Special Report 86-35

December 1986

US Army Corps of Engineers

Cold Regions Research & Engineering Laboratory

Roof blisters

Physical Fitness Building, Fort Lee, Virginia

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Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188 Exp. Date: Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Special Report 86-35	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Cold Regions Research and Engineering Laboratory 6b. OFFICE SYMBOL *(If applicable)* CRREL	7a. NAME OF MONITORING ORGANIZATION USA Engineer District, Norfolk
6c. ADDRESS *(City, State, and ZIP Code)* Hanover, New Hampshire 03755-1290	7b. ADDRESS *(City, State, and ZIP Code)* Norfolk, Virginia
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Office of the Chief of Engineers 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Order Number E87860003
8c. ADDRESS *(City, State, and ZIP Code)* Washington, D.C. 20314-1000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: 6.27.30A PROJECT NO.: 4A762730 AT42 TASK NO.: BS WORK UNIT ACCESSION NO.: 017

11. TITLE *(Include Security Classification)*

ROOF BLISTERS: Physical Fitness Building, Fort Lee, Virginia

12. PERSONAL AUTHOR(S)

Korhonen, Charles and Bayer, John

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
	FROM ____ TO ____	December 1986	19

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
FIELD	GROUP	SUB-GROUP	Blisters
			Roofs
			Thermograms

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The blisters on this 2-year old roof were first noticed one year after construction. Findings show that all blisters were built into the roof and that they will continue to develop in size and number. Currently, this roof is watertight, but leaks will occur as blisters begin to break. Rather than wait for problems, recommendations are provided for using a CRREL-designed pressure relief valve to prevent blisters from growing and ever becoming a problem.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL C. Korhonen	22b. TELEPHONE *(Include Area Code)* 603-646-4438	22c. OFFICE SYMBOL CRREL-EC

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
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SECURITY CLASSIFICATION OF THIS PAGE

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PREFACE

This report was prepared by Charles Korhonen, Research Civil Engineer of the Civil Engineering Research Branch, and John Bayer, Civil Engineering Technician of the Geotechnical Research Branch, both of the Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

This study was conducted for the U.S. Army Engineer District, Norfolk, order number E87860003, "Roof survey and testing of Physical Fitness Center, PN 146, Fort Lee, Virginia" and as part of DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions, Base Support, Cold Regions Facilities Maintenance Technology, Work Unit 017, Maintenance and Rehabilitation of Military Facilities in Cold Regions.

Bill Person, Area Engineer of Fort Lee, Virginia, and Charles McKenna and Alan Greatorex of CRREL technically reviewed this report.

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INTRODUCTION

On 18 and 19 December 1985 we examined the Physical Fitness Building roof at Fort Lee, Virginia, to determine the cause of its blisters and to recommend options for dealing with the blisters. The roof is divided into four levels, as shown in Figure 1. It consists of a gravel-covered built-up membrane and 3 in. of urethane/perlite composite board insulation on a metal deck. The perlite insulation (1/2-in. thick) is next to the deck, with the felt-faced urethane next to the membrane. No vapor retarder was used. The built-up membrane consists of four plies of asphalt-saturated organic felt mopped in solid with hot Type I asphalt. Roof construction was completed in November 1983 for Levels A, B, and D and in May 1984 for Level C. Blisters were first noticed in April 1984.

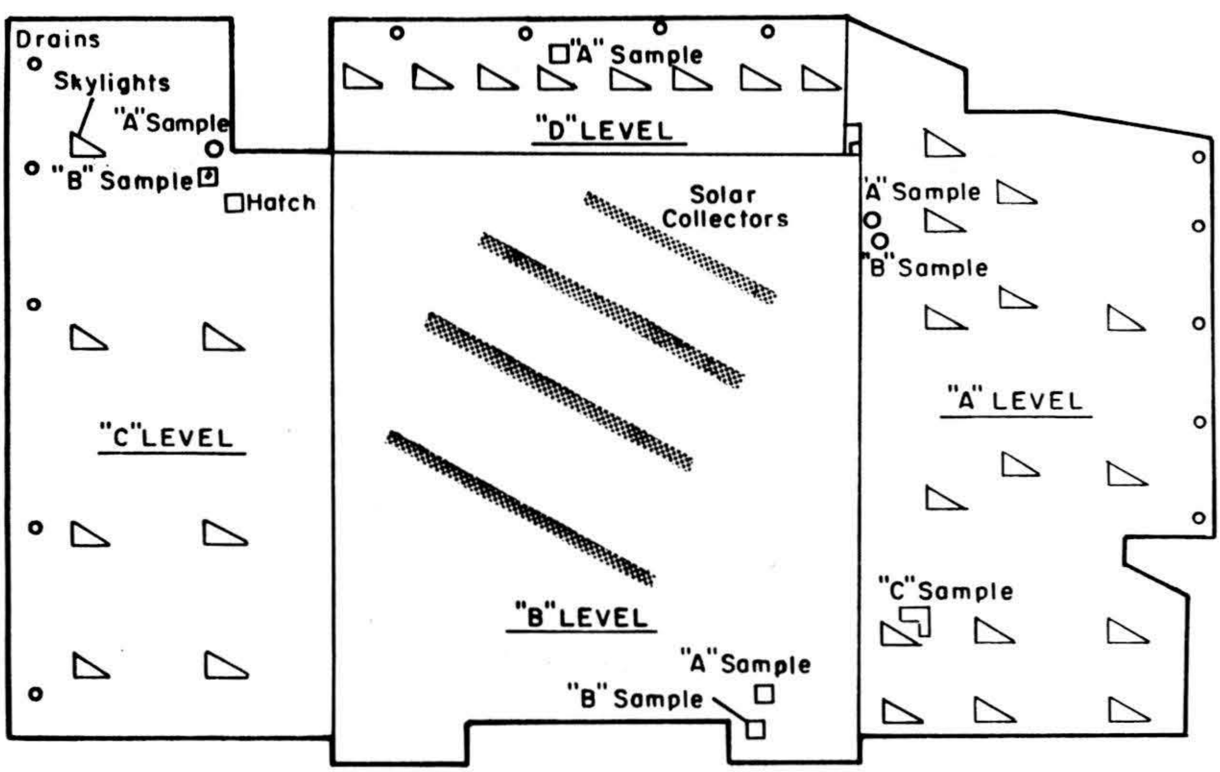


Figure 1. Plan view sketch of roof.

FINDINGS

To determine the cause of the blistering, we conducted visual examinations and infrared surveys, took 2-in.-diameter core samples of the membrane and insulation, cut open three blisters, and photographed the condition of the roof.

Visual Examination

The manager of the warehouse section indicated that roof Level C leaked after every rain. Water stains on the concrete floor were shown as evidence of these leaks. The stains, of which we saw three, coincided quite well with roof skylights (Fig. 2), indicating that either the skylights were improperly flashed to the roof or that some of the many joints on the skylights were faulty. No roof leaks were reported for the other three roof levels.

After interviewing the building occupants and examining the interior of the building, we examined all four roof levels in detail. On Level C, no obvious joint defects were noted on the three "leaky" skylights, which left flashing flaws as a probable cause of the reported leaks.

There are about 100 noticeable blisters on the four roof levels. In daylight, however, it was very difficult to locate even a few of the blist-

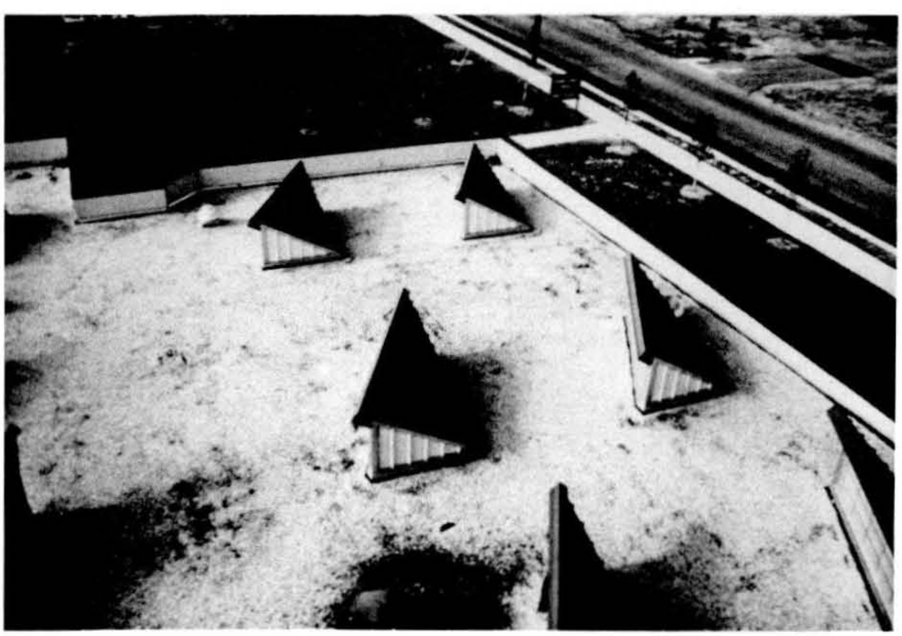


Figure 2. Skylights on roof level C.

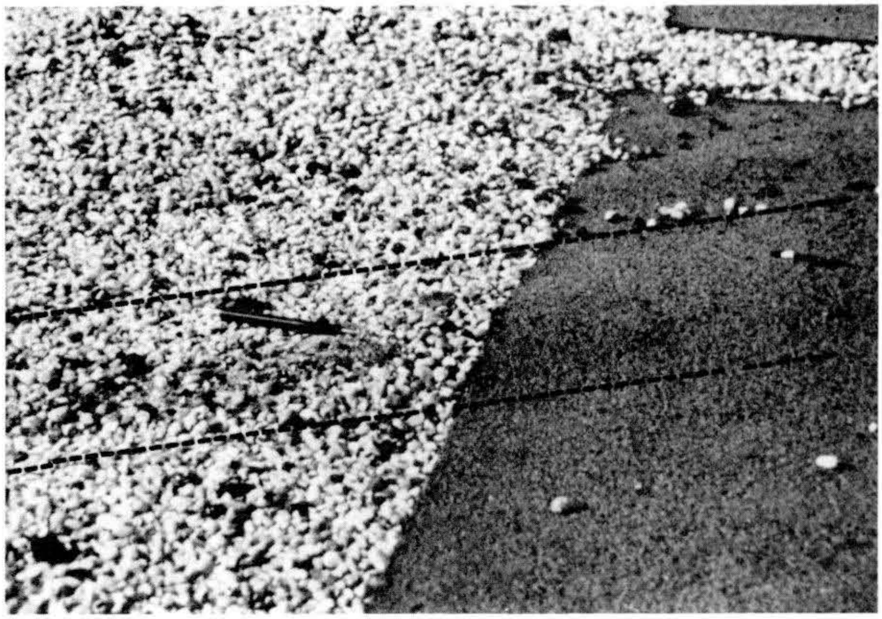


Figure 3. This blister (dotted line) extends past the edge of the walkway tread, indicating that it is a membrane blister.

ers. Only at night, with the aid of a flashlight held level near the roof surface, were we able to see them. We learned that the blisters are much more pronounced in the summer and grow most noticeably in the fall. This makes sense, as our recent studies show internal blister pressures increase with temperature and grow best when the days are hot and the nights are cool (Korhonen 1986).

Levels A and D contain the most blisters, while the largest blisters are on Level B under the walkway treads between the rows of solar collectors. In these situations, blistering often occurs between the built-up membrane and the tread, which presents no problem to the roof other than in appearance. However, several blisters extended past the edge of the tread (Fig. 3), indicating blistering of a more serious nature. The difference in size between these "walkway blisters" and the other blisters on the roof illustrates the value of a reflective roof surface in slowing down blister growth. The relatively dark walkway surface absorbs more solar heat and becomes hotter, causing blisters to grow faster than those covered by the lighter-colored gravel. These large blisters, in a foot traffic area, are quite vulnerable to damage.

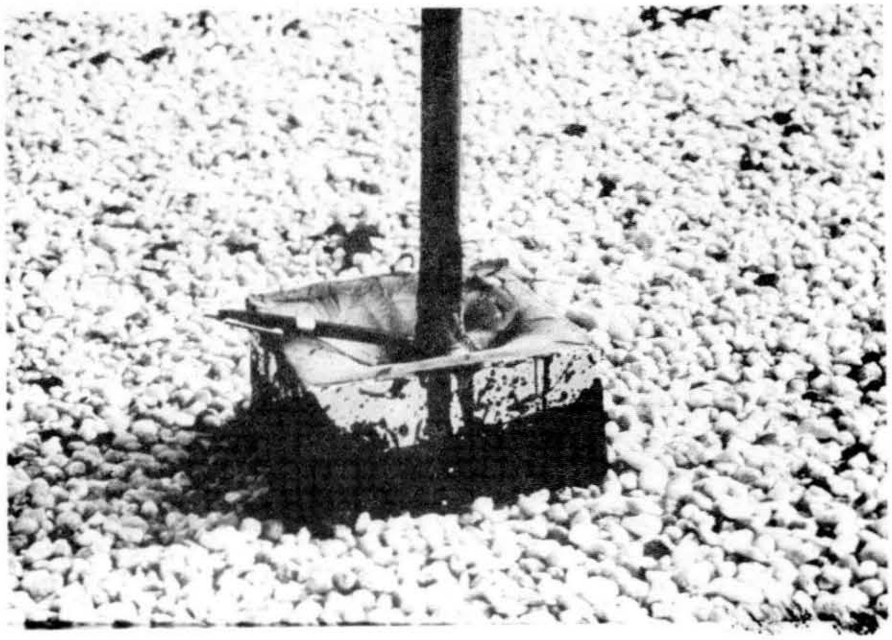


Figure 4. Pitch pocket in need of filling.

A few other roof items in need of immediate attention were also noticed during our examination. Nearly all the pitch pockets are in need of filling (Fig. 4). In their present condition water can be funnelled into the roof should cracks develop in the bitumen. On several of the roof drains the baskets were clogged with leaves (Fig. 5). These should be cleaned to prevent ponding of water. None of the access doors onto the

Figure 5. Debris-clogged drain.

Figure 6. Clothesline strung between two skylights.

roof levels was locked. This invites unauthorized foot traffic, as evidenced by a clothesline (Fig. 6) on Level A, and increases the likelihood of damaged blisters and roof leaks. We had to patch one blister that had been previously broken near the clothesline. The doors should be locked to prevent further damage.

Infrared Survey

To determine if any of the blisters were broken and had allowed water to leak into the roof we conducted an infrared roof moisture survey. An AGA Thermovision 750 infrared scanner was used on the night of 18 December to search for hot spots on the roof surface, which are indications of wet insulation. To the IR scanner much of the roof appeared thermally mottled (i.e. bright and dark spots). Some thermally bright areas could be attributed to varying gravel thickness and other non-moisture-related causes, but those areas suspected of being wet insulation were outlined with white spray paint and core-sampled the following day.

Particular attention was directed toward the roof areas near the "leaky" skylights on Level C. Comparing thermal images of areas near skylights that did not leak with those of the suspect skylights failed to reveal any signs of wet insulation. Therefore, it does not appear that the flashings are faulty. But if leaks persist, water testing of each skylight is recommended, as joint defects too small to see could still be the cause of the problems.

Core Sample Results

Core samples of the membrane and insulation were taken from Levels A, B, and C to verify the infrared moisture survey results. No insulation samples were taken on Level D because the insulation under one of the blisters cut open on that level appeared dry. That blister was in a thermally bright area containing a slightly thicker bitumen flood coat.

Samples A and B on Levels A, B, and C were taken in thermally bright and dark areas representing potentially wet and dry insulation, respectively. Sample C, Level A, was taken from beneath the blister cut open and examined on that roof level. As shown in Table 1, each insulation sample was essentially dry. The moisture contents are based on the dry weight of the composite urethane/perlite insulation removed from the roof. Thus, we are not sure how that moisture was distributed within each sample. If the moisture was uniformly distributed throughout the insulation, a moisture content of 38%, which corresponds to an 80% thermal value, would be considered to be wet and unacceptable (Korhonen 1982, Tobiasson and Ricard 1979). Even if all the moisture detected in these samples were concentrat-

Table 1. Core sample results.

Level	Sample	Insulation moisture content (% by wgt.)	Membrane thickness (in.)	Number of plies
A	A	4.5	0.700	11
	B	4.5	0.225	5
	C	12.3	0.200	4
B	A	3.8	0.307	5
	B	6.9	0.260	5
C	A	5.6	0.560	10
	B	3.7	0.305	6
D	A*	-	0.150	4

* Core sample taken only of the membrane on a blister.

ed in either of the insulations, the samples would still be dry. Thus, the moisture is considered to be normal and the roof membrane on all four levels is considered to be watertight.

The reason for samples A being thermally brighter than B on all three levels (A,B,C) can be seen from the dramatic difference between membrane thicknesses (Table 1). Samples A are considerably thicker than samples B. Thicker membranes store more solar heat and remain warmer longer than thinner membranes and thus appear thermally brighter at night.

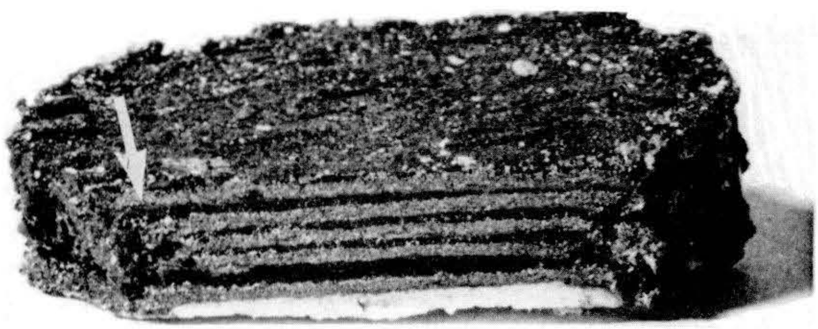
The variations in membrane thicknesses, besides explaining thermal differences, also indicate variations in membrane construction. Normally one would expect a 4-ply membrane to be about 3/8 to 1/2 inches thick. None of the 4-, 5-, or even 6-ply samples in Table 1 comes close to these expectations. However, it is not the number of moppings that determines a good roof but whether the moppings are uniformly applied to wet the felts sufficiently to achieve complete interply bond. It is of interest to note that Levels A and D have the thinnest membranes and contain the highest density of blisters. Perhaps not enough bitumen was used to achieve void-free application on these levels. It is not clear why the moppings were so thin, but one cause could have been overheated bitumen. As the kettle temperatures rise the moppings generally become thinner.

We are convinced that the many voids within the membrane samples were built in during construction. A close examination of each membrane sample cross-section in Figures 7 through 10 reveals not only the thinness of the interply moppings but also numerous voids within the moppings. Some of these voids were caused by entrapped particles (Fig. 11), but the majority were caused by a lack of interply adhesion. Breaking the samples apart revealed that the felt on either side of each of these voids contained some bitumen but not enough to bond one felt to another. Obviously, in these cases, the bitumen had been mopped on too thinly.* It is voids such as these that are the seeds of blisters.

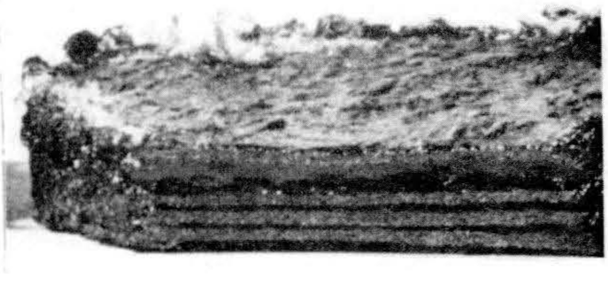
Samples A from Levels A and C were the thickest, containing 11 and 10 plies respectively. We understand that scaffolds were placed on Level A during construction and that the extra plies were for protection. We assume that some equipment was temporarily stored on Level C in the area of

*The 2-in.-diameter samples can only be used as an indication of mopping quantities. To represent mopping quantities more accurately, a 12x12-in. membrane sample is needed.

a. Sample A



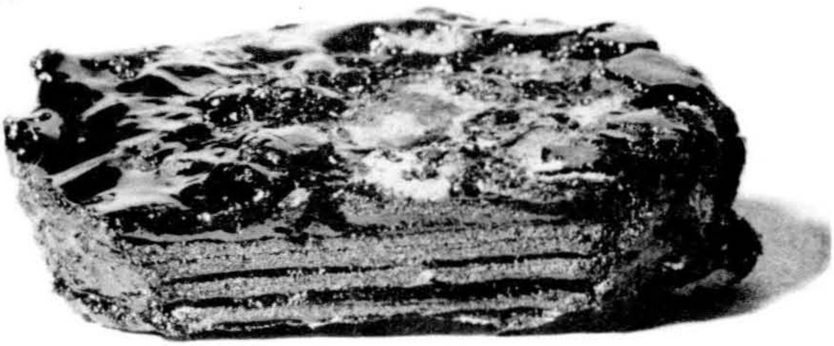
b. Sample B



c. Sample C (from blister)

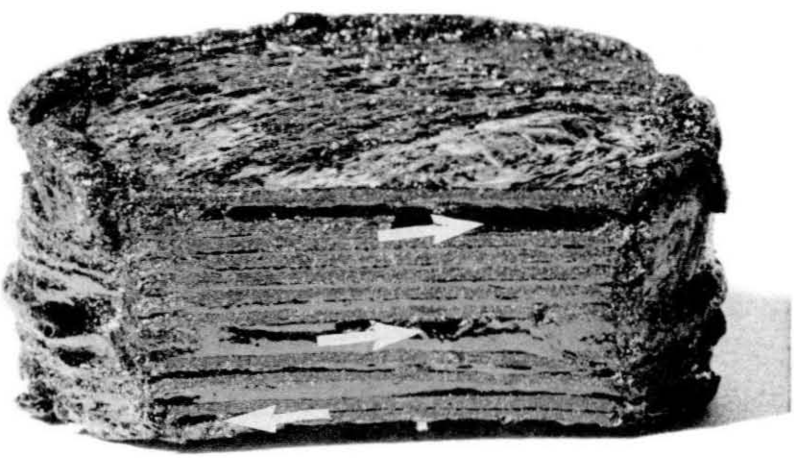
Figure 7. Closeup of Level A membrane samples. (Arrows show voids.)

a. Sample A

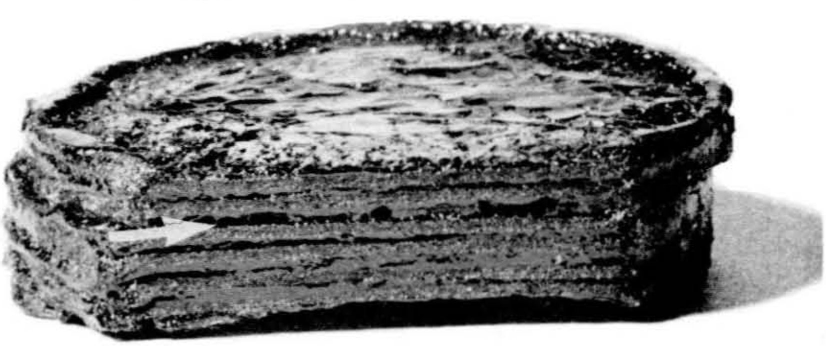


b. Sample B

Figure 8. Closeup of Level B membrane samples. (Arrow shows void.)



a. Sample A



b. Sample B

Figure 9. Closeup of Level C membrane samples. (Arrows show voids.)

Figure 10. Closeup of Level D membrane sample taken from a blister.

Figure 11. Particles of urethane insulation (arrows) entrapped within the plies of this membrane sample.

sample A and likewise required extra protection. The extra felts in themselves are no problem but Figures 7a and 9a show voids within their interply moppings that most likely will lead to future blisters. If other such voids exist within this roof they will also lead to a future crop of blisters.

Blister Cuts

Three blisters, two on Level D and one on Level A, were cut open and examined. Each blister occurred at the interface between the felt facer on the urethane insulation and the built-up membrane. With urethane, blisters

Figure 12. Arrows point to areas with insufficient bitumen coating. (A 2-in.-diameter sample was removed.

frequently occur at that location because hot bitumen usually bubbles and froths when mopped onto the facer during construction. Blisters then start from the numerous little air voids that are trapped beneath the felts as they are laid during construction. Generally this problem can be avoided by placing a thin layer of air-permeable insulation between the urethane and the built-up membrane. However, no bitumen bubbling was evident within the blisters we opened, which indicated that this was not a problem during construction. The evidence we saw suggested that each blister was caused by voids due to a thin, non-uniform bitumen mopping and not to entrapped air bubbles. For example, Figure 12 shows that the underside of one Level D blister was smooth but not completely bitumen-coated. The same was true for the other two blisters. This lack of bitumen moppings is considered to be the cause of these blisters, which corroborates the core sample findings previously discussed.

Surrounding each blister several smaller blisters were noted (Fig. 13). This indicates that the many voids seen within the core samples are widespread and are developing into blisters.

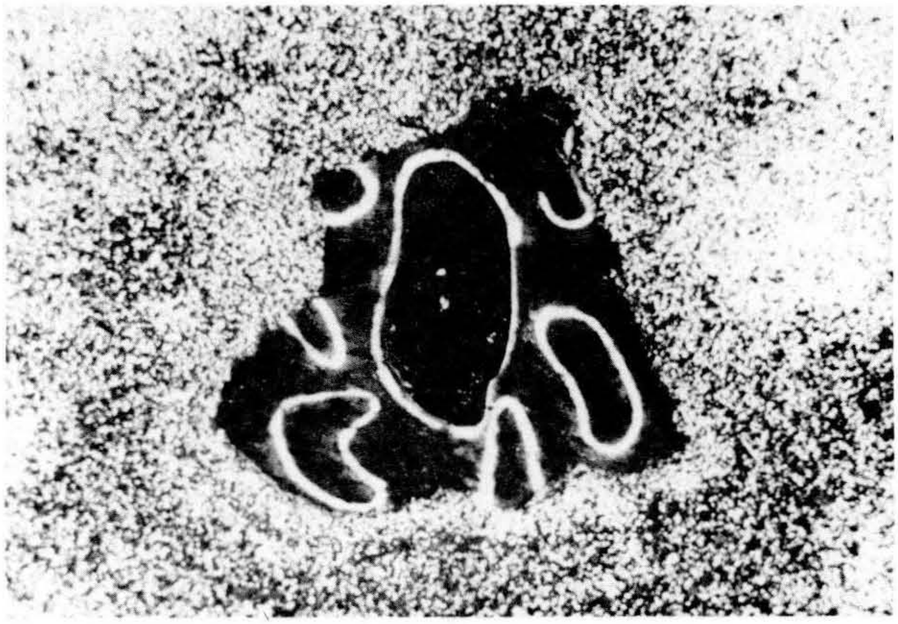


Figure 13. Numerous smaller blisters were seen once the gravel was removed.

Core Sample and Blister Patches

The outside air temperature ranged from 35 to about 45°F when the core samples and blister cuts were patched. This could affect the performance of the patches, so next summer an additional layer of reinforcing mesh and roof cement should be added to each patched area. Then each patch should be covered with gravel and marked with spray paint for future reference.

SUMMARY AND CONCLUSIONS

This two-year-old roof contains about 100 noticeable blisters, most of which are on Levels A and D, and many more small ones that are just beginning to develop. All blisters appear to have been built in during construction. They are caused by voids due to inadequate amounts of moppings and by entrapped debris.

Despite the blisters, this roof is watertight and not in immediate danger of failure. Because of the blisters, however, this roof is not likely to remain watertight for many more years. The blisters will continue to grow in number and get larger until they break. Water then will have direct access to the insulation because many of the blisters occur at the interface between the insulation and the built-up membrane.

Since it takes time for a blister to grow large enough to become vulnerable to damage, the many small blisters are not expected to become a problem for at least five years or more. However, the larger noticeable blisters are susceptible to damage now. Therefore, something should be done to deal with them now.

RECOMMENDATIONS

To achieve the maximum useful life from any roof it is important to maintain it properly. On this roof several items are in need of immediate attention:

- The baskets on some of the roof drains are partially clogged with debris and need to be cleaned to prevent water from ponding on the roof. One small defect, such as a cracked blister, in a ponded area can let vast quantities of water into a roof.
- Nearly all the pitch pockets on this roof have depressions in them and thus are potential sources of leaks. They should be filled with roof cement to prevent water from collecting in them.
- Unauthorized foot traffic must be stopped. We discovered one broken blister near a clothesline on Level A. All access ways onto each roof level should be locked to prevent any further damage.
- Level C reportedly has roof leaks that appear to be associated with the skylights there and not with the roof membrane or its flashings. If leaks persist on this roof level then the seams on all skylights should be inspected and tested for leakage.

Although this roof membrane currently is watertight, blisters are a major problem threatening to shorten its life. There are a few options that can be followed in dealing with these blisters. Current guidance within the Corps and the roofing industry suggests that nothing be done to a blister if it is intact and its surface is not eroded. Cutting open and patching a blister that is in good condition may actually do more harm than good by damaging other roof areas in the process of patching the blister. In addition, it is not economically feasible or practical to attempt to patch more than a few blisters.

However, because blisters continue to grow and become bigger the gravel surfacing will eventually begin to roll off and expose the flood

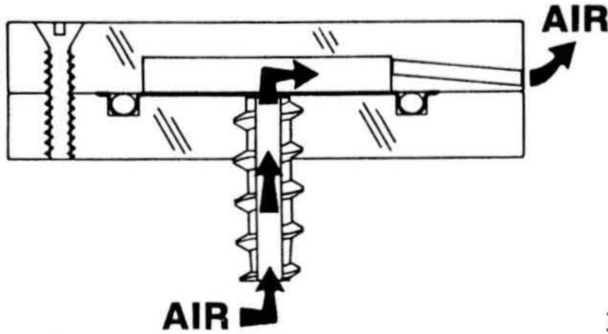


Figure 14. Schematic of blister valve.

coat to accelerated aging by the sun. The guidance on this suggests that the blister's eroded surface be coated with roof cement and gravel.

Sooner or later blisters will break, either because of natural causes or because someone steps on them or drops something on them. Then the gravel should be completely spudded away for some distance around the broken blister before cutting it open or completely removed from the roof. The blister should then be patched with alternating layers of roof cement and reinforcing fabric to complete the repair. Great care must be taken not to entrap air pockets within the patch, which would create new blisters. Patching a blister is tricky as well as time-consuming (we estimate 1 hour per blister).

Following this guidance is basically adopting a wait-and-see maintenance program; one that reacts to a problem after it has happened.

Rather than wait until a problem occurs, blisters could be prevented from growing and ever becoming a problem by preventing blisters from pressurizing. Last summer a CRREL-designed pressure relief valve was tested and shown to work quite well at stopping blister growth. As shown in Figure 14, the valve consists of a hollow shaft covered by an air permeable/water impermeable membrane protected by an environmentally tough housing. Its small size, 1-1/2 in. diameter x 1/2 in. high, makes it very resistant to damage from foot traffic and, once inserted, the blister deflates and collapses, so it is much less apt to be damaged. Our studies show that it takes about 2 minutes to install a valve into a blister.

We recommend that consideration be given to installing blister valves into the large blisters (approx. 100) on this roof. We estimate that it should take two people 1-1/2 to 2 days to complete this task. In the following years, as other blisters begin to develop, these original blister valves can be removed (the 1/4-in.-diameter hole must be patched) and reinserted into new blisters. We expect the patched blisters to eventually redevelop but by following this approach no blister should become big enough to where it breaks and causes premature leaks.

We are convinced that by stopping blister growth now many more years of useful life can be expected from this roof.

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