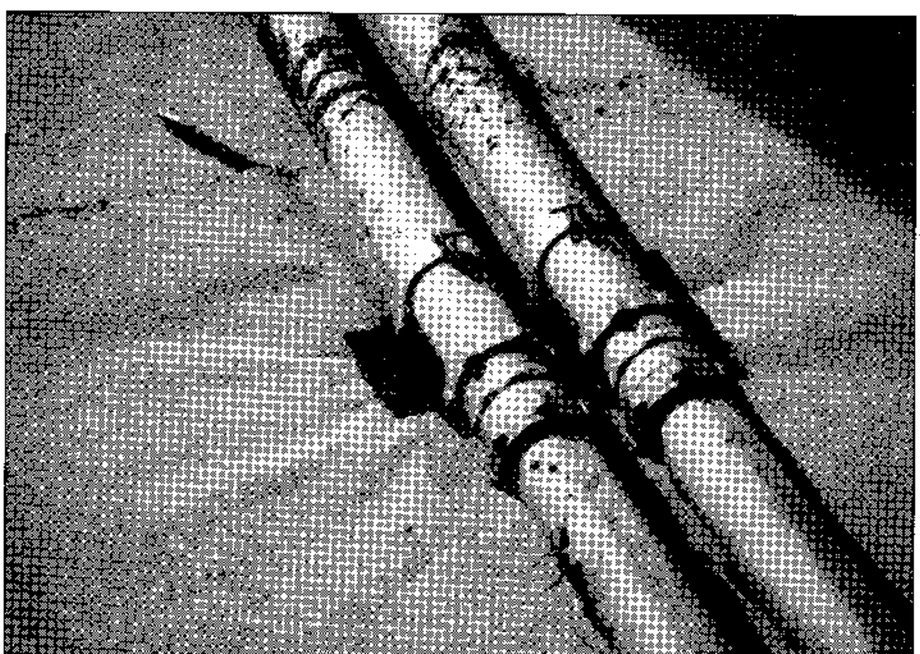

Photo 9. *Roof 26: Heavy conduits are inadequately supported on this SBS modified bitumen membrane. The insulation has been crushed and a fishmouth occurs at the endlap (an ink pen extends into the open lap). Over time, membrane leakage near the supports may occur. This one-year-old roof is located in Phoenix.*

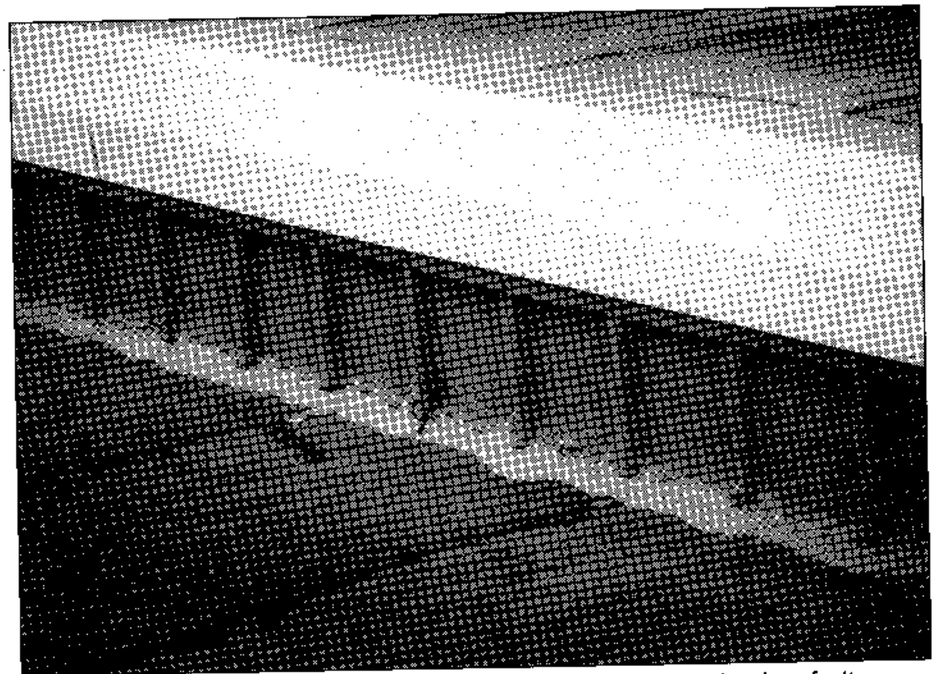

Photo 10. *Roof 63: A low wall occurs between upper- and lower-level roofs. It appeared that the low roof/wall intersection was poorly detailed in the original construction. When the roof was reroofed, the existing awkward condition was not changed. Unless this detail is periodically repaired, premature leakage is likely. This five-year-old roof is located in New York.*

Several of these poor details were found on reroofing projects. Typically, these details originated with the poor design/construction of the original roof (Photo 10). During design of the reroof, rather than correcting the original deficiencies, the awkward conditions were accepted and mediocre details emerged.

6.2 Materials

Material deficiencies appear to have caused or contributed to impaired performance of many of the roofs. Noteworthy items observed were:

Crazing and Cracking: Twenty-eight (38 percent) of the APP and 11 (31 percent) of the SBS membrane roofs were observed to have noticeable membrane surface crazing (weather-checking) or cracking. Cracking was characterized as "linear," "random" or "spider web" (see Appendix A for definitions). *(Note: In the following discussion, the term "cracking" includes "crazing.")*

Linear cracking was limited to APP modified bitumen membranes. Eight roofs (11 percent) experienced this phenomenon. The roofs ranged in age from two to seven years, and involved products from five manufacturers. Seven of the roofs were located in the Chicago area and one was located in the Seattle area.

Random cracking involved 21 (29 percent) of the APP modified bitumen membranes (Photos 11 and 12). The roofs ranged in age from two to nine years (the age of two roofs is unknown), and involved products from nine manufacturers. Five of the roofs were located in the Chicago area, five were in the New York area, five were in the Seattle area, four were in the New Orleans area and two were located in the Kansas City area. On three roofs, the cracking was more severe in ponded areas (Photo 13). On one roof, cracking only occurred in ponded areas. On one roof, cracking only occurred where the membrane was not protected by the coating. On one roof, cracking only occurred where grease from an exhaust fan had caused loss of coating. A small length of sheet on two roofs, was installed upside down—these sheets were cracked. (These two roofs were 13 years old, and were by the same manufacturer. The sheets on these roofs had protective reinforcement near the top side of the sheet.)

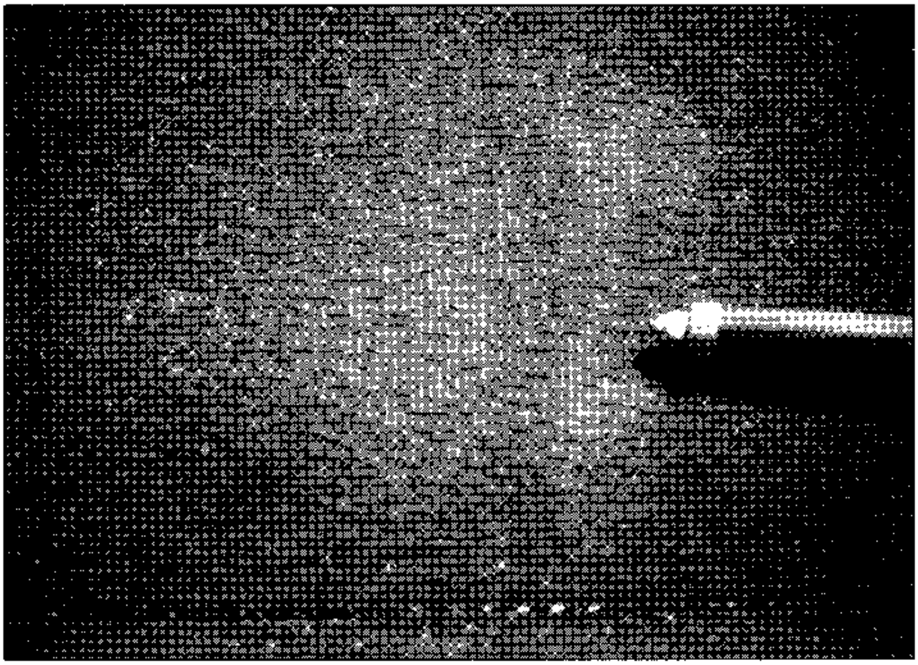

Photo 11. *Roof 7A: Random membrane surface cracking of an APP modified bitumen membrane is shown. (A lumber keel shows the scale.) This six-year-old roof is located in Chicago.*

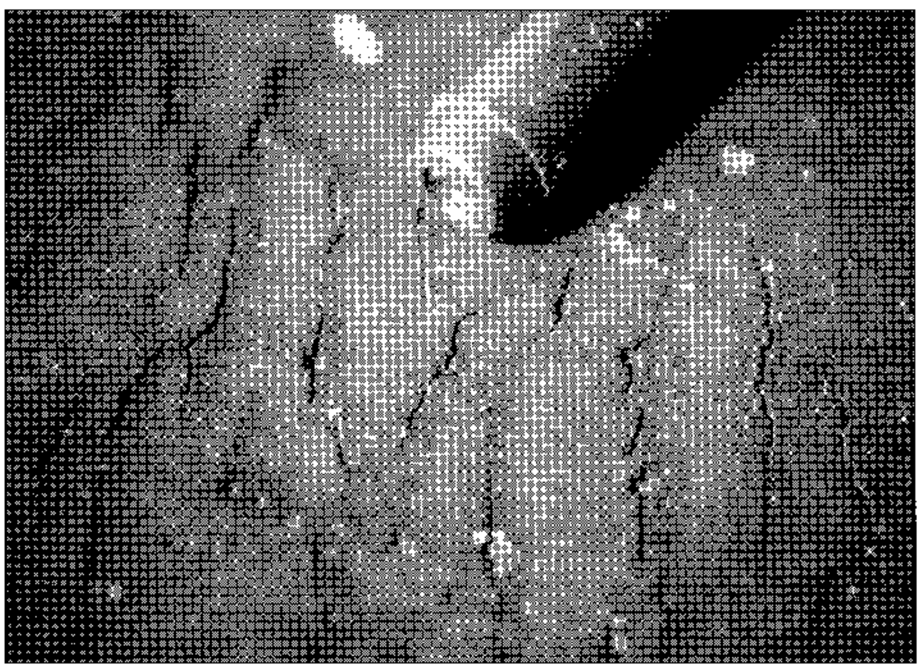

Photo 12. *Roof 66: Random membrane surface cracking of an APP modified bitumen membrane is pictured. Several of the cracks extend from small craters (this same phenomenon was observed by Carlson in Reference 8). This nine-year-old roof is located in New York.*

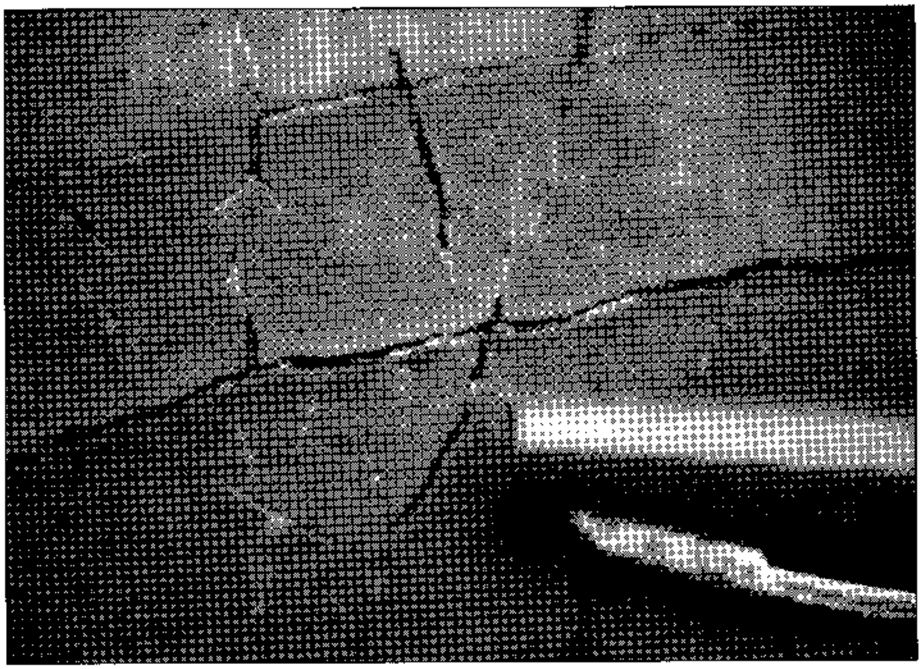

Photo 13. *Roof 67: Deep random membrane surface cracking of an APP modified bitumen membrane is shown. On this roof, the cracking was more severe in ponded areas. This photo was taken near the edge of a large pond—depending upon the water level, this portion of the membrane could be submerged or dry. This eight-year-old roof is located in New York.*

Random cracking also involved 11 (31 percent) of the SBS modified bitumen membranes (Photos 14, 15, 16 and 17). The roofs ranged in age from three to ten years old (the age of three roofs is unknown), and involved products from four manufacturers (the manufacturer of one roof is unknown). Five of the roofs were located in the Phoenix area, three were in the New York area, two were in the Kansas City area and one was in the Chicago area. On two roofs, cracking only occurred in ponded areas (Photo 17). On one roof, the cracking was more severe in ponded areas. On one roof, cracking only occurred where the granules had been lost. On one roof, cracking only occurred where solvent-based paint had been sprayed on the roof when the painter was cleaning the spray equipment. On one roof, the cracking was possibly caused by a contaminate spilled on the roof.

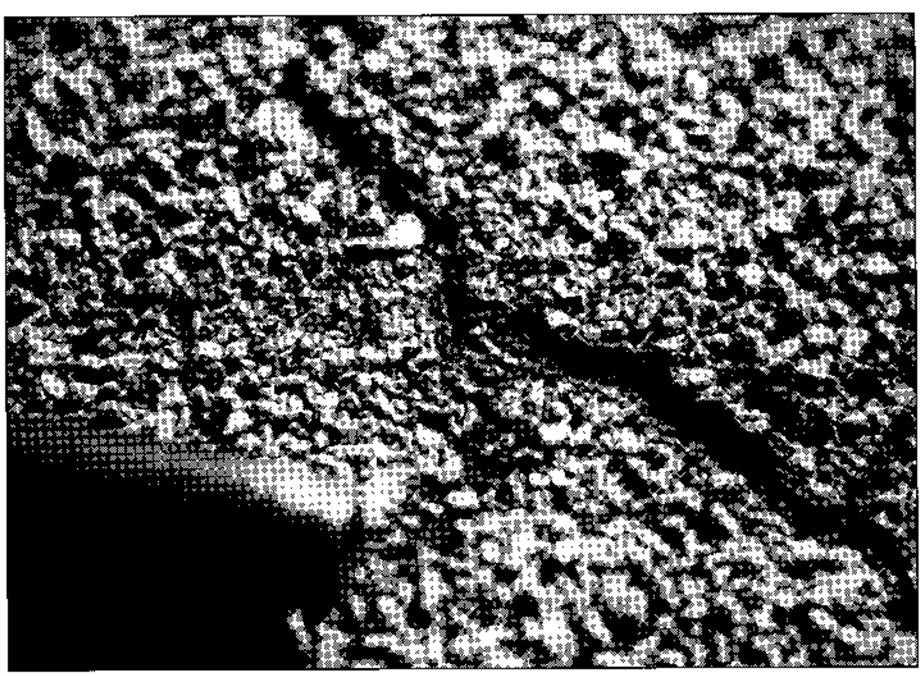

Photo 14. *Roof 31: Random membrane surface cracking of an SBS modified bitumen membrane is illustrated. This four-year-old roof is located in Phoenix.*

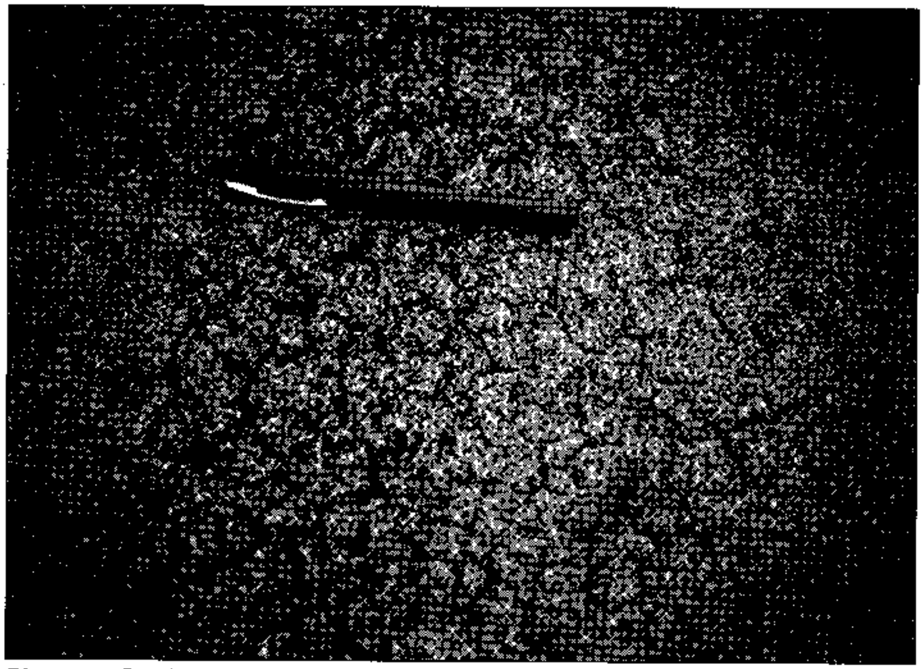

Photo 15. *Roof 58: Random membrane surface cracking of an SBS modified bitumen membrane is shown. A substantial number of granules had been lost from this roof. The roof had a slope of approximately 3:12 (25 percent). Cracking was more severe on the western exposure, compared to the eastern exposure. At Roof 57A, which was a similar building nearby, and of the same age and membrane manufacturer, similar granule loss and cracking was observed. On that roof, the cracking was more severe on the southern, rather than the northern exposure. These ten-year-old roofs are located in New Orleans.*

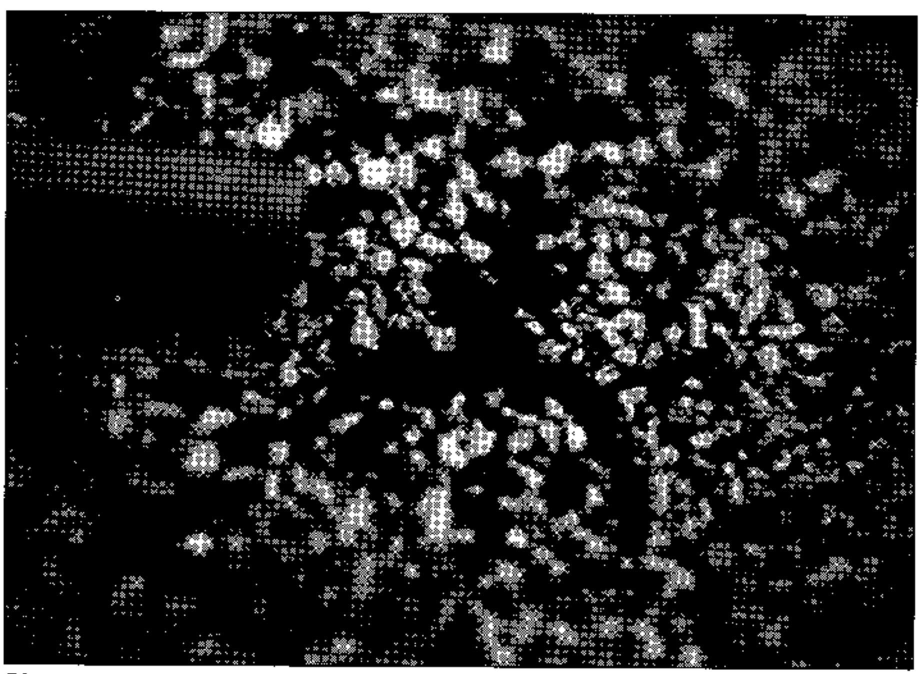

Photo 16. *Close-up of Photo 15: Note the large amount of granule loss and the development of a crack near the center of this photo. The surface of the exposed membrane has also deteriorated.*

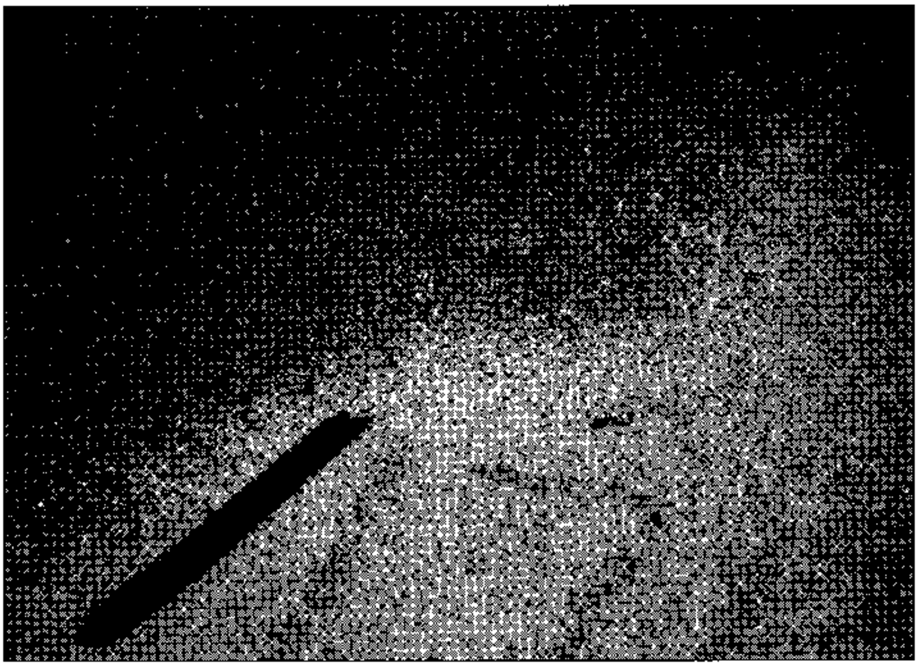

Photo 17. *Roof 17B: Granule loss and random membrane surface cracking of an SBS modified bitumen membrane. This condition was limited to ponded areas (the darker, upper area of the photo is under water). This five-year-old roof is located in Kansas City.*

Spider web cracking was limited to APP modified bitumen membranes. Four roofs (five percent) experienced this phenomenon. The roofs were four, five and six years old (the age of one roof is unknown), and involved products from two manufacturers (the manufacturer of one roof is unknown). Two of the roofs are located in the New York area, one is in the Chicago area and one is in the Seattle area.

Development of surface cracks were observed on APP modified bitumen membranes in five of the climatic areas. Cracking was not observed in Phoenix, although only five APP membrane roofs were observed in that area. A lack of cracking in Phoenix appears to be due to the use of coatings on all of the roofs observed, and the very good condition of those coatings.

Based on the observations, it appears that many APP modified bitumen membranes are susceptible to cracking unless they are protected by coatings or granules, or the cap sheet is manufactured with a protective reinforcement near the top of the sheet (Photo 18). Crazing and cracking of APP modified bitumen sheets in The Netherlands has also been reported.[23] Cracking of granular-surfaced SBS modified bitumen membranes appears to be related to granule loss. If crazing develops into cracking, and the cracks propagate through the membrane, leakage and diminished roof service life may occur.

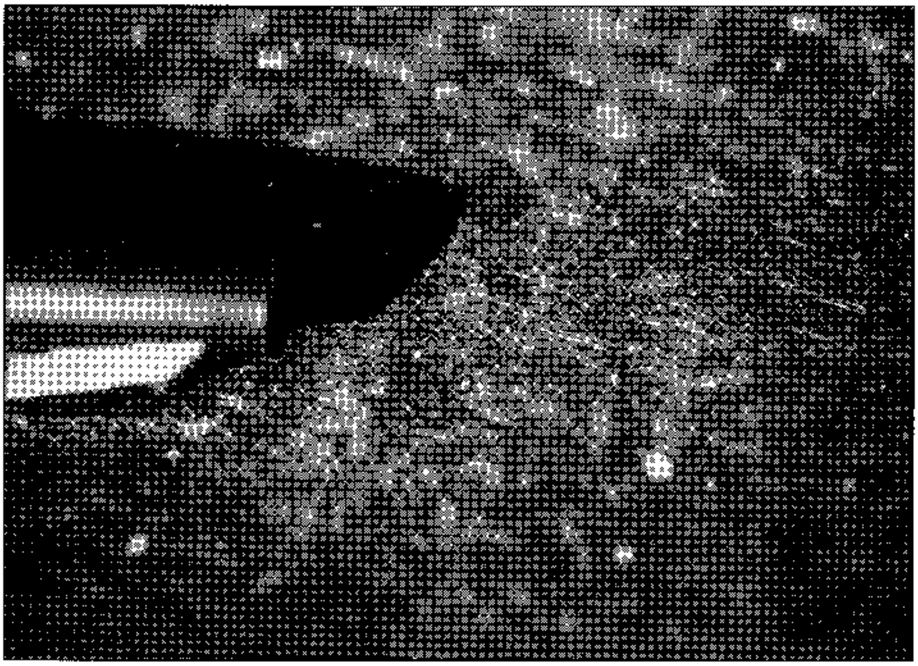

Photo 18. *Roof 52: This APP modified bitumen membrane, with protective reinforcement near the top of the sheet, shows very little weathering effects. A few grains of sand and dirt are on the membrane, and some reinforcement fibers can be seen on the surface. This 13-year-old roof is located in New Orleans.*

To retard the potentially detrimental effects of cracking, a field-applied coating could be applied. (However, the membrane should not be leaking and it should otherwise be in good condition prior to coating.)

Delamination: Ten (14 percent) of the APP membrane roofs experienced delaminations within the cap sheet (see Appendix A for definition). The roofs ranged in age from six to 13 years old (the age of one roof is unknown), and involved products from three manufacturers. Seven of the roofs (70 percent) used products from the same manufacturer. Three of the roofs are located in the Kansas City area, three are in the New Orleans area, two are in the Chicago area, one is in the New York area and one is in the Seattle area. On Roof 53 in New Orleans, delamination only occurred at ponded areas. Separation occurred between the glass fiber reinforcement near the middle of the sheet and the bitumen matrix above it (an additional layer of glass fiber reinforcement also occurs near the top of the sheet). Some of the mid-reinforcement had also separated from the bitumen matrix below it. The delaminated areas appeared as very low blisters, and wrinkles occurred at some of the delaminated areas. A test cut at one of the delaminations did not reveal any water intrusion. In all cases, it appeared that the portion of the sheet that occurred above the separation was in good condition and remained watertight.

At Roof 49 in New Orleans, delaminations similar to those at Roof 53 were observed, however, these delaminations were not limited to ponded areas, and water had entered some of the delaminated areas (Photo 19). At other areas on this roof (areas with different substrate conditions) delaminations were found above several of the insulation fasteners, as shown in Photo 20.

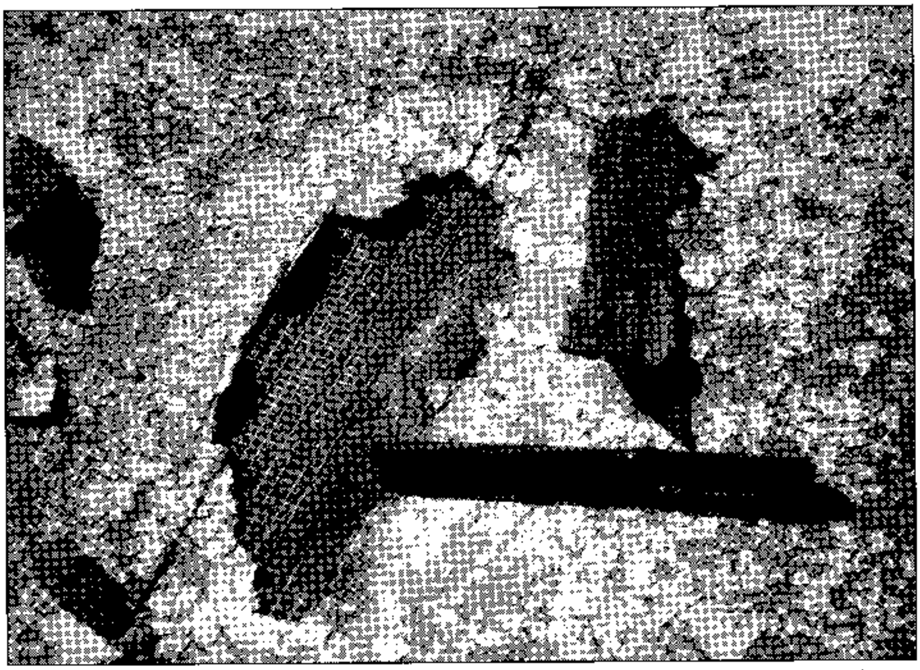

Photo 19. *Roof 49: Delamination of portions of an APP modified bitumen sheet is pictured. The separation occurred between the glass fiber reinforcement near the middle of the sheet and the bitumen matrix above it (an additional layer of glass fiber reinforcement also occurs near the top of the sheet). Prior to cutting away the separated area for observation, the top portion of the sheet had ruptured, which thereby permitted water to enter the void area. The membrane had an aluminum-pigmented cutback coating applied over an emulsion coating. In this area, much of the aluminum coating had weathered away. This eight-year-old roof is located in New Orleans.*

Photo 20. *At another area of Roof 49, delaminations occurred above screw-and-plate fasteners that were used to attach the insulation, as depicted by the large diameter dark circles. A test cut at one of these areas revealed the separation occurred in the same location as described in Photo 19. Although in this case, the portion of the sheet above the separation was not deteriorated, as it was in Photo 19.*

At Roofs 21B and 21C in Kansas City, the glass fiber reinforcement near the top of the sheet had delaminated and ruptured in several locations (Photo 21). A deep crack was observed at some of these areas (Photo 22). According to project records, these jobs used an experimental ("test") reinforcement.

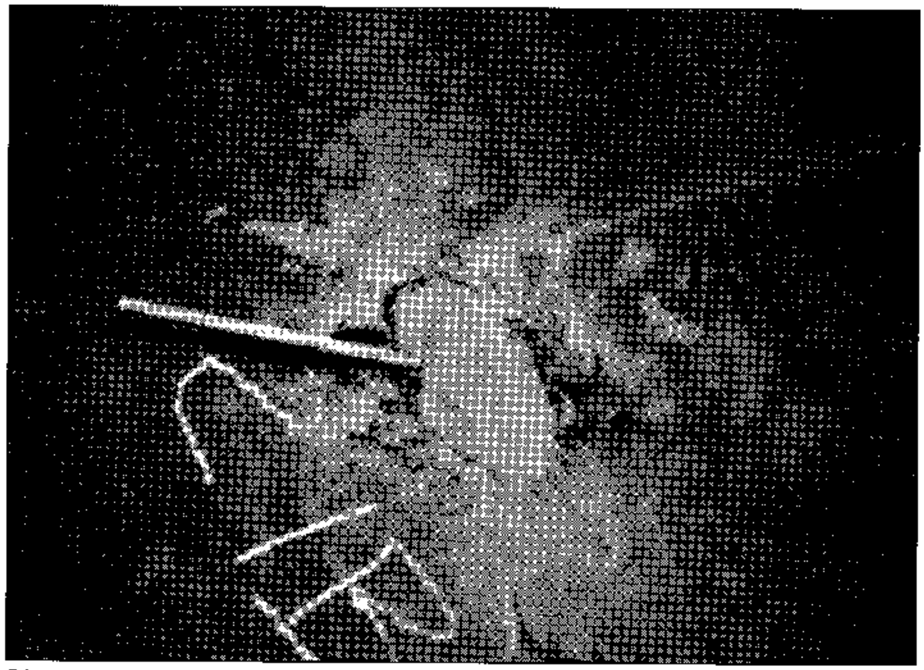

Photo 21. *Roof 21B: Separation and rupture of the glass fiber reinforcement near the top of the APP modified bitumen sheet is shown. This nine-year-old roof is located in Kansas City.*

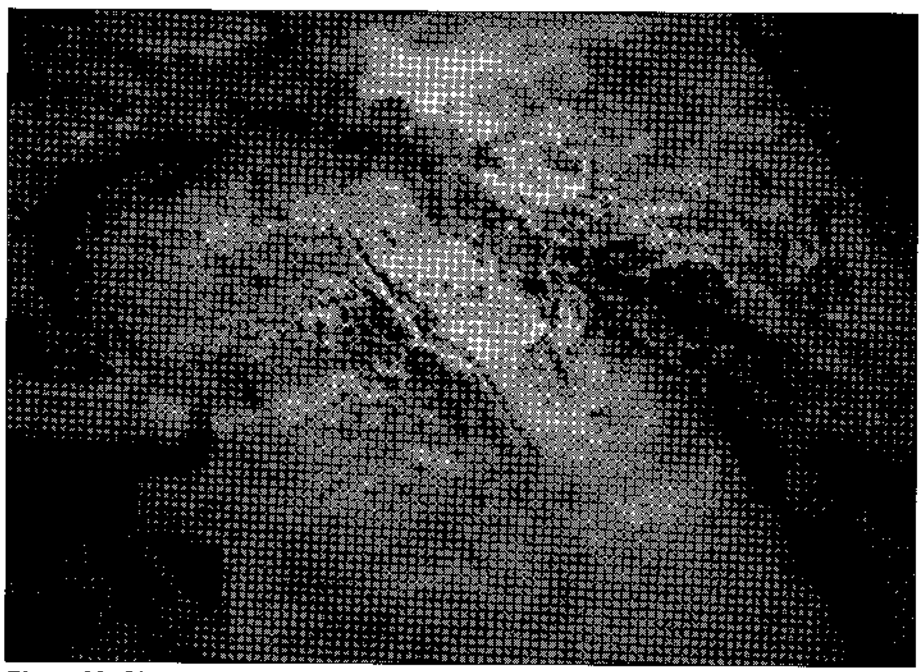

Photo 22. *Close-up of Photo 21: A deep crack occurred in the exposed surface of the sheet. (The crack was full of water when the photo was taken.)*

Delamination of metal (aluminum) foil surfacing was observed on Roof 7D in Chicago (Photo 23) and Roof 44B in Seattle (Photos 24 and 25). These APP modified bitumen roofs used products by the same manufacturer. Delamination of the foil is believed to be related to thermal cycling of the membrane.[24] Unless thermal movements are adequately accounted for by the foil embossing, foil delamination can occur. (Nine other foil-surfaced membranes were observed that did not exhibit signs of delamination. These roofs ranged in age from one to eight years old. Eight of these roofs were modified with SBS.)

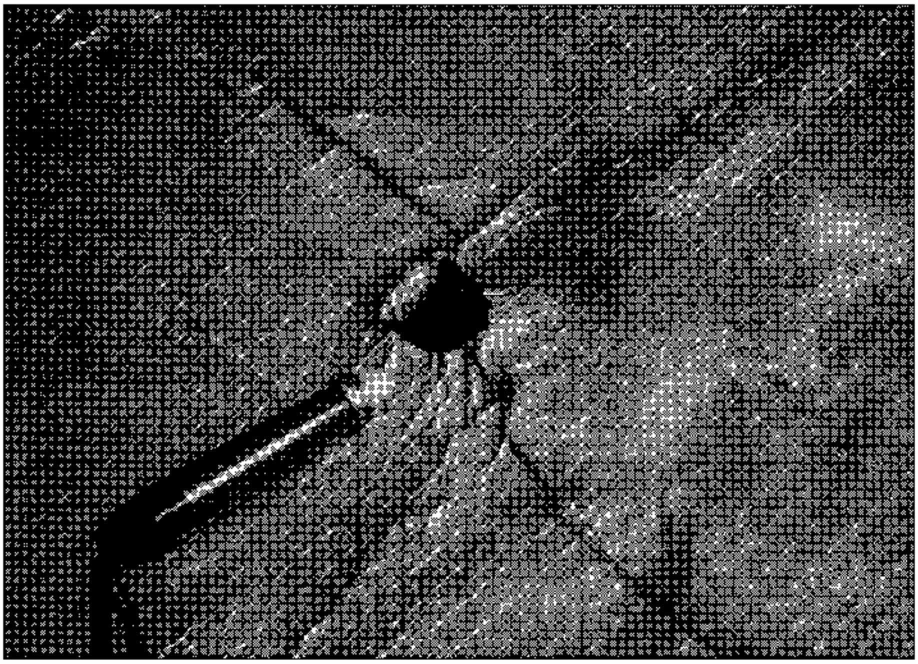

Photo 23. *Roof 7D: Metal foil delamination (and tear) on an APP modified bitumen membrane is pictured. The age of this roof is unknown. It is located in Chicago.*

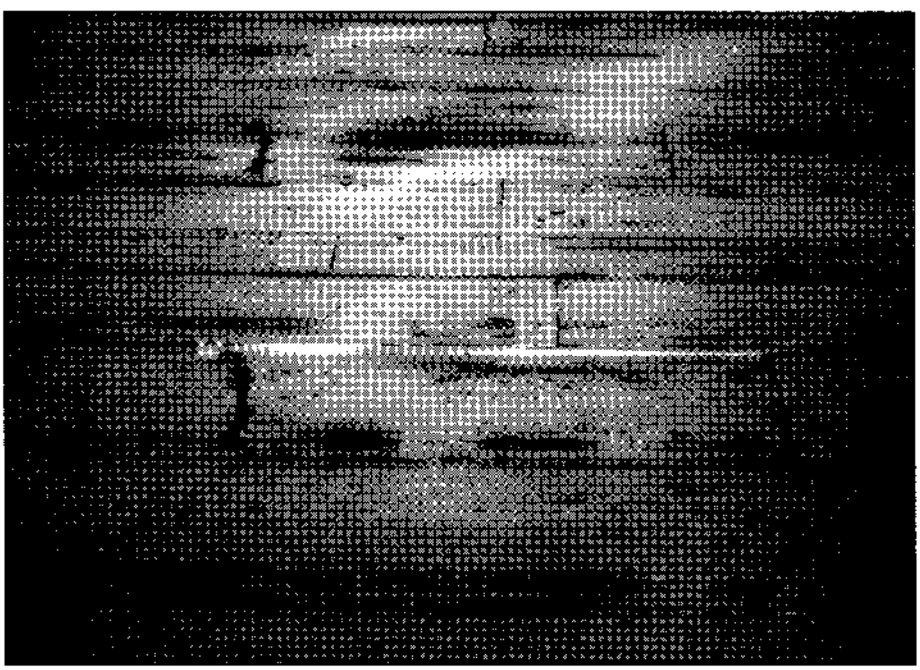

Photo 24. *Roof 44B: Metal foil has torn at several locations across this sheet and has delaminated (peeled) from the sheet. This five-year-old roof is located in Seattle.*

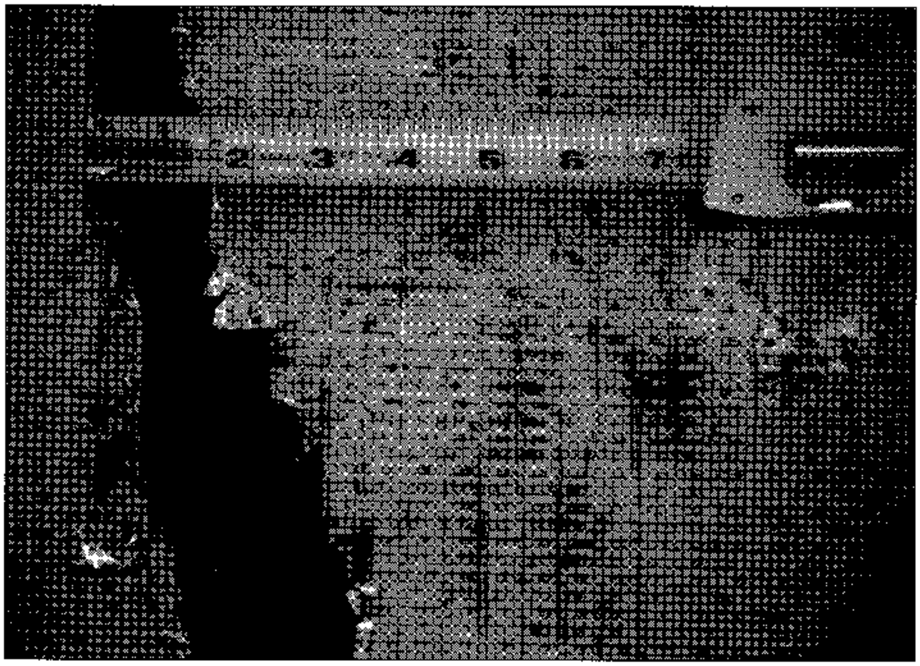

Photo 25. *Close-up of Photo 24.*

Four (11 percent) of the SBS membrane roofs experienced delaminations within the cap sheet. (On Roof 69, modified bitumen sheets were only used for the base flashings—the remainder of the membrane was built-up.) Two of the roofs were five years old and one was seven years old (the age of the fourth roof is unknown), and involved products from three manufacturers (the manufacturer of one product is unknown). Three roofs experienced the same type of problem. Small diameter (i.e., up to ½ in. [13 mm]) blisters occurred above the reinforcement, within the bitumen matrix (Photo 26). On Roofs 56 and 69 (New Orleans and New York), the blisters were more prevalent on those surfaces that received a greater amount of solar radiation. The fourth roof was experiencing peeling of the factory-applied polymeric film surfacing.

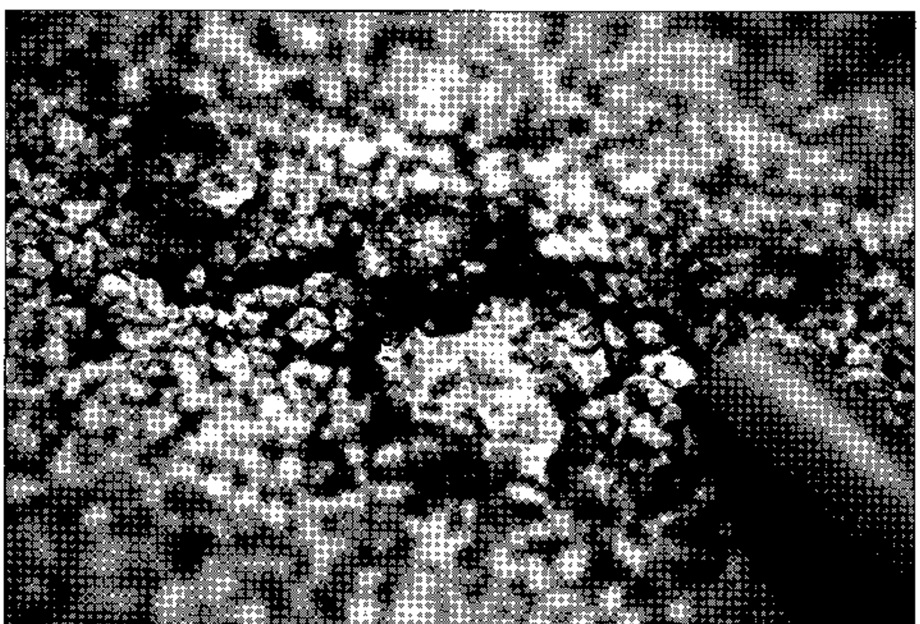

Photo 26. *Roof 56: Close-up of a ruptured blister on a granular-surfaced SBS modified bitumen membrane (the blister was ruptured by the investigator) is shown. The blister occurred in the bitumen matrix, above the reinforcement. In this case, the void was dry. Note the lack of granules in this area. The roof had a slope of approximately 3:12 (25 percent). This ten-year-old roof is located in New Orleans.*

Fiberglass Bloom: Fiberglass bloom (as defined in Appendix A) was observed on six roofs (all of which were modified with APP). The roofs ranged in age from two to 13 years old. All of the roofs used products from the same manufacturer.

Three of the roofs were located in the Kansas City area, and the other three were located in the Chicago, New Orleans and Seattle areas. In advanced stages, most of the glass fiber reinforcement near the top of the sheet becomes detached from the bitumen matrix (Photo 27).

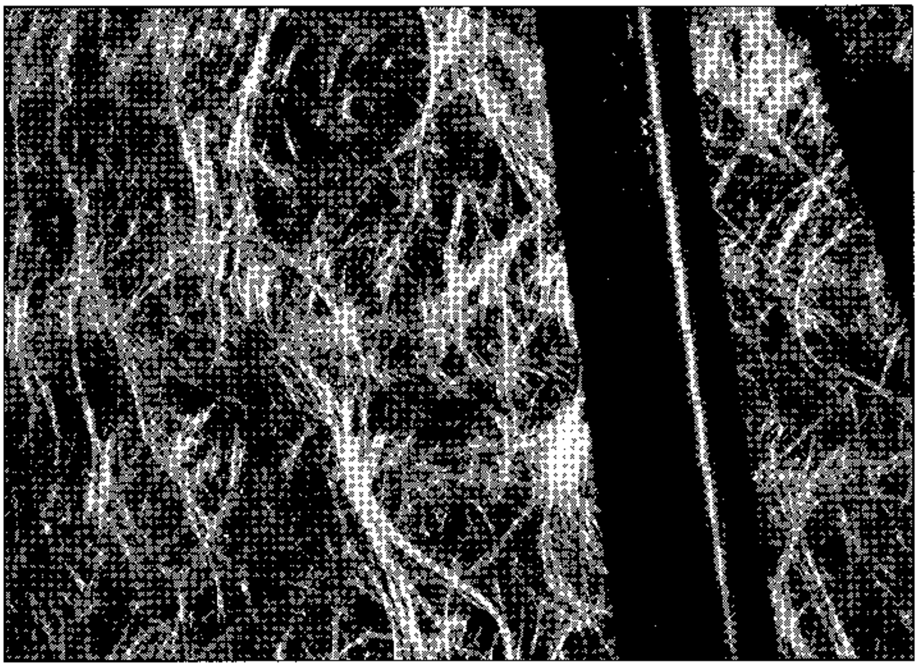

***Photo 27.** Roof 13B: Close-up of an advanced stage of fiberglass bloom on an APP modified bitumen membrane is illustrated. The majority of this roof had a low slope, although this photo was taken at a steep-sloped area. This nine-year-old roof is located in Kansas City.*

Finger Blisters: Finger blisters (as defined in Appendix A) were observed on nine (12 percent) of the APP and one (3 percent) of the SBS membrane roofs (Photo 28). The roofs ranged in age from two to nine years old, and involved products from eight manufacturers. No apparent accelerated deterioration of the membrane was observed in the vicinity of the finger blisters.

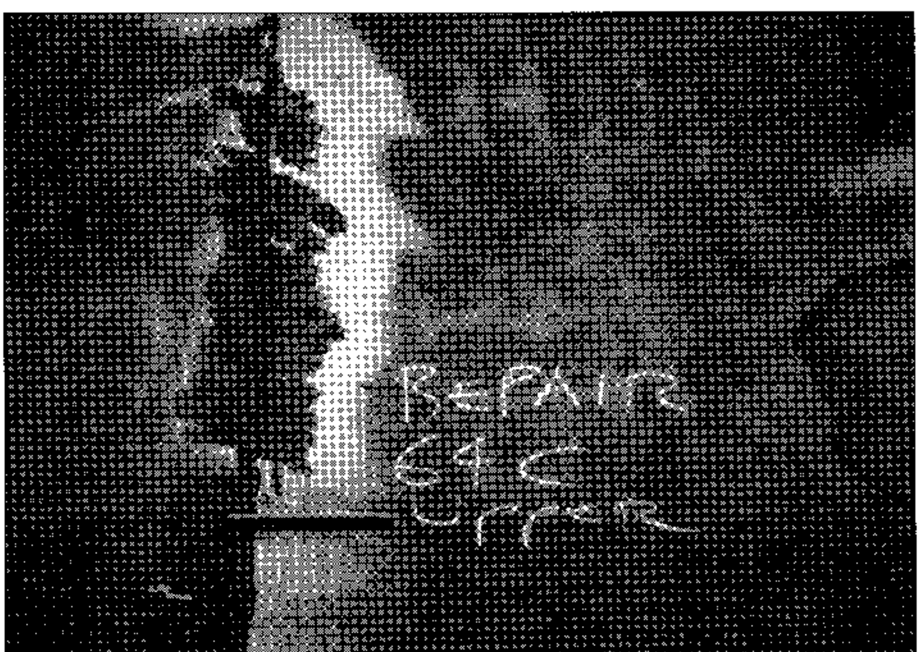

***Photo 28.** Roof 64C: Finger blisters occurred near the upper right hand area of this photo of an APP modified bitumen membrane. This photo also shows a lap that was repaired some time after the roof was installed. The addition of a stripping ply over the repaired area would offer a more conservative repair. This three-year-old roof is located in New York.*

Granule Loss: Three (4 percent) of the APP membrane roofs were observed to have noticeable granule loss. The roofs were two, five and seven years old, and involved products from three manufacturers. Two roofs were located in the Kansas City area and one in the Chicago area. The two-year-old roof in Kansas City had experienced several lap problems. Some of these may have been related to poor granule embedment (Photo 29). The seven-year-old roof in Kansas City had granules that were field-applied into an emulsion coating. The granules were placed on the 2:12 (17 percent) slope for aesthetics.

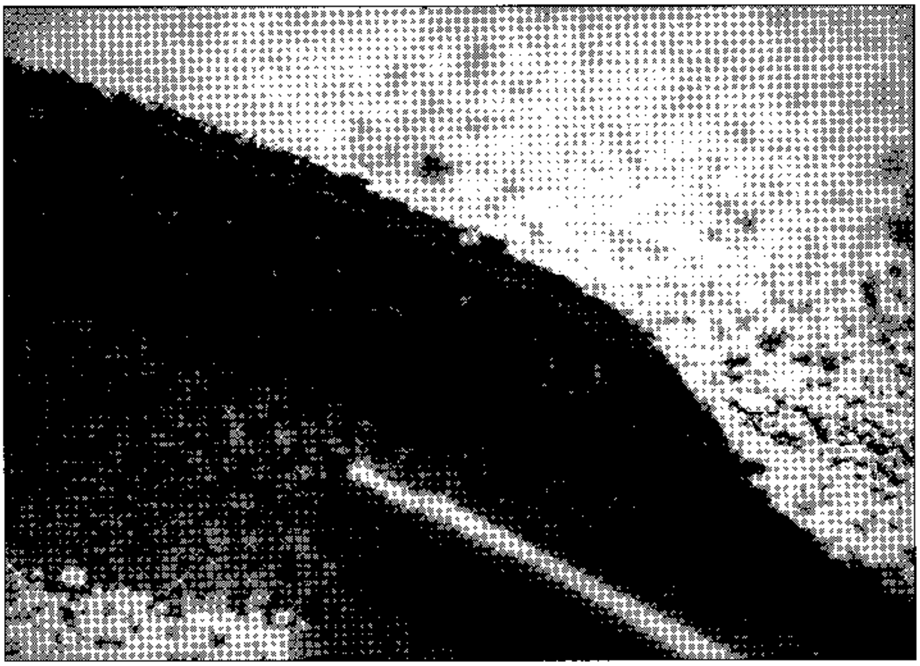

Photo 29. *Roof 16: Close-up of a loose endlap on an APP modified bitumen membrane is pictured. This roof experienced a substantial amount of granule loss and lap problems, which may also have been associated with the granules. Note that several granules are embedded on the underside of the top sheet. This two-year-old roof is located in Kansas City.*

Eleven (31 percent) of the SBS membrane roofs were observed to have noticeable granule loss. The roofs ranged in age from one to ten years old (the age of one roof is unknown), and involved products from five manufacturers. Four of the roofs are located in the Phoenix area, three in the New Orleans area, two in the Kansas City area and two in the New York area. Four of the roofs showed granule loss at ponded areas (Roofs 17B [Photo 17], 26, 27C and 31). Three of the roofs (56, 57A and 58) had a 3:12 (25 percent) slope. Granule loss from these three ten-year old roofs may have been related to water run-off. Granule loss from Roof 28 was caused by construction abuse by other trades (i.e., installation of stone veneer on a mechanical equipment screen). Granule loss from Roof 65A may have occurred because of foot traffic on a hot sheet during application in a confined work area. Also on this roof, granules were lost along the ridge of a blister (Photo 30). The most profound example of granule loss occurred on Roof 68, wherein most of the granules were missing (Photo 31). This granule loss appeared to be associated with ponding, which occurred over most of the roof. (The vertical flashings still had good granule coverage.)

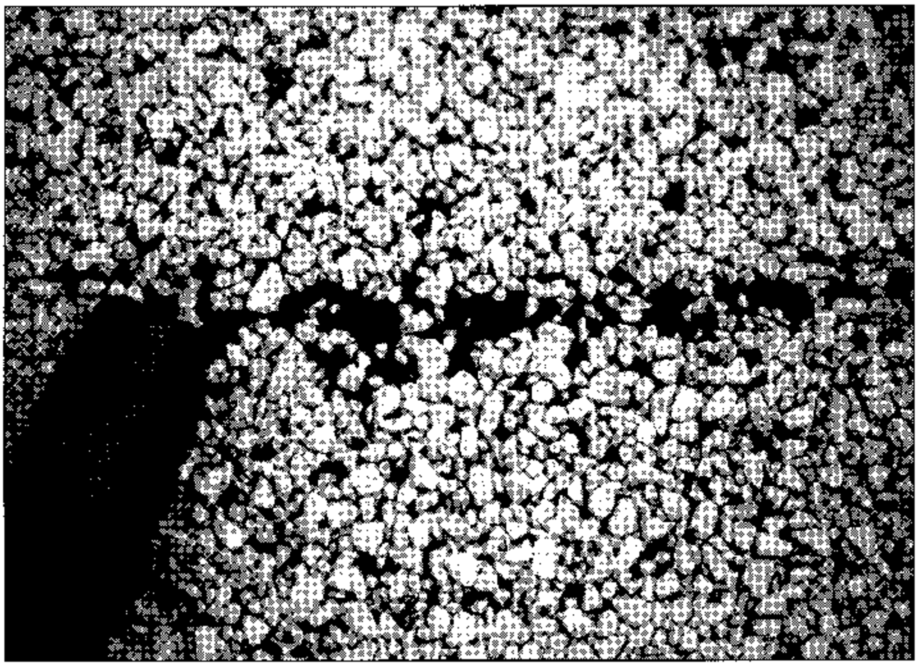

Photo 30. *Roof 65A: Close-up of granule loss along the ridge of a blister on an SBS modified bitumen membrane is shown. Note that even away from the ridge line, the granule coverage is not continuous. This five-year-old roof is located in New York.*

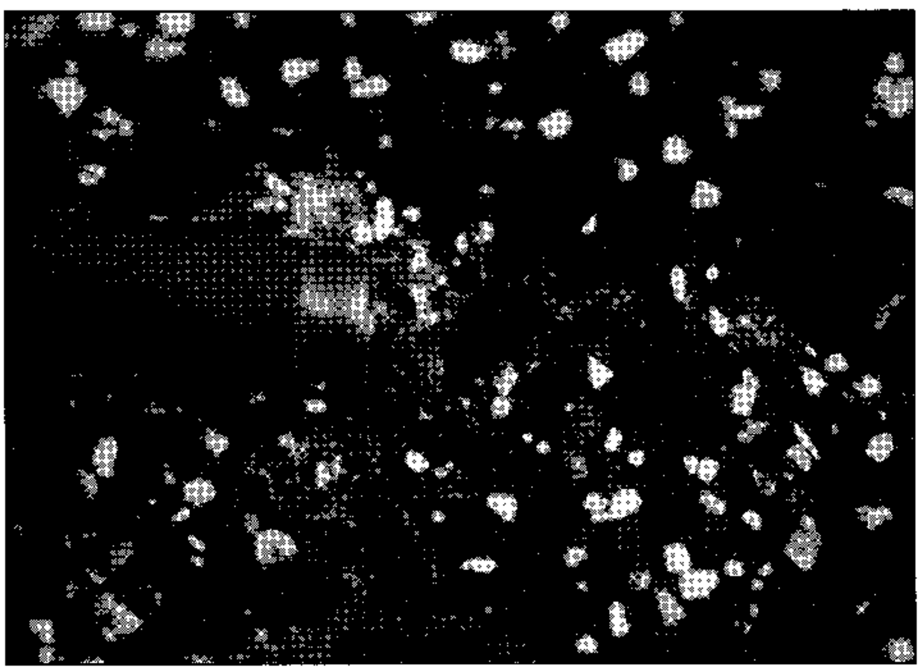

Photo 31. *Roof 68: Close-up of granule loss on an SBS modified bitumen membrane is pictured. This loss appeared to be associated with ponding. This seven-year-old roof is located in New York.*

Granule-surfaced SBS modified bitumen sheets depend on the granules for ultraviolet (UV) protection. Granule loss will accelerate UV degradation (Photos 16 and 31) and perhaps shorten the membrane service life. It also appears that granule loss can lead to cracking (Photos 15 and 16), as previously discussed in this Section. To retard these detrimental weathering effects, a field-applied coating could be applied. (However, the membrane should not be leaking and it should otherwise be in good condition prior to coating.)

Ponding: Section 6.1 discussed ponding with respect to the design of the roof system. This section discusses ponding with respect to its interaction with the modified bitumen sheet's physical properties.

Several observations were made of the detrimental effects of ponding. In some cases, the problems only occurred in ponded areas, and in others, they were more pronounced in the ponded areas. Examples include: membrane surface cracking (Photo 13), granule loss (Photos 17 and 31), delamination (Roof 53, as previously described in the Delamination discussion in this section) and lap separation (Photo 32).

Photo 32. *Roof 2: Lap separation (lifting and peeling) of a self-adhering polymeric-surfaced SEPS membrane roof is shown. This separation occurred in a ponded area. The age of this roof, which is located in Chicago, is unknown.*

Although not normally considered as ponds, condensate water from rooftop HVAC units was also observed to be detrimental. At Roof 26 (in the Phoenix area), a small, very shallow pool of condensate water backed up behind a sidelap that ran perpendicular to the roof slope. Several of the granules from the SBS membrane had been lost in this area.

While good roof drainage is advantageous (and required by the three U.S. model building codes), it is still incumbent upon modified bitumen sheets to possess a reasonable degree of resistance to the harmful effects of standing water or continually wet conditions (e.g., condensate water trickling across the membrane). From this survey, it appears that this is possible. Although observations revealed examples of APP and SBS modified bitumen roofs that were adversely affected by ponding, some examples of both types of membranes did not exhibit noticeable ponding-induced problems.

Roll Run-Out: Roof 6 exhibited roll run-out (hooking) problems (Photo 33). Hooking (as defined in Appendix A) is normally associated with tensioning problems on the reinforcement during the sheet's manufacture. This problem can present difficulties to the contractor during application, and it can lead to an aesthetically objectionable roof.

Photo 33. *Roof 6: Several of the APP modified bitumen sheets on this roof exhibited hooking. This two-year-old roof is located in Chicago.*

Shrinkage: Shrinkage was observed on four (11 percent) SBS modified bitumen membrane roofs. Two were located in Chicago (Roofs 2 and 9), one was located in Phoenix (Roof 31) and one was located in Seattle (Roof 48). Shrinkage was observed on one (1 percent) APP modified bitumen membrane roof. It was located in Seattle (Roof 44A). The most pronounced shrinkage was observed at endlaps on Roof 9 (Photo 34). These five jobs all used products from different manufacturers.

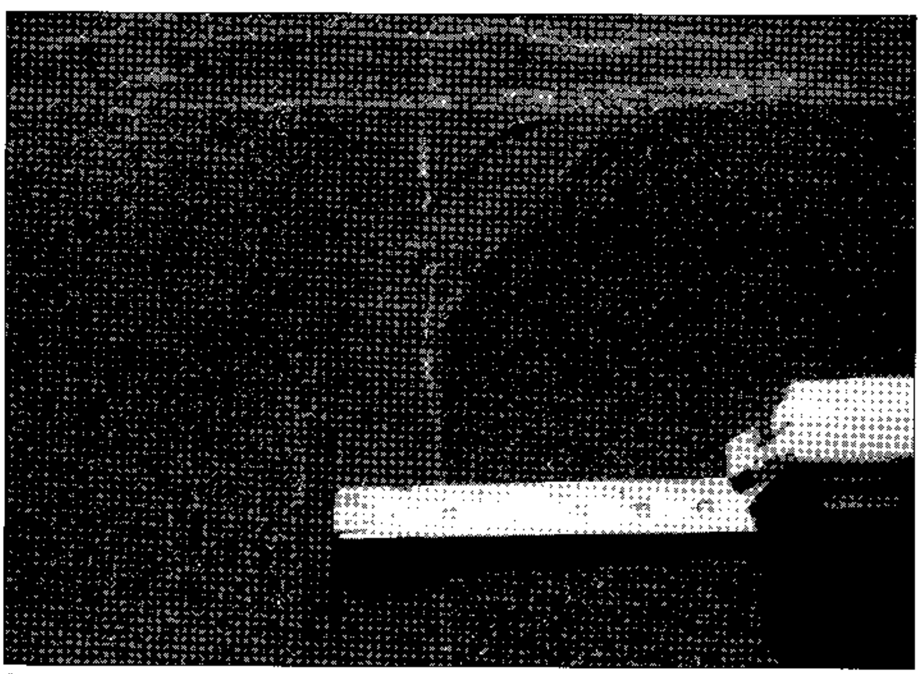

Photo 34*. Roof 9: Approximately 2 in. (50 mm) of shrinkage at the endlap of an SBS modified bitumen sheet is pictured. This two-year-old roof is located in Chicago.*

If the shrinkage is very severe and if the lap is small, the strength of the lap can be adversely affected. For example, if an endlap is pulled apart by 2 in. (50 mm) as shown in Photo 34, and if the lap was originally 4 in. (200 mm), the remaining lap may have insufficient strength.

Cross-Machine Wrinkles: On Roof 50 (a five-year-old APP modified bitumen membrane roof in New Orleans), wrinkles in the cross-machine direction were observed near the end of the sheet. These wrinkles were induced when the roll was wound during manufacture. Sheets should be factory rolled in a manner that will eliminate wrinkling and permit the entire length of the roll to be used.

6.3 Application

Workmanship deficiencies appear to have caused or contributed to impaired performance of many of the roofs. Noteworthy items observed were:

Blistering: Interply blistering was a primary type of problem observed on SBS modified bitumen membrane roofs and the second primary type of problem observed on APP modified bitumen membrane roofs. Eleven (31 percent) SBS and 14 (19 percent) APP modified bitumen membrane roofs were blistered. These 25 jobs used products from 11 different manufacturers. Three of the jobs were located in Chicago, six were in Kansas City, two were in Phoenix, three were in Seattle, three were in New Orleans and 8 were located in New York.

On at least one roof (Roof 63), some of the blisters occurred within the interplies of the old built-up membrane.

Roof 31 (a four-year-old SBS modified bitumen membrane in Phoenix) was hot-applied over an existing built-up roof that had a mineral surface cap sheet. Small amounts of moisture may have been contained in the granule surfacing at the time of application of the new modified bitumen sheet.

Since modified bitumen cap sheets have an extremely low perm rating, they are susceptible to blistering if they are installed over wet or damp substrates. Blistering can also occur due to lack of embedment.

Blisters often do not present problems. However, if a blister has a separated lap (or one that may soon separate), it should be repaired (Photos 35 and 36).

Photo 35. *Roof 17B: The cap sheet lap has nearly pulled apart near the top of this large blister. This five-year-old SBS modified bitumen membrane is located in Kansas City. Although in many instances blister repair is not needed, this illustrates a condition where repair is important.*

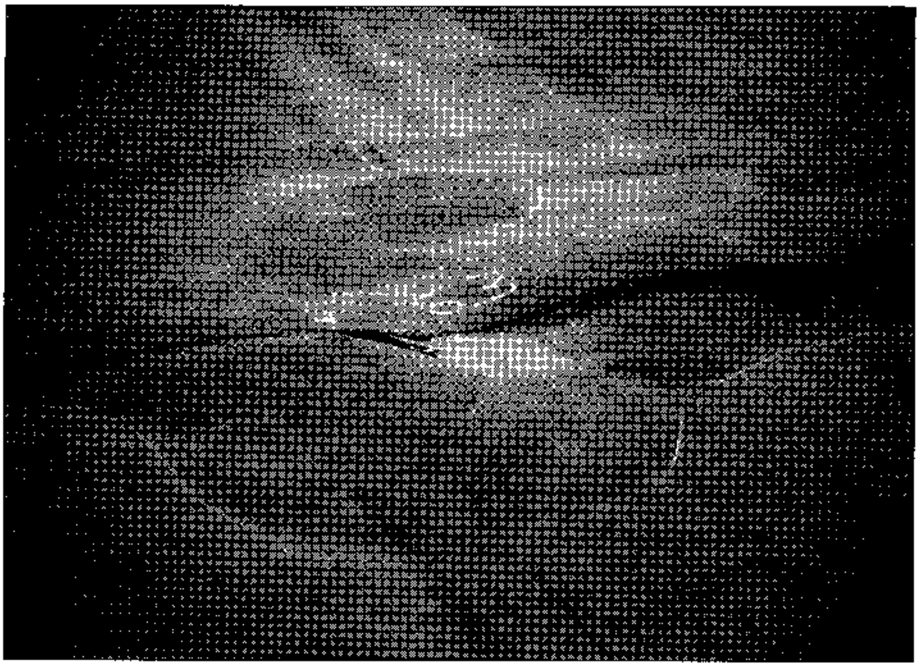

Photo 36. *Roof 63: An ink pen is extended 2¼ in. (55 mm) into an open sidelap. The blister directs water into this open lap. This five-year-old SBS modified bitumen membrane is located in New York.*

Open or Loose Laps: Open or loose laps was the third primary type of problem observed on APP and the leading primary type of problem observed on SBS modified bitumen membrane roofs. Fifteen (42 percent) SBS and 18 (25 percent) APP modified bitumen membrane roofs had open field laps, open base flashing laps or fishmouths. These 33 jobs used products from 12 different manufacturers (the manufacturer on one job is unknown). Ten of the jobs were located in Chicago, four were in Kansas City, five were in Phoenix, two were in Seattle, seven were in New Orleans and five were located in New York.

In some instances, lap problems are very difficult to detect. For example, the problems shown in Photos 37 and 38 were discovered when water was pushed from the lap when it was stepped or pushed on.

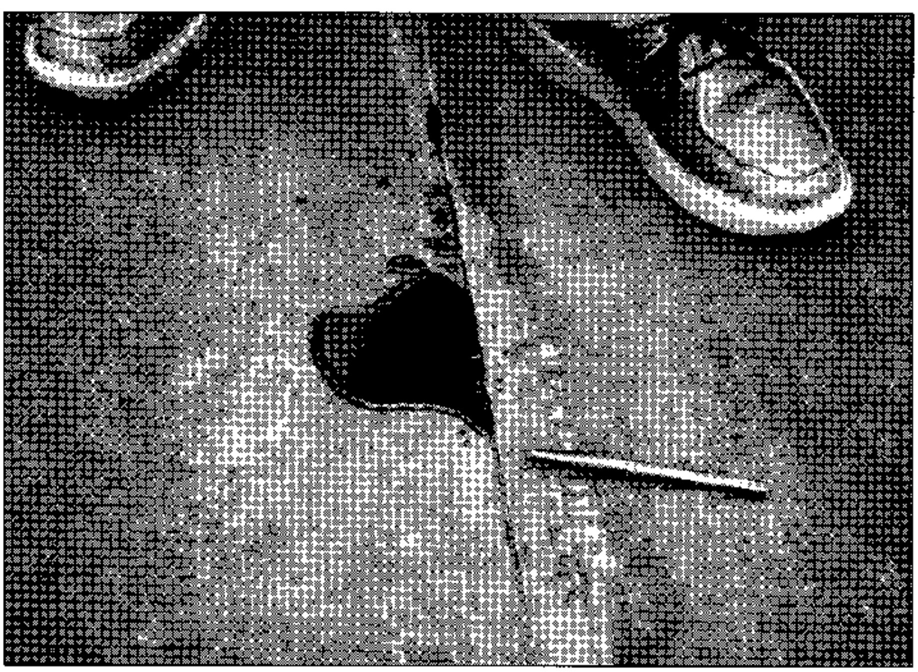

Photo 37. *Roof 54B: Water flowed out of this lap when it was stepped on. This six-year-old APP modified bitumen membrane is located in New Orleans.*

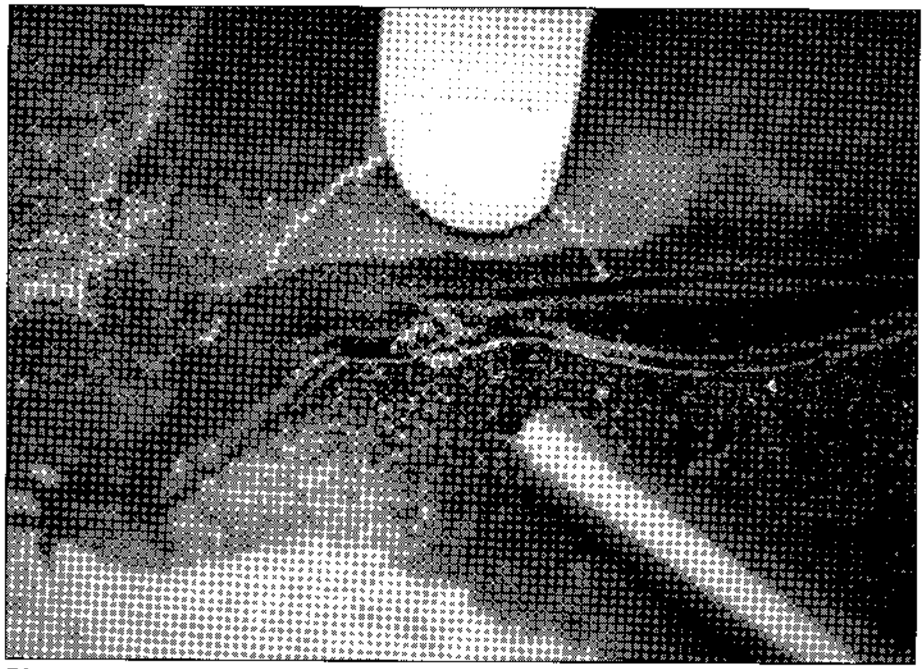

Photo 38. *Roof 64C: This roof had experienced several lap problems (see Photo 28). Along the lap area, a thumb was pressed on the lap in an attempt to see if it contained water. Some water was laying on part of the membrane where this photo was taken. When the lap was pushed, air bubbles were formed (the ink pen points toward the bubbles). Even though there was bitumen bleed-out from the lap, the lap is not continuously sealed. This three-year-old APP modified bitumen membrane is located in New York.*

Some of the lap problems appeared to be related to conforming to substrate irregularities, as shown in Photos 39 and 40. Because of the substrate irregularity, creep-rupture (as defined in Reference 25) may have played a role in these problems.

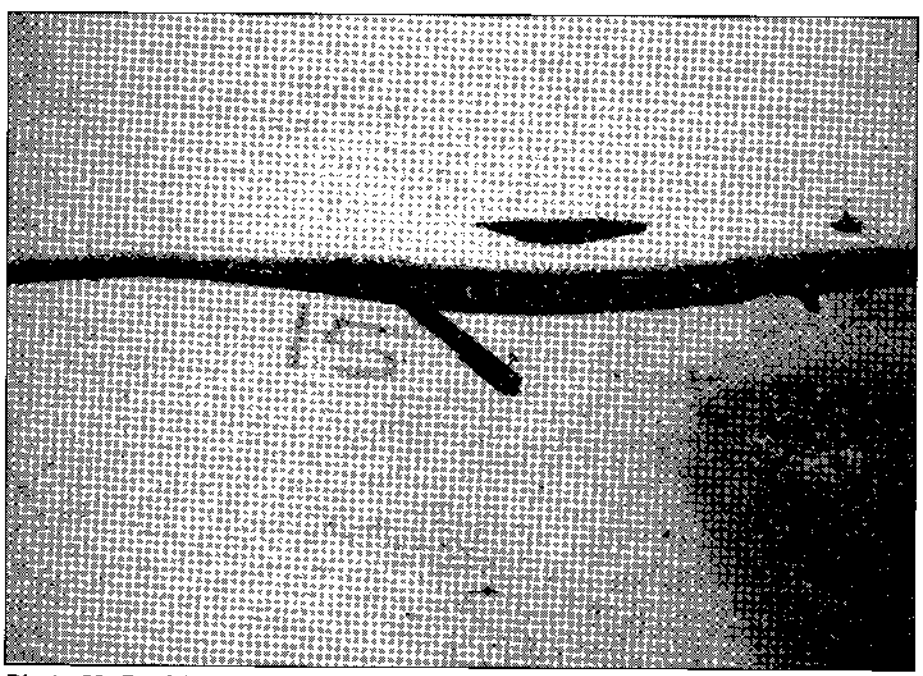

Photo 39. *Roof 15A: This lap problem is located near a roof drain, which is out of the picture to the right. The roof insulation was tapered to slope to the drain. The open lap is near the outer edge of the taper. This two-year-old SBS modified bitumen membrane is located in Kansas City.*

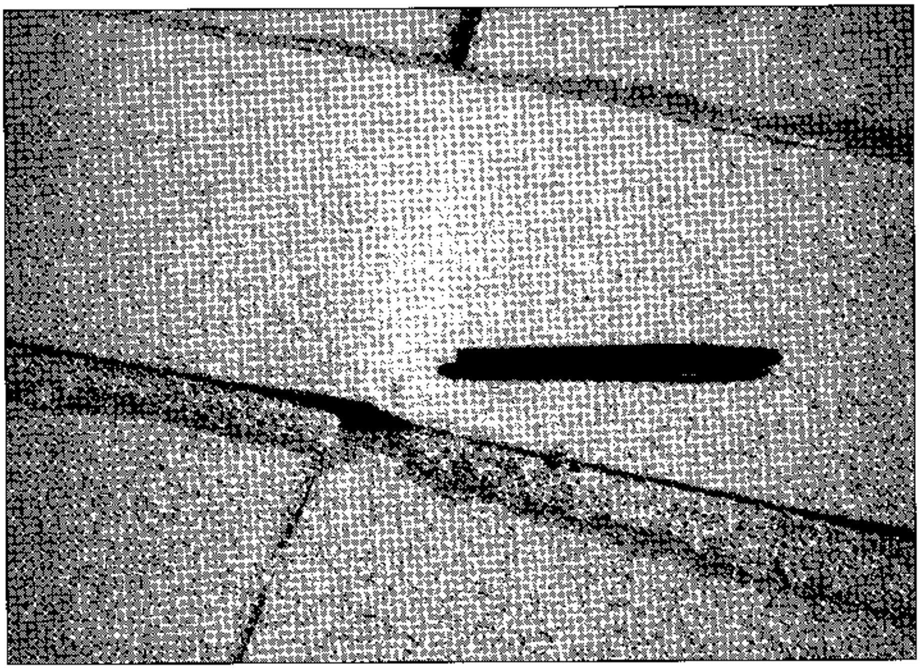

Photo 40. *Roof 24B: This lap problem occurred at the T-joints of a header sheet. This three-year-old SBS modified bitumen membrane is located in Phoenix.*

The open endlap shown in Photo 41 appeared to be related to development of a ridge. Creep-rupture also may have played a role in this problem.

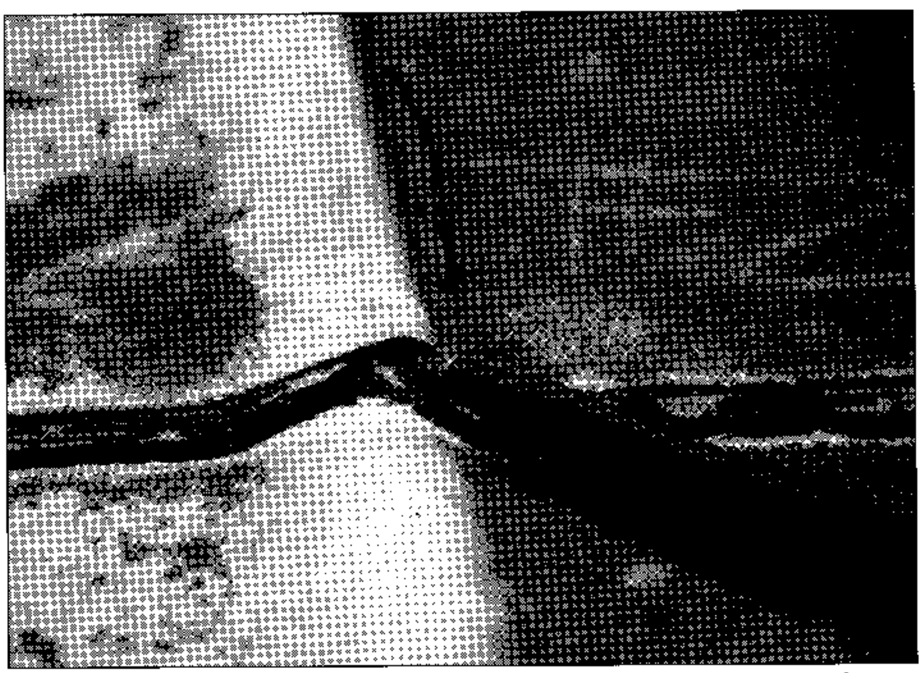

Photo 41. *Roof 2: An endlap opening at a ridge is shown. The age of this SEPS modified bitumen membrane, which is located in Chicago, is unknown.*

The loose endlap shown in Photo 29 may have been associated with the substantial loss of granules, which was experienced on this roof. Particularly in the case of granular-surfaced sheets, the use of 6 in. (150 mm) endlaps is desirable to ensure lap integrity.[26]

Some of the lap problems may have been related to material deficiencies, while others were likely related to insufficient heating (torching) of the lap (Photo 42) or use of mopping asphalt that was either not hot enough or cooled prior to sheet embedment.

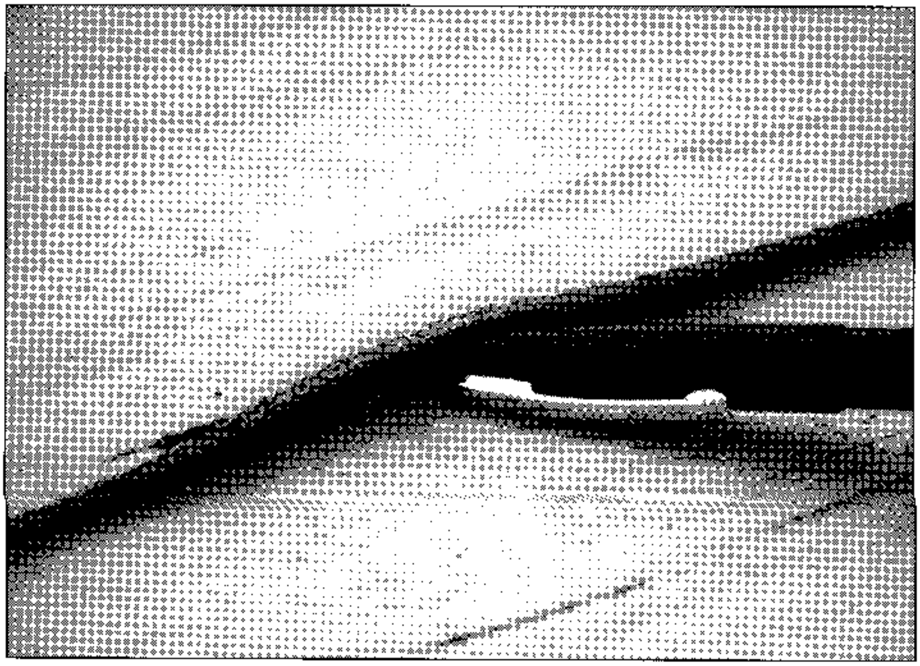

Photo 42. *Roof 3B: The lap of the APP modified bitumen membrane was not sufficiently heated at the time of application. This two-year-old roof is lcoated in Chicago.*

Loose Base Flashings: Loose base flashings associated with design were discussed in Section 6.1. Loose base flashings associated with application are typically related to insufficient heating (torching) of the sheet or use of mopping asphalt that was not hot enough or that cooled prior to sheet embedment.

Loose Metal Edge Flashings: One (3 percent) SBS and six (8 percent) APP modified bitumen membrane roofs had loose metal edge flashings (Photo 4). These seven jobs used products from five different manufacturers. One job was located in Chicago, one was in Kansas City, two were in New Orleans and three were located in New York. In some cases, the loose flashing was probably related to the lack of an application of asphalt primer to the metal. In other cases, it was probably related to insufficient heating (torching) of the sheet or use of mopping asphalt that was not hot enough or that cooled prior to sheet embedment.

Splitting at metal edge flashing joints was discussed in Section 6.1.

Exposed Selvage: Two SBS modified bitumen membrane roofs were observed with exposed selvage. In the exposed area, the membrane is susceptible to UV radiation. If the selvage is inadvertently left exposed, it should be protected by a stripping ply, granules set in asphalt roof cement or a coating.

Traffic on a Hot Sheet: On some roofs, there was a substantial amount of foot traffic on the cap sheet while the sheet was still hot. This resulted in permanent footprint depressions (Photo 43). While this is probably primarily just an aesthetic consideration, traffic over hot sheets should be minimized. (In confined work areas, it is difficult to avoid this.)

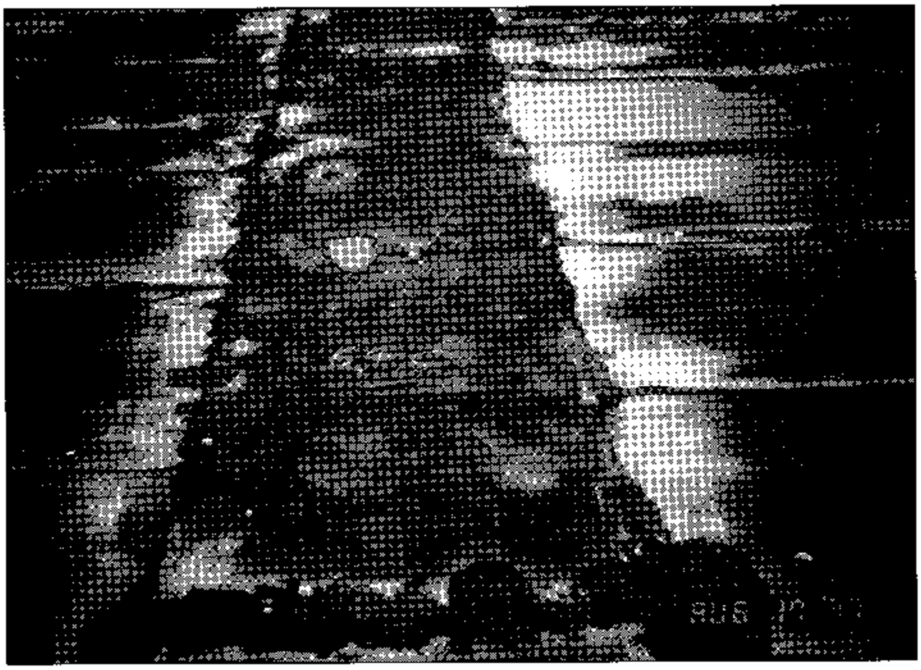

***Photo 43.** Roof 64C: Footprint depressions were made in the header sheet. These are caused by walking over the sheet while it is hot.*

Lack of Endlap Stagger: In one area on Roof 64C, the endlaps were aligned (Photo 44). Endlaps are typically recommended to be staggered by three feet (900 mm) minimum.

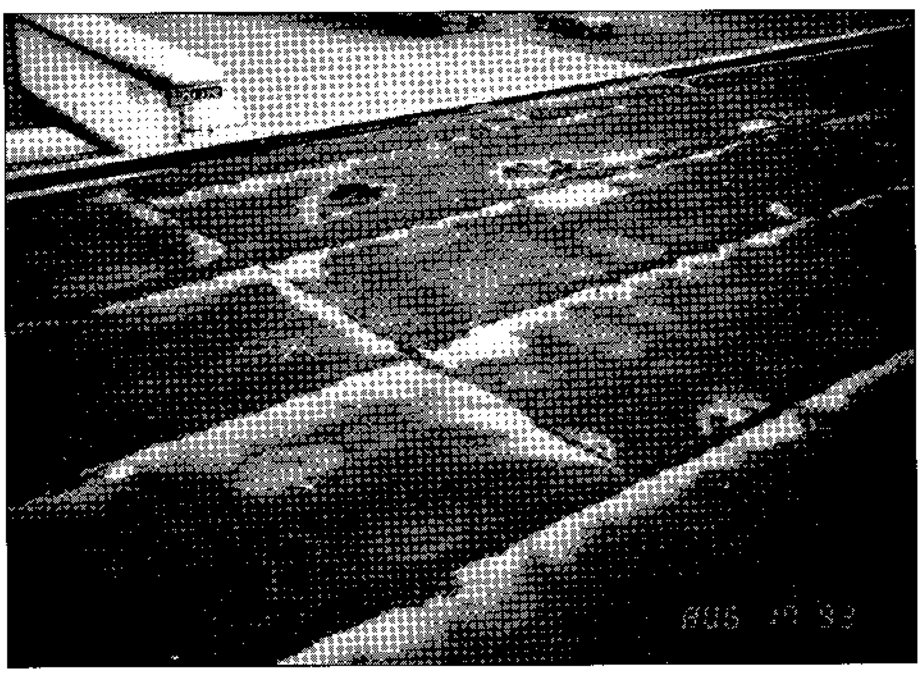

***Photo 44.** Roof 64C: These three endlaps were not staggered, but there were no apparent problems. This three-year-old APP modified bitumen membrane is located in New York.*

Field-Applied Coating: A wide variety of field-applied coatings were observed. The coatings in the best condition occurred in Phoenix and Seattle. It appeared that this was related to workmanship.

Successful coating performance depends in part on adequate membrane surface preparation and coating application. However, in most cases, it was not possible to determine if coating performance problems were related to application, design or materials (Photo 45).

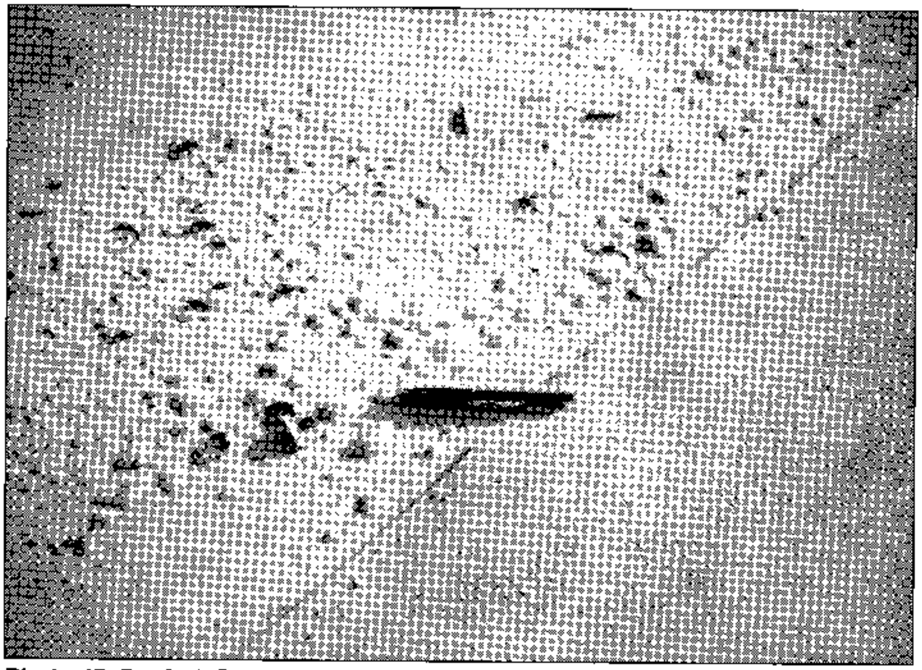

Photo 45. *Roof 51: Blistering of an emulsion coating on a ten-year-old APP modified bitumen membrane in New Orleans is pictured. The broken blisters were ruptured by the investigator. The cause of the blisters was not determined.*

6.4 Abuse and Lack of Maintenance

Abuse after roof installation or lack of periodic maintenance was observed on many roofs. Lack of maintenance was primarily manifested by debris on the roof, which in some cases interfered with roof drainage. Abuse included the placement of sharp heavy objects on the roof (Photo 46), and a dart and a car key stuck into the membrane. Also, as previously discussed in Section 6.2, solvent-based paint caused cracking on one roof and it appeared that cracking was caused on another roof by a spilled contaminant.

Photo 46. *Roof 4A: Wood pallets and heavy pieces of steel and other material are laying on the membrane of this manufacturing facility. The membrane has been punctured in the foreground, near the ink pen. This nine-year-old APP modified bitumen membrane is located in Chicago.*

It appears that modified bitumen roof systems can offer a high degree of resistance to mechanical damage. Both granule and smooth surfaced roofs demonstrated the ability to withstand reasonable amounts of traffic without showing damage, or easily suffering from cuts and abrasions. However, the use of walkways in high traffic areas and around HVAC units that require frequent servicing should still be considered.

Most of the contaminant problems were point sourced and could have been addressed during the design stage of the roof system. For instance, an oil or grease trap could be used to catch processing oils and grease that are vented onto the roof.

6.5 Natural Phenomenon

Hail and wind storms affected some of the roofs. Some of the hail damage appeared to be minor and perhaps will have no impact on roof service life. However, one roof was scheduled for replacement because of the hail damage (Photo 47). The few roofs that had experienced wind damage were damaged to a limited extent. (Except for Roof 54A and 54B, the damage had been repaired prior to the inspections).

Photo 47. *Roof 16: This granule-surfaced APP modified bitumen membrane (which was composed of a cap sheet and a base sheet over phenolic insulation) was punctured by hail in a number of locations. The dark spots are where emergency repairs were made with asphalt roof cement. This two-year-old roof is located in Kansas City.*

6.6 Unknown Causes

Other problems which have caused or contributed to impaired performance of some of the roofs were also observed, however the causes of these problems were not determined:

Factory Splice: On Roof 63, one of the rolls of cap sheet material contained a factory splice (Photo 48). Either the roll with the splice was not marked to indicate that it had a splice, or the mechanics did not cut out the splice.

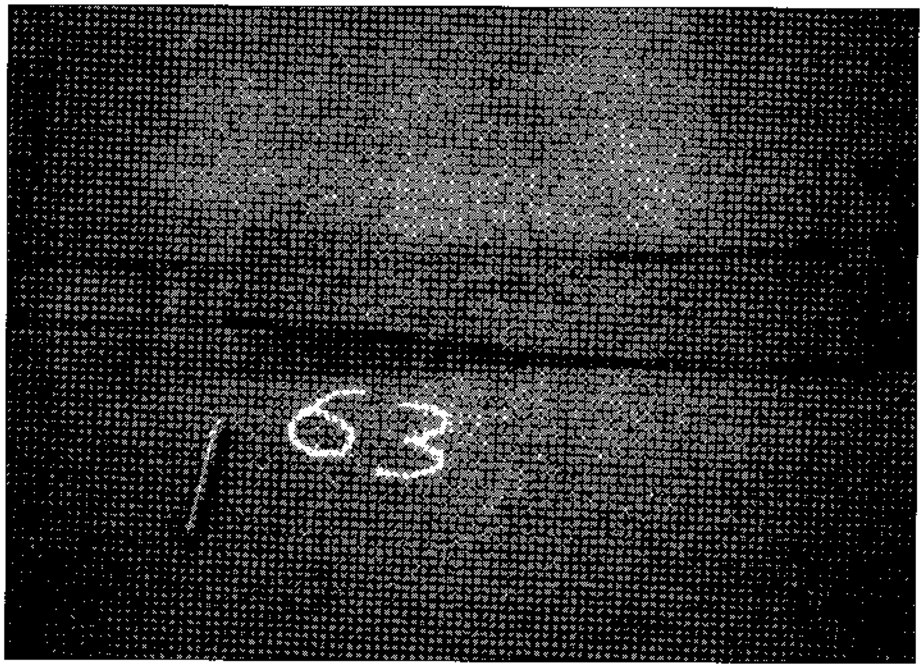

Photo 48. *Roof 63: The factory splice was not cut out of this cap sheet before it was installed. Water infiltration through the cap sheet is possible. This five-year-old SBS modified bitumen membrane roof is located in New York.*

Fastener Backout or Pop-Up: On Roof 72, several of the insulation fastener plates and screw heads were pressing up against the membrane (Photo 49). Either the fasteners were backing out or popping up. This resulted in the development of deep membrane cracks.

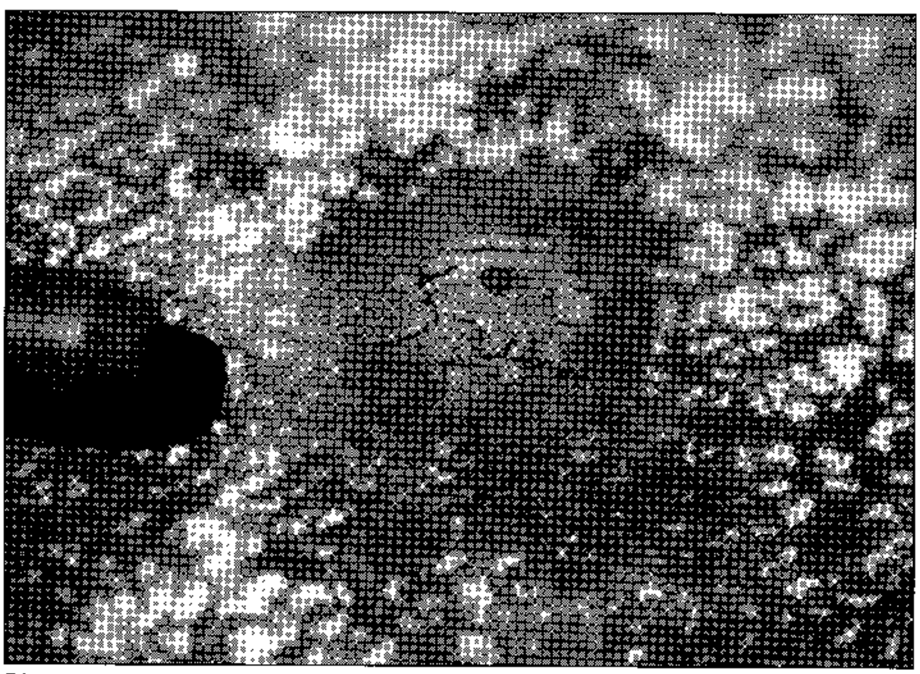

Photo 49. *Roof 72: Fastener backout or pop-up caused the development of these deep membrane cracks. This six-year-old APP modified bitumen membrane roof is located in New York.*

Diagonal Walking: On three roofs (Roofs 8, 21A and 71), the membrane was experiencing diagonal walking (Photo 50). This phenomenon is typically caused by lack of insulation attachment. Lack of attachment may have been caused by design or workmanship deficiencies.

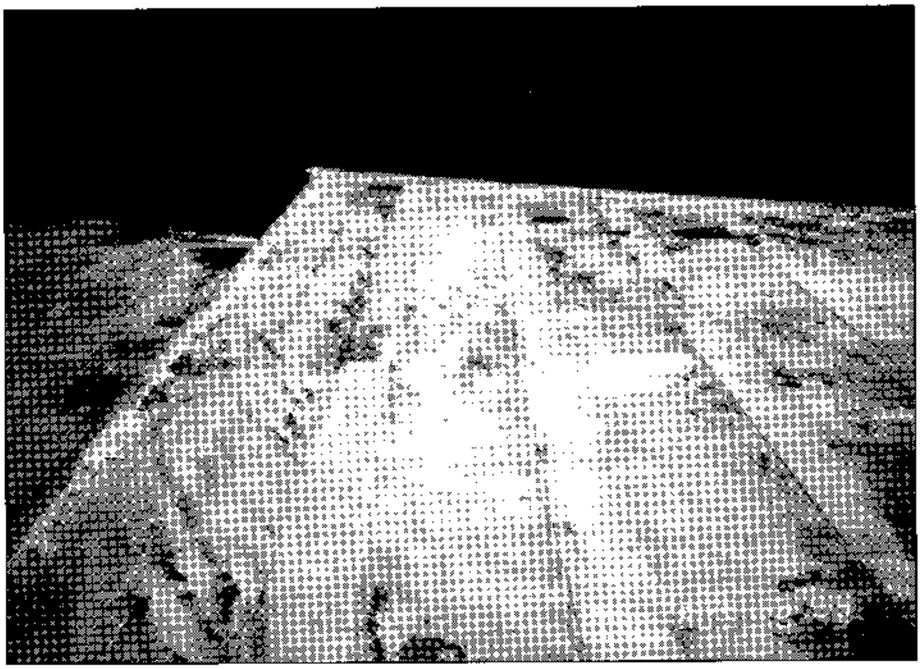

Photo 50. *Roof 71: Diagonal walking is typically caused by lack of insulation attachment. This eight-year-old APP modified bitumen membrane is located in New York.*

Expansion Joint Cover: At several of the joints at the bellows of the expansion joint cover on Roof 64B, the joint cover failed (Photo 51). This failure did not appear to be related to movement of the expansion joint cover. It appeared to be a material or workmanship failure.

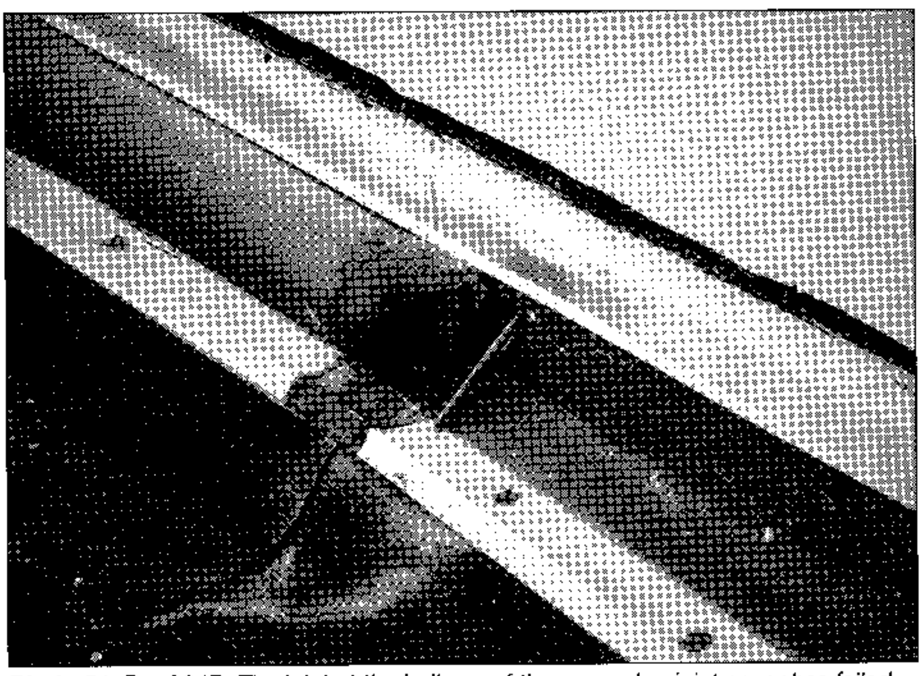

Photo 51. *Roof 64B: The joint at the bellows of the expansion joint cover has failed. This appeared to be a material or workmanship failure. This six-year-old roof is located in New York.*

Slippage: Slippage of base flashings was observed on Roof 16 (an APP membrane in Kansas City) and on Roof 56 (an SBS membrane with a slope of approximately 3:12 [25 percent] in New Orleans). Base flashing slippage is also discussed in Section 6.1.

Membrane slippage was observed on two SBS membranes — Roof 19B in Kansas City and on Roof 27B in Phoenix. Roof 19B had a slope of approximately 3:12 (25 percent). Roof 27B had a copper foil surface, which was dark brown in color. Most of this roof had very steep slopes, but slippage was only observed in one small area that had a slope of approximately 3:12 (25 percent).

Slippage is typically associated with SBS sheets installed in mopping asphalt.[12] Because modified bitumen sheets are heavy compared to base and ply sheets, they are more susceptible to slippage. To avoid slippage, ASTM D 312 Type IV asphalt is typically recommended by sheet manufacturers.[27] Slippage may also be related to asphalt fall-back during heating, premature cooling of the mopping asphalt prior to sheet embedment, or to incompatibility between the mopping asphalt and the sheet.[12]

On slopes exceeding 2:12 (17 percent), back-nailing of the plies is recommended per *The NRCA Roofing and Waterproofing Manual.*

Reference 6 discusses remedial work that was performed on a modified bitumen membrane that had slipped.

7. CONCLUSIONS

1. A large number of roofs were surveyed (109). They represented a number of system variations and manufacturers of membrane and coating products. However, a high percentage of the APP and SBS modified bitumen membrane roofs in this study used products from a small number of manufacturers. Therefore, caution should be exercised when evaluating and interpreting the data collected and presented in this report.

2. The mean age of the roofs inspected was four and a half years, with a range from one to 13 years. Excluding design or application deficiencies and abuse, some of the roofs will not likely achieve the design service life unless protective coatings are applied.

3. *Qualitatively, based upon the overall performance rating used (Table 5), a majority of the roofs surveyed will likely achieve their design service lives. A majority (76 percent) of the roofs inspected were rated to be in good or excellent condition.* However, significant problems related to design, materials, application, abuse, and lack of maintenance and repair were observed on many of the roofs.

   Polymer modified bitumen roof membranes are a viable roofing option on a variety of building types over a wide range of climatic conditions in the United States. But, a combination of quality design, materials, application, care and maintenance are essential to achieve optimum long-term performance.

4. Twenty-four percent of the roofs were given a rating of "3" (the poorest rating). Several of these roofs had a number of contributing problems. Eighty-one percent of these roofs had problems related to membrane material, 46 percent had problems related to workmanship and 35 percent had problems related to design. (Note: The total percentage exceeds 100 percent because several roofs had problems in more than one of these categories.) One roof was severely damaged by hail and another by wind.

   Products from nine membrane manufacturers were used on these roofs.

5. No inherent superiority of polymer (i.e., APP versus SBS) or reinforcement type (i.e., glass fiber versus polyester) was observed.

6. Observations revealed that very few roofs received periodic inspections. Roof longevity can be enhanced when building owners implement routine inspections and have follow-up maintenance and repairs performed when needed.

   Several of the roofs inspected exhibited problems that could be corrected very economically, but if ignored, would eventually be expensive to correct.

7. A few of the roofs were clearly abused. Although modified bitumen membrane roofs are relatively abuse-resistant, they are not immune to significant damage.

8. Field-applied coatings were generally found to enhance the performance of modified bitumen roof membranes. But, because of very limited information on coatings (e.g., manufacturer, membrane preparation, weather at time of application, application rate and number of coats), it was difficult to assess the performance of coatings and evaluate various types of coating problems in this study.

9. Based upon the inspections, primary impediments to roof system longevity (in addition to abuse and lack of maintenance) include the following.

   Design: Impediments include poor design detailing (particularly on many of the reroofing projects), lack of provisions to accommodate building movement at deck/parapet junctures and lack of provisions for positive drainage.

   Materials: For some APP modified bitumen sheets, the primary area of concern is propagation of cracks through unsurfaced membranes or through membranes without protective reinforcement near the top of the cap sheet. For some SBS modified bitumen sheets, the primary area of concern is degradation of the membrane because of ultraviolet (UV) exposure after loss of granules.

Note:

- In the United States, cracking and UV degradation previously had not been identified as significant issues with modified bitumen roof membranes. Development of leakage from either failure mode likely requires several years of in-service exposure.

- Development of crazing on the surface of the membrane does not necessarily mean that the crazing will develop into cracking. Similarly, development of cracks does not necessarily mean that they will propagate through the membrane.

Application: Impediments include workmanship deficiencies (unrelated to material deficiencies and/or building movement) that lead to open laps.

10. Ponding and small pools of water (including condensate drainage from HVAC units) affected the surface of some APP and SBS modified bitumen membranes and some coatings, but had no noticeable effect on others. Ponding effects were manifested by peeling of coatings, cracking of APP membranes, and granule loss and cracking of SBS membranes.

11. The primary problems observed with the APP modified bitumen membrane systems were: membrane crazing/cracking, blisters, open or loose laps and loose base flashing. Products from five or more different manufacturers and jobs located in four or more of the climatic areas inspected were involved in all four of these primary problems.

    The primary problems observed for the SBS modified bitumen membrane systems were open or loose laps, blisters, crazing/cracking, and granule loss. Products from five or more different manufacturers and jobs located in three or more of the climatic areas inspected were involved in all four of these primary problems.

8.1 Design

- Criteria need to be standardized for specifying polymer modified bitumen membrane roof systems. In 1989, Rossiter[28] suggested prescriptive and performance criteria that may be used for federal construction agencies in the absence of U.S. voluntary consensus standards. The criteria are summarized in Appendix J.
- For the membrane, a minimum of two plies (a base sheet and a modified bitumen cap sheet) are recommended.
- It is recommended that the roof surface have sufficient slope to provide "positive drainage" (as defined in the Glossary of *The NRCA Roofing and Waterproofing Manual*).
- It is recommended that endlaps of 6 in. (150 mm) minimum be specified.
- It is recommended that research be undertaken to determine a maximum recommended thickness for individual layers of lightweight insulation (e.g., plastic foam), to avoid membrane distress problems associated with inadequate shear resistance of the insulation system.
- When hot asphalt is to be applied over cover boards that have been installed over expanded polystyrene insulation, it is recommended that taping of the cover board joints be specified. Alternatively, if the cover boards are specified to be mechanically attached, a barrier sheet (such as a red rosin sheathing paper) could be specified between the polystyrene and the cover boards to avoid melting of the foam insulation and development of a void.[21]
- Deck/parapet (or wall) intersection: If the design of the intersection allows differential movement (due to thermal movement or live loads), it is recommended that an expansion joint detail be designed to avoid separation and development of diagonal wrinkles in the base flashing. For detail design guidance, see detail "MB-4" in the Fourth Edition of *The NRCA Roofing and Waterproofing Manual*.
- Parapets:
  - It is recommend that masonry parapets be assessed for suitability before they are sealed with membrane materials.
  - When reroofing is contemplated, it is recommended that the base flashing substrate conditions be assessed. In some situations, specifying the installation of plywood over the existing parapet may be prudent.
- Multiple ply membrane base flashings (a base sheet and a modified bitumen cap sheet) are recommended.
- It is recommended that research be undertaken to determine a maximum recommended height for membrane base flashings.
- It is recommended that cant strips be specified for transitions between horizontal and vertical surfaces.
- An additional ply of modified bitumen cap sheet material is recommended at inside and outside corners of membrane base flashings. Industry standardization is recommended.
- It is recommended that metal edge flashings (gravel stops) be primed with an asphalt primer and then fastened over the membrane and stripped in with modified bitumen cap sheet material.
- If termination bars are specified at the top of membrane base flashings, it is recommended that counterflashings also be specified to provide weather protection for the top of the base flashing.
- It is recommended that field- or factory-applied surfacing (coating or granules) or sheets with protective reinforcement (near the top of the sheet) be specified to avoid cracking problems with APP modified bitumen membrane roofs.

8.2 Materials

It is recommended that U.S. consensus standards with suitable criteria be adopted for APP and SBS modified bitumen roof sheets.

8.3 Installation

- It is recommended that applicators be alert to inconsistences in modified bitumen products caused by production changes or by changing manufacturers that affect application and performance characteristics. Baxter[29] warns that inconsistences in modified bitumen manufacturing processes may require adjustments in application methods, as summarized in Appendix K.
- It is recommended that applicators follow the recommendations provided by Carlson in 1992[30-32] related to fabrication of laps and installation of base flashings. (Note: These articles discussed repair techniques, but portions of them are applicable to new application.)
- It is recommended that applicators follow the ARMA/NRCA *Quality Control Guidelines for the Application of Polymer Modified Bitumen Roofing.*
- It is recommended that steep transitions (e.g., at roof drains) be avoided. Where possible, cut shallow slopes (e.g., 2:12 [17 percent]) or use tapered edge strips at slope transitions.

8.4 Maintenance

It is recommended that building owners have their roofs periodically inspected and maintained in accordance with the *SPRI/NRCA Manual of Roof Inspection, Maintenance, and Emergency Repair for Existing Single-Ply Roofing Systems* or the *ARMA/NRCA Manual for Inspection and Maintenance of Built-Up and Modified Bitumen Roof Systems: A Guide for Building Owners.*

8.5 Repair

- For repair of modified bitumen roofs, consult the ARMA/NRCA/SPRI single-ply repair manual (anticipated release date winter 1996). In the interim, the repair techniques discussed by Carlson[30-32] are recommended.
- For SBS modified bitumen roofs that have experienced granule loss, and for APP modified bitumen roofs that are experiencing crazing/cracking, it is recommended that application of a coating be considered if the roof is not leaking and is otherwise in good condition, in order to maximize the roof's service life.

  For preparation of surfaces to receive coating, consult the *ARMA/RCMA Evaluating and Preparing Modified Bitumen Membrane Roofing for Surface Coating Applications* document. Carlson[8] also presents preparation and coating recommendations.

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Appendix A: Definitions

Angel Hair: See "fiberglass bloom."

Checking: See "crazing."

Cracking: Fissures that extend well into a modified bitumen sheet from the sheet's top surface. For example, see Photos 11, 12, 13 and 15. Note: If the "cracking" is very shallow, it is referred to as "crazing."

Cracking manifests itself in one of three common patterns: linear, random or spider web. With linear cracking, the fissures are primarily oriented in one direction. With random cracking, the fissures appear in an irregular pattern. With spider web cracking, the fissure pattern somewhat resembles that of a spider web.

Craters: Hemispherical surface cavities in the modified bitumen sheet. Cracks often times extend outward from craters. For example, see Photo 12.

Crazing: Very closely spaced shallow surface cracking in a modified bitumen sheet that is associated with weather-induced deterioration. Crazing is also referred to as "checking" or "weather-checking."

Delamination (within sheet): Separation of the laminated layers of the modified bitumen sheet (e.g., separation of the reinforcement from the bitumen matrix, as shown in Photo 19, or separation of the foil surfacing, as shown in Photo 23).

Diagonal Wrinkling: Base flashing wrinkles associated with differential movement between the parapet and roof deck. For example, see Photo 5.

Fiberglass Bloom: Separation of the glass fibers from the bitumen matrix. This phenomenon is associated with modified bitumen sheets that have continuous filament reinforcement near the top of the sheet. For an example of an advanced stage of fiberglass bloom, see Photo 27.

Finger Blisters: Linear blister-like deformations of the modified bitumen sheet, which are oriented in the machine-direction of the sheet. When finger blisters occur, typically several of them are found adjacent to each other. Although they are referred to as blisters, they typically do not occur over a void. Finger blisters are related to the dimensional stability of the cap sheet's reinforcement at elevated temperatures during sheet application. In some instances, the reinforcement has inadequate dimensional stability, but often times, excessive heat welding causes instability. For example, see Photo 28.

Hooking: Curvature of the roll run-out. Hooking is normally associated with tensioning problems on the reinforcement during the modified bitumen sheet's manufacture. For example, see Photo 33.

Linear Cracking: See "cracking."

Random Cracking: See "cracking."

Spider Web Cracking: See "cracking."

Weather-Checking: See "crazing".

Appendix B

NRCA/MRCA Modified Asphalt Roofing Membrane Evaluation

Facility Background Information NRCA Pinpoint ID: ____________

Date of Roof Audit: ____________ Date of Installation ____________ Roof Age: ____________ mos.

Facility Name: ____________ Type of Facility: ____________

Facility Address: ____________

Cold Storage/Freezer Areas: ____________ Interior Humidified: ____________

Name of Facility Contact: ____________ Contact Phone No. ____________

Persons Present at Audit: ____________

How is Access Provided to the Roof: ____________

Weather (e.g., temp., wind, sun, etc.) During Audit: ____________

Configuration/Description of the Roof Assembly

Roof Construction: New ____________ Reroof with Tear-off ____________ Reroof without Tear-off ____________

Roof Area Designation: ____________ Estimated Roof Size: ____________ ft^2

Deck Structurally Sloped: ____________ Amount of Slope: ____________

Roof Deck Type: ____________ Drainage System Type: ____________

Vapor Retarder Present: ____________ Type: ____________

Roof Insulation: ____________ Type: ____________ No. Layers: ____________ Thickness: ____________ in.

Base Sheet Included: ____________

Roof Perimeters: ____________

Roof Mounted Equipment: ____________ Walkways: ____________

Roof Traffic: ____________ How Extensive: Light ____________ Medium ____________ Heavy ____________

General Roof Conditions (Other than Membrane Observations)

Insulation Wet: ____________ How Extensive: ____________ % Area Locations: ____________

Drain Freely: ____________ Percent Ponded: ____________ Locations: ____________

Mechanical Damage Present: ____________ Describe: ____________

Contamination Present: ____________ Describe: ____________

Has the Roof Leaked: ____________ Roof Age at Leaks: ____________ Describe Leaks: ____________

____

____

Repairs Made: ____________ Have they Worked: ____________ Describe: ____________

____

____

____

Core Sampling at the Time of the Audit

Were Samples Removed: ____________ How Many: ____________ Locations: ____________

If no, why: ____________ If yes, where are they: ____________

Configuration/Description of the Roof Membrane

NRCA Pinpoint ID: ______

Mod. Bit. Membrane Type: APP ______ SBS ______ Other (describe) ______

No. of Base Plies: ______ Type of Base Plies: ______

Base Ply Attachment: Mechanical ______ Set in Asphalt ______ Adhesive ______ Heat Weld ______ Other ______

Surfacing: None ______ Granules ______ Foil ______ Coating (describe) ______ Other ______

Membrane Manufacturer Name: ______ Mfrs. Product Designation: ______

Coating Manufacturer Name: ______ Mfrs. Product Designation: ______

Flashing Type: ______ No. of Flashing Plies ______

Membrane/Flashing Laps Tooled: ______

Roof Membrane Conditions

Weathering of Surface Appears Normal: ______

Surface Appears Weathered:

Degranulation: ______ Degree ______ Comments: ______

Cracks/Crazing: ______ Degree ______ Comments: ______

Other Surface Conditions (describe): ______

Comments on Conditions: ______

______

Auditor Suggests a Coating is Needed: Yes ______ No ______ Comment ______

Membrane Blistered: ______ Degree ______ Location in Membrane: ______

Indications of Shrinkage (describe): ______

Side Lap Conditions: Sealed ______ Separated ______ Degree ______ Water in Laps ______

End Lap Conditions: Sealed ______ Separated ______ Degree ______ Water in Laps ______

Comments on Laps: ______

______

______

Coating Age: ______ mos. Coating Condition: Normal ______ Weathered (describe) ______

______

Perimeter Problems: None ______ Describe ______

Penetration/Mount Problems: None ______ Describe ______

Other Conditions: Splits ______ Punctures ______ Delamination ______ Wind Damage ______

Comments on Other Conditions (e.g., degree, cause, etc.): ______

______

______

Auditors General Opinion of the Membrane: Excellent ______ Good ______ Fair ______ Poor ______

Other Comments: ______

______

______

______

Weather Data Sunshine and Precipitation (through 1991)						
City	**Sunshine**				**Precipitation**	
	% of Possible Sunshine, Year	**Mean No. of Days**			**Water Equivalent, Normal Year (inches [mm])**	**Snow, Ice Pellets, Hail (Max. Monthly, inches [mm])**
		Clear	**Partly Cloudy**	**Cloudy**		
Buffalo	49	53.9	103.3	208.1	37.52 (953)	68.4 (1737) (Dec. 1985)
Rochester	51	61.7	105.2	198.3	31.27 (794)	64.8 (1646) (Feb. 1958)
Chicago	54	84.8	105.5	174.9	33.34 (847)	35 (889) (Dec. 1978)
Kansas City	62	122.6	95.2	147.4	35.16 (893)	14.2 (361) (Jan. 1977)
New Orleans	60	102.7	118.7	143.8	59.74 (1517)	2.7 (69) (Dec. 1963)
Phoenix	86	211.4	84.3	69.6	7.11 (181)	0.6 (2) (Feb. 1939)
Seattle	46	56.7	80.9	227.3	38.60 (980)	57 (1448) (Jan. 1950)

Appendix Table C

Weather Data
Temperature and Humidity (through 1991)

	Temperature °F (°C)										Mean Relative Humidity (%)[2,3]			
	Daily Max. Year	Daily Max. July	Daily Min. Year	Daily Min. Jan.	Record High Year	Record Low Year	Heating Degree Days[1]	Cooling Degree Days[1]	Mean No. of Days Temp. ≥90°F (32°C)	Mean No. of Days Temp. ≤32°F (0°C)	Year 6:00 a.m.	July 6:00 a.m.	Year, Noon	July, Noon
Buffalo	55.8 (13.2)	80.2 (26.8)	39.3 (4.1)	17 (-8.3)	99 (37) 1948	-20 (-29) 1961	6,798	476	2.9	132.1	80	78	63	55
Rochester	57.2 (14)	82.3 (27.9)	38.7 (3.7)	16.3 (-8.7)	100 (38) 1953	-19 (-28) 1974	6,713	531	9.1	133.9	81	82	61	54
Chicago	58.7 (14.8)	83.3 (28.5)	39.7 (4.3)	13.6 (-10.2)	104 (40) 1988	-27 (-33) 1985	6,455	740	17.7	132.5	80	82	60	56
Kansas City	63.7 (17.6)	88.5 (31.4)	44.4 (6.9)	17.2 (-8.2)	109 (43) 1984	-23 (-31) 1989	5,283	1,333	39.4	110.4	81	84	59	56
New Orleans	77.7 (25.4)	90.7 (32.6)	58.7 (14.8)	43 (6.1)	102 (39) 1980	11 (-12) 1989	1,490	2,686	70.1	13.2	87	91	63	66
Phoenix	85.1 (29.5)	105 (40.6)	71.2 (21.8)	52.3 (11.3)	122 (50) 1990	17 (-8) 1950	1,442	3,746	168.6	7.5	51	45	32	28
Seattle	58.9 (14.9)	75.2 (24)	43.9 (6.6)	34.3 (1.3)	99 (37) 1981	0 (-18) 1950	5,121	184	3.3	31	83	82	74	65

[1] Base: 65°F (18°C).

[2] When comparing relative humidity (R.H.) data, also consider temperature data. For example, the July noon R.H. at New Orleans and Seattle is 66 and 65%. But since the daily maximum July temperature is 90.7°F (32.6°C) versus 75.2°F (24°C), the absolute humidity in New Orleans is much higher.

[3] The 6:00 a.m. R.H. was actually recorded at 7:00 a.m. in Buffalo and Rochester, 5:00 a.m. in Phoenix and 4:00 a.m. in Seattle. The noon R.H. was actually recorded at 1:00 p.m., 11:00 and 10:00 a.m., respectively.

Appendix Table D

Manufacturer ID	Buffalo/Rochester		Chicago		Kansas City		New Orleans		Phoenix		Seattle		Total # of	
	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS	APP	SBS
1	2		6		13	1	6		5		3		35	1
2				1										1
3	4		3		1		1			1	1		10	1
4			7		1						3		11	
5			2	1	1		1						4	1
6		2				2								4
7								5		8		5		18
8										1				1
9							3						3	
10	1										1		2	
11		1									1		1	1
12	1												1	
13			2	1									2	1
14												2		2
15											1		1	
16												1		1
17												1		1
18											1		1	
19												1		1
Unknown	1	1								1	1		2	2
# of Different Manufacturers	4	2	5	3	4	2	4	1	1	3	7	5	11	13
Total Number of Roofs:													73	36

Note: 1. 79% of the APP roofs utilized products from three manufacturers.
2. 53% of the SBS roofs utilized products from one manufacturer.
3. Six manufacturers sold their modified bitumen product line to other manufacturers, one manufacturer is no longer in business and one manufacturer's modified bitumen product is now only intended for protected membrane roofs.

Appendix Table E: *Roofs as a function of manufacturer, polymer modifier and city.*

No. of Roofs	Facility Type
1	Auditorium
1	Church
1	Exhibit Hall
1	Hospital
27	Manufacturing (including light and heavy)
1	Motel
6	Recreation
7	Residential (condominiums or dormitories)
10	Retail
20	Office
25	School
3	Vehicle Maintenance
6	Warehouse

Appendix Table F: *Roofs as a function of facility type.*

APPENDIX TABLE G

CHICAGO		1A	1B	2	3A	3B	4A	4B	4C	4D	4E	5	6	7A	7B	7C	7D
WRINKLING				•													
WIND BLOW-OFF																	
SPLITTING AT M.E.F.					•												
SPLITTING																	
SLIPPAGE																	
SHRINKAGE				•													
RIDGING																	
PUNCTURE/IMPACT DAMAGE							•										•
POST-APPLICATION PATCHES								•									
PONDING																	
POCKMARKS																	
LAPS OPEN AT B.F.				•													
LAPS OPEN OR LOOSE		•		•	•	•		•									
INSUL. CRUSHING/EQUIP.																	
INSUL. BOARD WARP																	
GRANULE LOSS																•	
FOOTPRINTS																	
FLASHING LOOSE AT M.E.F.						•											
FLASHING LOOSE AT B.F.																	
FISHMOUTH		•		•													
FINGER BLISTERS													•				
FIBERGLASS BLOOM		•															
FASTENERS TENTING																	
EXUDATION		•														•	
EXPOSED SELVAGE																	
EXPOSED REINF./TOOLING														•			
EXPANSION JOINT OPEN																	
DIAGONAL WALKING																	
DELAM. (WITHIN SHEET)				JJ								U		•			JJ
DEBRIS ON ROOF						•											
CRACKING (SPIDER WEB)					•												
CRACKING (RANDOM)				L	•									•		•	
CRACKING (LINEAR)								•								•	
CRACKING AT B.F.																	
COATING EROSION					•	•											
COATING DELAM./PEELING									•								
COATING BLISTER																	
BLISTER (INTERPLY)		•			•												
UNSURFACED	Surfacing	•	•											•	•		
POLYMERIC	Surfacing			•													
METAL FOIL	Surfacing																•
LATEX	Surfacing																
GRANULE-SURFACED	Surfacing											•	HH			•	
EMULSION	Surfacing						•	•	•	•							
ALUMINUM-PIGMENTED	Surfacing				•	•											
AGGREGATE-SURFACED	Surfacing										•						
SELF-ADHERING	Attachment			•													
HOT-APPLIED	Attachment																
HEAT-WELDED	Attachment	•	•		•	•	•	•	•	•	•		•	•	•	•	•
COLD ADHESIVE	Attachment											•					
SBS				•								•					
APP		•	•		•	•	•	•	•	•	•		GG	•	•	•	•
MANUFACTURER		1	1	2	4	3	1	1	5	5	1	5	13	1	4	4	4
AGE (YEARS)		2	4	?	?	2	9	7	2	4	9	3	2	6	5	5	?
RATING		1	1	2	2	1	1	2	1	1	1	2	1	3	1	2	2
JOB NUMBER		1A	1B	2	3A	3B	4A	4B	4C	4D	4E	5	6	7A	7B	7C	7D

APPENDIX TABLE G

	JOB NUMBER	7E	7F	7G	8	9	10	11	KANSAS CITY	12A	12B	12C	13A	13B	14	15A	15B	16
	WRINKLING							•										
	WIND BLOW-OFF																	
	SPLITTING AT M.E.F.																	
	SPLITTING																	
	SLIPPAGE																	B
	SHRINKAGE					•												
	RIDGING														•			
	PUNCTURE/IMPACT DAMAGE				•								•					K
	POST-APPLICATION PATCHES												•					•
	PONDING												•	•				
	POCKMARKS	•																
	LAPS OPEN AT B.F.	•																
	LAPS OPEN OR LOOSE		•	•		•		•								•		
	INSUL. CRUSHING/EQUIP.																	
	INSUL. BOARD WARP																	
	GRANULE LOSS																	•
	FOOTPRINTS																	
	FLASHING LOOSE AT M.E.F.																	
	FLASHING LOOSE AT B.F.	F	E	•														•
	FISHMOUTH															•		
	FINGER BLISTERS														•			
	FIBERGLASS BLOOM													A				
	FASTENERS TENTING																	
	EXUDATION						•								•			
	EXPOSED SELVAGE																	
	EXPOSED REINF./TOOLING																	
	EXPANSION JOINT OPEN																	
	DIAGONAL WALKING				•													
	DELAM. (WITHIN SHEET)																	
	DEBRIS ON ROOF												•	•				
	CRACKING (SPIDER WEB)																	
	CRACKING (RANDOM)		•	•														
	CRACKING (LINEAR)		•		•										•			
	CRACKING AT B.F.	•		•				•							•		•	
	COATING EROSION						•	•										
	COATING DELAM./PEELING																	
	COATING BLISTER																	
	BLISTER (INTERPLY)				•					•								
Surfacing	UNSURFACED	•	•	•						•	•	•	•	•			•	
Surfacing	POLYMERIC																	
Surfacing	METAL FOIL																	
Surfacing	LATEX																	
Surfacing	GRANULE-SURFACED				•	•										•		•
Surfacing	EMULSION														•			
Surfacing	ALUMINUM-PIGMENTED						•	•										
Surfacing	AGGREGATE-SURFACED																	
Attachment	SELF-ADHERING																	
Attachment	HOT-APPLIED															•		
Attachment	HEAT-WELDED	•	•	•	•		•	•		•	•	•	•	•	•		•	•
Attachment	COLD ADHESIVE																	
	SBS					•										•		
	APP	KK	•	•	•		•	•		•	•	•	•	•	•		•	•
	MANUFACTURER	4	4	4	13	13	3	3		1	1	1	1	1	5	6	1	3
	AGE (YEARS)	8	5	?	2	2	3	3		7	6	1	10	9	3	2	5	2
	RATING	2	3	3	2	1	1	2		2	1	1	2	2	2	1	2	3

APPENDIX TABLE G

JOB NUMBER	17A	17B	18	19A	19B	20	21A	21B	21C	22	PHOENIX	23A	23B	23C	24A	24B	25
RATING	2	2	2	3	2	3	3	3	3	3		2	2	1	1	2	1
AGE (YEARS)	5	5	7	5	?	5	9	9	8	7		<1	1	2	3	3	<1
MANUFACTURER	1	6	1	1	1	4	1	1	1	1		1	1	1	7	7	8
APP	•		•	•		•	•	•	•	•		•	•	•			
SBS		•			•										•	•	•
Attachment																	
COLD ADHESIVE																	
HEAT-WELDED	•		•	•		•	•	•	•	•		•	•	•			
HOT-APPLIED		•			•										•	•	•
SELF-ADHERING																	
Surfacing																	
AGGREGATE-SURFACED																	
ALUMINUM-PIGMENTED												•	•	•			
EMULSION						•											
GRANULE-SURFACED		•	G		•											•	•
LATEX																	
METAL FOIL															•		
POLYMERIC																	
UNSURFACED	•			•			•	•	•	•							
BLISTER (INTERPLY)	•	•					•	•		•							
COATING BLISTER																	
COATING DELAM./PEELING												L					
COATING EROSION			•											•			
CRACKING AT B.F.	•	•										•					
CRACKING (LINEAR)						•				•							
CRACKING (RANDOM)		L		L	J	•										P	
CRACKING (SPIDER WEB)																	
DEBRIS ON ROOF		•															
DELAM. (WITHIN SHEET)								H	H	•							
DIAGONAL WALKING							•										
EXPANSION JOINT OPEN																	
EXPOSED REINF./TOOLING																	
EXPOSED SELVAGE																	•
EXUDATION				•		•								•			
FASTENERS TENTING																	
FIBERGLASS BLOOM								H	H								
FINGER BLISTERS						•											
FISHMOUTH																Q	•
FLASHING LOOSE AT B.F.						E	•										
FLASHING LOOSE AT M.E.F.			•														
FOOTPRINTS						•											
GRANULE LOSS		L	G		•												
INSUL. BOARD WARP				•													
INSUL. CRUSHING/EQUIP.																	
LAPS OPEN OR LOOSE		•														•	•
LAPS OPEN AT B.F.	•									•			•				
POCKMARKS																	
PONDING	•	•		•													
POST-APPLICATION PATCHES			K			•	•	•		•							
PUNCTURE/IMPACT DAMAGE	•		K					•									
RIDGING	•					•											
SHRINKAGE																	
SLIPPAGE					•												
SPLITTING																	
SPLITTING AT M.E.F.																	
WIND BLOW-OFF																	
WRINKLING																	

APPENDIX TABLE G

	JOB NUMBER	26	27A	27B	27C	27D	28	29	30	31	32	SEATTLE	33	34A	34B	35	36	37
	WRINKLING																	
	WIND BLOW-OFF																	
	SPLITTING AT M.E.F.																	
	SPLITTING																	
	SLIPPAGE			•														
	SHRINKAGE									•								
	RIDGING																	
	PUNCTURE/IMPACT DAMAGE														•	•		
	POST-APPLICATION PATCHES									•								
	PONDING				•	•				•								•
	POCKMARKS																	
	LAPS OPEN AT B.F.																	
	LAPS OPEN OR LOOSE	•	•															
	INSUL. CRUSHING/EQUIP.	•																
	INSUL. BOARD WARP																	
	GRANULE LOSS	RR			L		C			L								
	FOOTPRINTS	•																
	FLASHING LOOSE AT M.E.F.																	
	FLASHING LOOSE AT B.F.										F						•	
	FISHMOUTH	•	•															
	FINGER BLISTERS																	
	FIBERGLASS BLOOM																	
	FASTENERS TENTING																	
	EXUDATION								•									
	EXPOSED SELVAGE																	
	EXPOSED REINF./TOOLING																	
	EXPANSION JOINT OPEN																	
	DIAGONAL WALKING																	
	DELAM. (WITHIN SHEET)																	
	DEBRIS ON ROOF									•								
	CRACKING (SPIDER WEB)																	
	CRACKING (RANDOM)				AA	•	D			•								
	CRACKING (LINEAR)																	
	CRACKING AT B.F.							•		•								
	COATING EROSION																	
	COATING DELAM./PEELING							L	L									
	COATING BLISTER																	
	BLISTER (INTERPLY)				•					•			•					•
Surfacing	UNSURFACED																	
	POLYMERIC																	
	METAL FOIL		•	•							M				•			
	LATEX							•										
	GRANULE-SURFACED	•			•	•	•			•			•	•		•	•	•
	EMULSION																	
	ALUMINUM-PIGMENTED								•									
	AGGREGATE-SURFACED																	
Attachment	SELF-ADHERING																	
	HOT-APPLIED	•	•	•	•		•			•			•	•	•	•	•	•
	HEAT-WELDED							•	•		•							
	COLD ADHESIVE																	
	SBS	•	•	•	•	•	•			•	•		KK	•	•	KK	•	KK
	APP							•	•									
	MANUFACTURER	7	7	7	7	?	7	1	1	3	7		7	14	7	7	14	7
	AGE (YEARS)	1	1	8	8	?	3	3	6	4	4		5	3	3	4	2	2
	RATING	2	1	2	3	2	2	2	1	3	1		1	1	1	1	1	1

APPENDIX TABLE G

WRINKLING																	
WIND BLOW-OFF															•		
SPLITTING AT M.E.F.																	
SPLITTING					NN												
SLIPPAGE																	
SHRINKAGE										•							•
RIDGING																	
PUNCTURE/IMPACT DAMAGE		•				•			•								
POST-APPLICATION PATCHES					•		•								•		
PONDING																	
POCKMARKS																	
LAPS OPEN AT B.F.																	
LAPS OPEN OR LOOSE												•		•			
INSUL. CRUSHING/EQUIP.																	
INSUL. BOARD WARP																	
GRANULE LOSS																	
FOOTPRINTS																	
FLASHING LOOSE AT M.E.F.																	
FLASHING LOOSE AT B.F.		MM													E		
FISHMOUTH																	
FINGER BLISTERS					•	•									•		
FIBERGLASS BLOOM									•								
FASTENERS TENTING																	
EXUDATION																•	
EXPOSED SELVAGE																	
EXPOSED REINF./TOOLING																	
EXPANSION JOINT OPEN																	
DIAGONAL WALKING																	
DELAM. (WITHIN SHEET)											PP						
DEBRIS ON ROOF						•											
CRACKING (SPIDER WEB)			•														
CRACKING (RANDOM)		QQ	•		•					•						AA	
CRACKING (LINEAR)				•													
CRACKING AT B.F.							•								•		
COATING EROSION		•					•	OO	•	•					•		OO
COATING DELAM./PEELING		LL															
COATING BLISTER																	
BLISTER (INTERPLY)																	•
UNSURFACED	Surfacing		•	•	U											•	
POLYMERIC	Surfacing																
METAL FOIL	Surfacing										•	•	•	•			
LATEX	Surfacing																
GRANULE-SURFACED	Surfacing					•											
EMULSION	Surfacing						•	•	•	•							•
ALUMINUM-PIGMENTED	Surfacing	•													•		
AGGREGATE-SURFACED	Surfacing																
SELF-ADHERING	Attachment																
HOT-APPLIED	Attachment																•
HEAT-WELDED	Attachment	•	•	•	•	•	•	•	•	•					•		
COLD ADHESIVE	Attachment																
SBS						GG							•	•			•
APP		•	•	•	•		•	•	•	•	•	•			•	•	
MANUFACTURER		10	4	3	15	16	1	1	1	11	4	4	7	17	?	18	19
AGE (YEARS)		3	5	4	8	4	7	9	5	3	5	?	2	1	4	2	6
RATING		2	3	3	3	2	1	1	2	3	3	2	1	1	2	2	2
JOB NUMBER		38	39A	39B	40	41	42	43A	43B	44A	44B	44C	44D	45	46	47	48

APPENDIX TABLE G

						Attachment				Surfacing																																													
JOB NUMBER	RATING	AGE (YEARS)	MANUFACTURER	APP	SBS	COLD ADHESIVE	HEAT-WELDED	HOT-APPLIED	SELF-ADHERING	AGGREGATE-SURFACED	ALUMINUM-PIGMENTED	EMULSION	GRANULE-SURFACED	LATEX	METAL FOIL	POLYMERIC	UNSURFACED	BLISTER (INTERPLY)	COATING BLISTER	COATING DELAM./PEELING	COATING EROSION	CRACKING AT B.F.	CRACKING (LINEAR)	CRACKING (RANDOM)	CRACKING (SPIDER WEB)	DEBRIS ON ROOF	DELAM. (WITHIN SHEET)	DIAGONAL WALKING	EXPANSION JOINT OPEN	EXPOSED REINF./TOOLING	EXPOSED SELVAGE	EXUDATION	FASTENERS TENTING	FIBERGLASS BLOOM	FINGER BLISTERS	FISHMOUTH	FLASHING LOOSE AT B.F.	FLASHING LOOSE AT M.E.F.	FOOTPRINTS	GRANULE LOSS	INSUL. BOARD WARP	INSUL. CRUSHING/EQUIP.	LAPS OPEN OR LOOSE	LAPS OPEN AT B.F.	POCKMARKS	PONDING	POST-APPLICATION PATCHES	PUNCTURE/IMPACT DAMAGE	RIDGING	SHRINKAGE	SLIPPAGE	SPLITTING	SPLITTING AT M.E.F.	WIND BLOW-OFF	WRINKLING
NEW ORLEANS																																																							
49	3	8	1	•			•				•	•								N							•																			•	•								
50	1	5	5	•			•				•										•																											•							O
51	2	10	1	•			•					•							•	•						•	•																			•									
52	2	13	1	•			•										•							R										•																			•		
53	S	13	1	•			•										•							R			L											•								•									
54A	2	8	1	•			•										•																																				•	•	
54B	3	6	1	•			•										•																					•					•				•							•	
55	1	5	3	•			•				•									•	•											•												•											
56	3	10	7		•								T					•						•			U									•				•			•								B				
57A	2	10	7		•								T											•							•					•				•			•											•	
57B	2	<1	7		•	•							•																							•							•												
58	2	10	7		•								T					•						•																•								•							
59	1	2	7		•		•								•																																								
60	2	6	9	•			•				•							•		D	•			•		•											E						•												
61	2	5	9	•			•				•										•														•		F						•	•											
62	2	4	9	•							•										•			•																						•									

APPENDIX TABLE G

NEW YORK

		63	64A	64B	64C	65A	65B	66	67	68	69	70	71	72
	JOB NUMBER	63	64A	64B	64C	65A	65B	66	67	68	69	70	71	72
	RATING	2	1	1	3	2	2	2	3	3	2	2	3	3
	AGE (YEARS)	5	7	6	3	5	4	9	8	7	7	5	8	6
	MANUFACTURER	6	1	1	10	6	?	3	3	11	?	3	12	3
	APP		•	•	•		•	•	•			•	•	•
	SBS	•				•				BB	CC			
Attachment	COLD ADHESIVE													
Attachment	HEAT-WELDED		•	•	•			•	•			•	•	•
Attachment	HOT-APPLIED	•				•				•				
Attachment	SELF-ADHERING													
Surfacing	AGGREGATE-SURFACED													
Surfacing	ALUMINUM-PIGMENTED						•	•				•	•	•
Surfacing	EMULSION													
Surfacing	GRANULE-SURFACED	•				•				•	•			
Surfacing	LATEX													
Surfacing	METAL FOIL													
Surfacing	POLYMERIC													
Surfacing	UNSURFACED		•	•	•				•					
	BLISTER (INTERPLY)	X	•	•	•	•			•	•			•	
	COATING BLISTER													
	COATING DELAM./PEELING											EE	EE	
	COATING EROSION							•				EE		•
	CRACKING AT B.F.													
	CRACKING (LINEAR)													
	CRACKING (RANDOM)				•			•	AA			DD	AA	
	CRACKING (SPIDER WEB)						•							•
	DEBRIS ON ROOF					•	•							•
	DELAM. (WITHIN SHEET)								•		U			
	DIAGONAL WALKING												•	
	EXPANSION JOINT OPEN				•									
	EXPOSED REINF./TOOLING													
	EXPOSED SELVAGE													
	EXUDATION													•
	FASTENERS TENTING								•					FF
	FIBERGLASS BLOOM													
	FINGER BLISTERS				•			•	•					
	FISHMOUTH													
	FLASHING LOOSE AT B.F.	•			•						•		F	
	FLASHING LOOSE AT M.E.F.	V										•	•	
	FOOTPRINTS				Y			•						
	GRANULE LOSS					Z				•				
	INSUL. BOARD WARP													
	INSUL. CRUSHING/EQUIP.													
	LAPS OPEN OR LOOSE	W			•					•		•		
	LAPS OPEN AT B.F.										•			
	POCKMARKS													
	PONDING		•	•	•		•		•	•				•
	POST-APPLICATION PATCHES				•								•	•
	PUNCTURE/IMPACT DAMAGE													
	RIDGING	•												
	SHRINKAGE													
	SLIPPAGE													
	SPLITTING													
	SPLITTING AT M.E.F.													
	WIND BLOW-OFF								•					
	WRINKLING													

Legend:

A angel hair
B slippage of base flashing
C construction abuse by other trades
D possibly caused by contaminate spilled on roof
E diagonal wrinkling
F rupture or cracking at diagonal wrinkling
G granules set in emulsion
H fiberglass reinforcement separated and ruptured, crack propagating downward below reinforcement
J at area of granule loss
K because of hail
L at ponded area
M factory-applied paint on foil surfacing was peeling
N at ponded areas, aluminum-pigmented coating peeled from the emulsion coating. At other areas, the emulsion peeled from the membrane
O at end of roll
P caused by solvent-based paint
Q at T-joint of stripping header
R at sheet installed upside down
S rating of 2 at steep-sloped areas, rating of 3 at low-sloped areas
T poor granule coverage—possibly due to granule loss from the steep-sloped roof
U small diameter (i.e., up to ½ in., 13 mm) blisters occur above the reinforcement, within the bitumen matrix
V poor detail—reused existing metal edge flashing
W factory splice opened up
X some of the blisters are within the old BUR
Y distortion of sheet (numerous small bird baths)—apparently due to overheating
Z in confined work area—granule loss may have occurred because of foot traffic on hot sheet. Also, granule loss at ridge of a blister.
AA cracking more severe in ponded areas
BB cap sheet is very thin at edge of sheet
CC BUR with modified bitumen base flashings
DD cracking where membrane is not protected by coating
EE loss of coating more severe in ponded areas
FF apparently due to back-out—membrane is cracked over fastener head
GG several sheets hooked
HH drum rolling
JJ delamination of foil or polymeric film
KK metal foil surfaced base flashings
LL caused by grease from exhaust fan
MM top of base flashings open at HVAC units, and base flashing termination bar at parapets is buckling
NN splits occur over insulation board joints (cap sheet torched directly to felt-faced foam insulation)
OO and coating cracking
PP foil torn across sheet and peeled
QQ at area were grease caused loss of coating
RR loss of granules at pools of condensate water from HVAC units

Notes:

1. Roofs 7A and 7B are on one building. Roofs 7C through 7G are on a separate building.
2. Roofs 39A and 39B are on separate buildings.
3. "Blisters (interply)" also includes blisters between the membrane and substrate.
4. "Cracking (linear)" and "Cracking (random)" includes weather-checking (crazing).
5. "Fishmouths" are also recorded as "laps open or loose."
6. Some roofs that were hit by hail did not exhibit apparent damage. Accordingly, these roofs are not identified in the table as having "puncture/impact damage."
7. Only jobs with large ponds are identified as having ponding.
8. Wind problems were only actually observed on Roof 54A and 54B. The other wind problem jobs were reported to the inspection team.
9. Many jobs had poorly designed and/or constructed details. This is not generally reflected in the table.
10. The table does not indicate the number of times that a particular problem occurred (e.g., the roof could have one blister or it could have 20).
11. A given problem on a given job may or may not be significant.

Number of Jobs			Type of Problem
APP	SBS	Total	
14	11	25	Blister (interply)
10	2	12	Cracking at Base Flashing
8		8	Cracking (linear)
21	11	32	Cracking (random)
4		4	Cracking (spider web)
7	4	11	Debris on Roof
10	4	14	Delamination (within sheet)
3		3	Diagonal Walking
1		1	Expansion Joint Open
1		1	Exposed Reinforcing/Tooling
	2	2	Exposed Selvage
11		11	Exudation
2		2	Fasteners Tenting
6		6	Fiberglass Bloom
9	1	10	Finger Blisters
1	9	10	Fishmouth
12	4	16	Flashing Loose at Base Flashing
6	1	7	Flashing Loose at Metal Edge Flashing
3	1	4	Footprints
1		1	Insulation Board Warp
	1	1	Insulation Crushing (caused by mechanical equipment)
13	14	27	Laps Open or Loose
6	2	8	Laps Open at Base Flashing
1		1	Pockmarks
14	6	20	Ponding
16	1	17	Post-Application Patches
11	4	15	Puncture/Impact Damage
3	1	4	Ridging
1	4	5	Shrinkage
1	3	4	Slippage (including base flashing slippage)
1		1	Splitting
3		3	Splitting at Metal Edge Flashing
4	1	5	Wind Blow-Off
2	1	3	Wrinkling

Note:

1. The table does not indicate the number of times that a particular problem occurred (e.g., the roof could have one blister or it could have 20).
2. A given problem on a given job may or may not be significant.
3. The problem may not be related to the polymer modifier.
4. See Appendix Table I for surfacing-related problems.

Appendix Table H: *Type of observed problems as a function of polymer modifier.*

Number of Jobs			Type of Problem
APP	SBS	Total	
1[1]		1	Coating Blister
11[2]		11	Coating Delamination/Peeling
21[3]		21	Coating Erosion
3	11	14	Granule Loss
2[4]	1[5]	3	Metal Foil
	1[6]	1	Polymeric Film

Note: See notes at Appendix Table H.

[1] Emulsion coating.

[2] Two roofs had emulsion coating, one had latex, seven had aluminum-pigmented and one had aluminum-pigmented over emulsion. On three roofs, the delamination occurred at ponded areas and on two roofs, it was more severe in ponded areas. On one roof, the delamination was caused by grease from an exhaust fan and on one roof it was possibly caused by a contaminate spilled on the roof. At the roof with aluminum-pigment coating over emulsion, at ponded areas, the aluminum-pigmented coating peeled from the emulsion. At other areas, the emulsion peeled from the membrane.

[3] 15 roofs had aluminum-pigmented coatings, five had emulsion and one had granules set in emulsion. One of the aluminum-pigmented coated roofs had more severe erosion in ponded areas. Two of the emulsion coated roofs also had cracked coating.

[4] Foil delaminated from the sheet on one roof, and on the other, it was delaminated and torn. These roofs are also listed in Appendix Table H.

[5] Factory-applied paint on foil was peeling.

[6] Polymeric film delamination. This roof is also listed in Appendix Table H.

Appendix Table I: *Surfacing problems as a function of polymer modifier.*

Appendix J: Summary of Reference 28

Summary of prescriptive and performance criteria as proposed by Rossiter.[28]

Suggested prescriptive criteria are presented in Table J1:

Requirement	Test Method	Criterion
Thickness	ASTM D 5147, Sec. 5	not <5% of nominal, 40 mil (1 mm) minimum[1]
Load, maximum	ASTM D 5147, Sec. 6	not <15% of nominal
Elongation, load	ASTM D 5147, Sec. 6	not <20% of nominal
Elongation, break	ASTM D 5147, Sec. 6	not <20% of nominal
Low-Temperature Flexibility	ASTM D 5147, Sec. 11	not >5°F (3°C) of nominal, 25°F (-4°C) maximum
Tear Resistance	ASTM D 5147, Sec. 7	not <20% of nominal, 30 lbf (130N) minimum

[1] Nominal value is value stated in manufacturer's literature or in the NRCA *Commercial Low-Slope Roofing Materials Guide.*

Table J1: *Summary of suggested prescriptive criteria.*

Suggested performance criteria are presented in a four key element format: requirement, criteria, test method and commentary. The criteria are summarized in Table J2:

Requirement	Test Method	Criterion
Fire Resistance	ASTM, UL or FM test	conform to code
Flow Resistance	UEAtc 27, Sec. 5.1.7	no slippage
Hail Impact	NBS BSS 55 or ASTM D 3746	no water penetration after impact
Strain Energy	ASTM D 5147, Sec. 6	not <3 lbf-in/in^2 (0.5 kN•m/m^2)
Uplift	ASTM, UL or FM test	conform to code
Dimensional Stability	ASTM D 5147, Sec. 10	maximum change, ±1%
Moisture Absorption	ASTM D 5147, Sec. 9	1 gram, maximum
Moisture Content	ASTM D 5147, Sec. 8	0.5% by mass, maximum
Pliability	ASTM D 5147, Sec. 11	no crack @ application temperature
Heat Exposure	ASTM D 5147, Sec. 12	• load-elongation <15% • flexibility not >32°F (0°C) • strain-energy not <3 lbf-in/in^2 (0.5 kN•m/m^2)

Table J2: *Summary of suggested performance criteria.*

Appendix K: Summary of Reference 29

Summary of cautions proposed by Baxter[29] concerning modified bitumen product inconsistencies. For additional information, refer to the cited reference.

- Polymer modified bitumen sheet products are complex systems of several components such as asphalts, polymers, reinforcements, fillers and parting agents.
- Type, quantity and quality of system components of modified bitumen products affect application and performance properties.
- Compatibility between polymer modifiers and asphalt may influence both application and performance properties.
- Type and placement of reinforcements used affects application and performance characteristics.
- Manufacturing changes often affect product consistency (i.e., "feel" to applicators) of modified bitumen sheet products. Products that look and feel different from familiar products should be checked.
- Complaints from foremen and crew members should be taken seriously and investigated.
- Contractors are advised to be alert to obvious changes in products at time of delivery.
- Manufacturers making significant alterations in their products (asphalts, modifiers, type and location of reinforcements, etc.) are advised to announce changes and issue revised application recommendations.

Appendix L: Acknowledgments

Task Force

Zachary Ellis, Chairman (NRCA), Richard Baxter (NRCA), Thomas Bollnow (MRCA), William Cullen (NRCA staff), Randy Denchfield (NRCA), Dr. Rene Dupuis (MRCA), Robert LaCosse (MRCA) and Thomas Smith (NRCA Staff)

Inspection Team

Buffalo and Rochester area: Dr. Rene Dupuis and Thomas Smith

Chicago area: Donald Berg, Thomas Bollnow, James Carlson, Dr. Rene Dupuis, Robert LaCosse and Thomas Smith

Kansas City area: Dr. Rene Dupuis, Robert LaCosse and Thomas Smith

New Orleans area: Zachary Ellis, Dr. Rene Dupuis, Robert LaCosse and Thomas Smith

Phoenix area: Dr. Rene Dupuis, Robert LaCosse and Thomas Smith

Seattle area: James Carlson, Dr. Rene Dupuis and Robert LaCosse

Cooperating Roofing Contractors

Buffalo and Rochester area:
Miles Dommell: Jameson Roofing Co., Inc. Buffalo, NY
Thomas Hamilton: Upstate Roofing, Inc., Rochester, NY
Mike Marinucci: Mcgonigle & Hilger Roofing, Inc., Lockport, NY
Theodore Sanders: Jos. A. Sanders & Sons, Inc., Buffalo, NY
John Van Buren: Leo J. Roth Corp., Rochester, NY
Ray Whitman: Bock & Whitman Roofing, Inc., Buffalo, NY

Chicago area:
Tom Bollnow: Hans Rosenow Roofing Co., Elk Grove, IL
Mario Cairo: CSR Roofing Contractors, Chicago, IL
James Karczewski: F.J.A. Christensen Roofing Corp., Carol Stream, IL
Michael Promen and Michael Young: Clark Roofing Company, Broadview, IL

Kansas City area:
Bonita Bryant: Valentine Roofing, Inc., Kansas City, KS
John Daly: Kaw Roofing & Sheet Metal, Inc., Kansas City, KS
Thomas Manson: Western Roofing Company, Kansas City, MO
L.B. Morris: Sellers & Marquis Roofing Co., Kansas City, MO

New Orleans area:
Zachary Ellis: The Ellis Company, Inc., Kenner, LA
Ron Gautreaux and Jude Laperouse: Edward Laperouse Metal Works, Houma, LA
Lester Haydel Jr.: Hy-Tech Roofing Services, Inc., Destrehan, LA

Phoenix area:
Joseph Bueche: Pioneer Roofing Co., Phoenix, AZ
Mark Farrell and Ernie Halhis: Progressive Roofing Inc., Phoenix, AZ
Donald Summers: Specialty Roofing Inc., Peoriz, AZ
Cyril Tilsen and Stuart Weisman: Universal Roofers & Builders, Inc., Phoenix, AZ

Seattle area:
Richard Bratland: C. Walter Smith Roofing Contractors, Everett, WA
Donald Bosnick: Bosnick Roofing, Inc. Tacoma, WA
Walter Crow, Jr. and Ted Peterson: Crow Roofing & Sheet Metal, Inc.
Donald Guthrie: Wayne's Roofing, Inc., Sumner, WA
G. Winton Smith: Western Roofing, Bellingham, WA