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INSTALLATION OF LOOSE-LAID INVERTED ROOF SYSTEM AT FORT WAINWRIGHT, ALASKA

David Schaefer

June 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
In the summer 1971 the Corps of Engineers replaced the roof on Building 1053 at Ft. Wainwright, Alaska, with a loose-laid inverted roof system. This roof system was selected to permit an evaluation of its performance and potential suitability for general use in Corps construction. The installation of the roof also permitted an analysis of its construction costs and a record of the construction procedures. Costs were identified in terms of costs of the materials used and the number of man-hours required. For the analysis, the job was broken down into four phases: 1) removal of the existing roofing material and

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preparation of the deck; 2) application of a surface of plywood decking; 3) placement of the butyl membrane and installation of flashings; and 4) placement of the insulation and ballast pavers. The results show that the installation time requirements compare favorably with those of conventional built-up roofs but the butyl membrane and the pavers cause higher material costs. Advantages are in the maintainability of the roof system and in its increased life expectancy.

PREFACE

This report was prepared by David Schaefer, Research Civil Engineer, Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory.

The work covered by this report was funded under DA Project 4A062112A894, Engineering in Cold Environments; Task 21, Cold Regions Building Systems for Military Installations; Work Unit 001, Roofs of Military Structures in Cold Regions.

The author thanks the U.S. Army Engineer District, Alaska, for their cooperation in gathering information for this report, and in particular Gary Sturman, the research coordinator, for his efforts to supply needed data. He also expresses appreciation to the Alaskan Projects Office of CRREL, which participated in this project, and in particular to Larry Vice, who was kind enough to furnish many of the construction photographs and man-hour requirements.

Dr. Haldor Aamot of CRREL was kind enough to help in the organization and review of this report.

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Background

Roofing failures have been one of the unfortunate "facts of life" for designers and builders of military structures in Alaska. The U.S. Army Engineer District, Alaska, has the design and construction mission for most military structures in Alaska and has been searching for economical methods to reduce roofing failures on military structures. The recently developed concept of a loose-laid inverted roof system seems intuitively to offer a relatively failure-proof roof.

It was decided to build such a roof structure on building 1053 at Ft. Wainwright, Alaska (Fig. 1). A contract was prepared for bidding in FY 1972. The U.S. Army Cold Regions Research and Engineering Laboratory was asked to cooperate in the instrumentation and evaluation of the roof. This report covers the construction techniques and labor requirements necessary to replace the existing roof with a loose-laid inverted roof system.

Introduction

For many years the conventional multi-ply bituminous built-up roofing has been used to cover structures having dead-level or extremely low slope (about 1%) roof decks. The incidence of failure due to various reasons has been high. The conditions conducive to roof failure are similar in temperate and cold regions, but failures are more frequent and costly in areas of extreme environmental conditions such as Alaska and northern Canada. Cullen[5] reports that at one Alaskan installation 71.5% of the bituminous built-up roofs required repair during the period 1957 to 1964. Brotherson[4] reports that during the last 20 years almost no change has occurred in the operation of applying built-up roofs and that several modifications of the materials used in the system have not solved any of the inherent problems.

Several factors contribute to the high probability of early failure of built-up roofing systems in cold regions. These include:

1. Movement-type failure that causes splitting or shrinkage of the membrane. This is commonly caused by contraction of the membrane due to thermal shocks. Thermal contraction is most noticeable at flashings. Cullen[5] claims that flashings are the most vulnerable part of a roof since the majority of leaks result from flashing failure.

2. Failure due to lack of, or improperly installed, vapor control measures.

3. Degradation of the bituminous materials caused by solar radiation and weathering.

4. "Built-in" failure mechanisms such as excessive moisture in substrate materials.

5. Poor workmanship and weather limitations.

6. Lack of proper roof drainage and failure (freeze-up) of roof drains to function properly.

All of the above mechanisms contribute to the invasion of moisture into the system and eventual leaks. Moisture entering into one or more of the roofing system components presents the most serious and costly problems.

Present Studies

Currently CRREL is studying several promising alternatives to the conventional built-up roofing system for use in cold regions. Typical efforts to solve the problems in built-up roofing systems traditionally concentrated on building a better built-up roof; the current approach taken by CRREL is to evaluate alternative systems. The loose-laid inverted roof system is one such system. This report is concerned with the construction, unit costs and manpower requirements necessary to install a loose-laid inverted roof system.

The Loose-Laid Inverted Roof System

The principal features of this roof system are:

1. A waterproofing membrane is placed on the structural deck. Several types of membrane may be utilized and newer materials such as plastic and elastomeric membranes show great promise.

2. A closed-cell rigid insulation is laid over the membrane to the required thickness. The insulation is not attached to the membrane, thus allowing unrestricted movement of both membrane and insulation. Presently, polystyrene insulations are used, but in general any type of insulation that is not affected by moisture may be utilized.

3. A system to prevent wind uplift and solar degradation of the insulating material is placed over the insulation. In the current study, concrete pavers (patio blocks) are specified but other materials such as graded gravel have been considered. Advantages of this type of system include:

a. The individual components are loose laid and are free to move relative to one another, thus reducing "splitting" failures.

b. The membrane is protected from solar degradation, which should increase its life. In addition, recently developed materials that are less susceptible to ultraviolet degradation can be used. Also, placing the membrane on the warm side of the roof makes it more thermally stable and unlikely to fail due to severe thermal shock.

c. The vapor barrier (i.e., membrane) is placed on the warm side of the roof, thus eliminating the necessity for a separate vapor barrier that must be used with conventional built-up roofs in cold regions. The use of a vapor barrier and built-up roofing causes a vapor trap or pocket, often accelerating the blistering and cracking of the built-up roofing membrane.

d. The insulation is closed cell and thus unaffected by free moisture present.

e. Brotherson[4] reports that a majority of the failures in built-up roofs occurred in roofs that were applied during the fall and winter months. Theoretically, the loose-laid inverted roof system could be installed at any time of the year, thus effectively increasing the construction season for roofing operations.

Location and Climate

Building 1053 is a motor vehicle repair and warm storage facility located at Ft. Wainwright, Alaska. Ft. Wainwright is located in interior Alaska, 2 miles from Fairbanks.

This area has a continental climate characterized by extremely cold winters and warm dry summers.[2] The highest temperature recorded at Fairbanks was 99°F (37°C) in July 1919 and the record low is -66°F (-54°C). Summer temperatures are strongly controlled by solar heating due in part to the long days, and tend to stay near normal with a spread of approximately 50°F (10°C), between record high and low for any day.[8] Winter temperatures follow a succession of relatively warm and cold spells with the spread between high and low temperatures for each day around 100°F (56°C).[7] During the winter months, it is not uncommon to have 15°F (-9°C) per hour temperature changes. The mean annual temperature is around 25°F (-4°C) with an average freezing index of 5800 degree-days Fahrenheit (3222 degree-days Celsius).[6]

Building 1053

This building was built in the early 1950's, during the expansion of Ft. Wainwright. It is a concrete structure 68 ft 4 in. by 160 ft, (20.8 x 48.8 m), having 12,000 ft^2 (1116 m^2) of floor space. The structural roof member consists of open-web steel Pratt trusses with 8 WF-17 roof purlins set 6 ft 5-3/4 in. (1.98 m) on center. The structural decking is corrugated steel.

The existing roofing system was a conventional built-up roof with a graded gravel surface. The insulation was composition board. The original roof was installed during the original construction of the building. There is no record of minor repairs performed prior to the replacement of this roof with the loose-laid inverted system.

The existing roof had a 1/8 in. per 12 in. (1%) slope to drain. The normal penetrations were present and consisted of ridge ventilation systems, roof drains and various other vents. Each drain controlled surface water in a 40 ft x 32 ft (12.2 x 9.8 m) area. Appendix A shows the roof plan and details for the inverted roofing system.

Upon removal of the existing roof, it was found that the steel deck had rusted in numerous places. This was especially evident in areas of high humidity where portions of the deck had rusted through. The insulating board was completely water soaked even though the built-up roofing (BUR) membrane appeared to be in fair shape.

Time Requirements

The contractor moved the necessary equipment and a majority of the materials to the job site on 1 July 1971. Actual work on the roof was not begun until 6 July 1971. Work was completed on 15 August 1971 after several delays. A period of inclement weather and an inability to get materials due to a dock worker's strike were the reasons for delays. After 20 July, the contractor had to wait for the arrival of materials and thus operated with a greatly reduced labor force. Table I shows the work accomplished on various dates.

Specific Contract Work

Basically the contract work called for the removal and replacement of the existing roof with a loose-laid inverted system. In order to replace the roof, a 1/2 in. (12 mm) exterior plywood sheathing was required over the steel decking since the membrane must be placed on a smooth surface. The roof drains had to be lowered to provide positive drainage at the membrane level. The principal components specified were:

Membrane:	1/16 in. (1.6 mm) thick butyl rubber (Fig. 7-15)
Insulation:	4 in. (100 mm) extruded polystyrene, type II Class B (Fig. 2 and 16)
Pavers:	15 lb (6.5 kg) maximum each paver, 8 in. x 16 in. (200 x 400 mm) (Fig. 17)
Flashings:	1/16 in.(1.6 mm) thick EPDM*(Fig. 21)

*Ethylene-propylene-diene-monomer

Table I. Progress chart of building 1053 roof replacement

Date 1971	Work Accomplished
1 July	Necessary equipment and materials moved and stockpiled at job site. (Fig. 2)
6-7 July	Contractor formally began work by removal of the existing built-up roof and preparation of the metal deck for plywood sheathing. (Fig. 3-5)
8-9 July	Plywood sheathing was lifted to the roof and placement begun. The foamed-in-place urethane was placed as shown on the plans (see App A). The roof drains were lowered to the membrane level by using dresser couplings. (Fig 6 and 18)
10 July	The plywood decking was completed in the morning and, between 1200 and 1500 hours, the butyl rubber membrane was rolled in place as indicated in Appendix B. The necessary roof penetrations were cut into the membrane but lap splices and penetration flashings were not made. (Fig. 7-15)
15 July	Field lap splices were made on the membrane, and penetration flashings and eave flashings were begun. The delay in splicing was due to a period of rain. The plywood deck was inspected prior to splicing and was found to be dry. (Fig. 15)
16 July	The placement of insulation and pavers was begun; initially just enough pavers were used to keep the insulation in place as there was a shortage of pavers. The EPDM and metal flashings were completed. (Fig. 16)
20 July	The last of the insulation was placed. At this time the project was essentially complete except for the complete placement of pavers. Sufficient pavers were placed on the insulation to keep them in place temporarily until the required amount could arrive. Between 20 July and 15 August the pavers arrived.
15 Aug	The last of the pavers were placed and the project was formally completed (Fig. 17)

A membrane manufacturer's representative was required to be on the job site during the laying and lap splicing of the membrane. The manufacturer also supplied shop drawings for the laydown and splicing of the membrane, which were to conform to the manufacturer's recommendations. Details from the shop drawings of the manufacturer are shown in Appendix B.

Costs and Man-Hours

Bids for roof repairs for the summer of 1971 were opened on 22 April. The loose-laid inverted roof on building 1053 was only one of nine scheduled roof repair projects at Ft. Wainwright. All projects were advertised for bid under a single contract number. Building 1053 was the third largest in size, having 109 squares (1 square = 100 ft^2 = 9.3 m^2). Table II gives a breakdown of the bids that were received for

Table II. Comparison of Bids for Roof Repair -- Bldg 1053

Bid	Cost	Cost/sq	Cost/m^2	% Govt. Estimate
Govt. Estimate	$41,600	$382	$35.50	-
1	30,444	279	25.90	73.0
2	36,000	341	31.70	86.5
3	56,000	514	47.80	134.5
4	62,000	578	53.75	139.0

schedule I (building 1053). The low bidder was awarded the contract to repair the existing roof. The government estimate of $41,600 included:

(1) $15,058 labor costs or $138/sq ($12.80/m^2)

(2) $13,126 materials costs or $120/sq ($11.20/m^2)

(3) $13,430 profit, overhead, bonding, etc.

The low bidder's estimate was 73% of the government estimate. If it is then assumed that the labor cost of the low bidder was 73% of the government estimate, the low bid labor cost was approximately $11,000 or $101 per square ($9.40/m^2).

This project can logically be broken down into separate tasks or operations:

1. Removal of existing roofing and cleaning or preparing metal deck to receive replacement roof (Fig. 3-5).

2. The application of the plywood decking to the prepared structural steel deck (Fig. 6).

3. The placement of the butyl membrane, EPDM flashing, urethane edge insulation, and lowering the roof drains to the required elevation (Fig 7-15).

4. The placement of the polystyrene insulation and concrete pavers (Figs. 16 and 17). Table III shows the labor requirements for each of these operations or tasks.

Table III. Labor and time requirements.

Operation	Hours-Men			
	Labor	Supervision	Q.C.[+]	Labor (hr/sq)
1	126-6	21-1	11-1	1.16
2	120-6	20-1	20-1	1.10
3	138-6	23-1	23-1	1.27
4	267-6[*]	72-1	57-1	2.45
Totals	651	136	111	5.98

[*] This is a projected labor requirement. Since there was a material shortage in operation 4, the contractor used a smaller crew.

[+] Refers to the quality control inspector, required on this contract. The function of this inspector is to ensure that the contractor gets the necessary tests, certifications etc. required by the contract. The Q.C. inspector is a contractor paid employee. He does not contribute to the actual production of the finished product.

Figures 18-20 show details of the roof drains as they were installed. A comparison with the details in Appendix A is easily possible. Figures 21-23 show details of the installation of flashings. They can be compared with details shown in Appendix B.

This project was for the removal and replacement of a roofing system. If it had been on new construction, operation 1 above would have been eliminated. There is also the possibility that operation 2 is unnecessary depending upon the type and condition of the structural deck. Table IV shows the labor requirements if certain tasks are not necessary as would be the case in new installation. The material's cost is considered to remain constant.

Table IV. Unit time requirements for loose-laid roof system.

Worker Class	hr/sq		
	Total job	Tasks 2-3-4(only)	Tasks 3-4(only)
Labor	5.98	4.82	3.72
Supervision	1.25	1.06	0.87
Totals	7.23	5.88	4.59

It was previously shown that \$138/sq (\$12.85/m^2) is the labor costs estimated by the government. This again is for removal and replacement of the existing roof. New construction would require less labor by a factor of 5.88/7.23 or 80%; thus for new construction, labor costs might be in the order of \$110/sq (\$10.20/m^2) and labor and materials costs in the order of \$230/sq (\$21.40/m^2).

The labor required to construct a 4-ply, gravel-surfaced bituminous built-up roof with 4 in. (100 mm) of insulation, can be estimated by using recognized estimators' guides. References 5 and 9 were used for this purpose and the results were:

1. To apply the insulated built-up roof requires 3.4 and 3.9 man-hours per square.

2. To remove an existing roof and replace with the above-mentioned roof, requires 4.5 to 5.4 man-hours per square.

On large jobs, supervision must be added to these figures; this would account for a 20% rise in the man-hour requirements. For the reroofing project on building 1053, operation 2 required 1.10 man-hours per square; thus to simply remove an existing roof and replace it with the loose-laid inverted system would require approximately 4.8 man-hours per square. This compares favorably with man-hour requirements for conventional built-up roofing.

Summary

Time requirements for placing a loose-laid inverted system compare favorably with requirements for conventional built-up roofs.

Costs are higher for this system primarily because of the expense of the butyl rubber, which costs about 2.5 times as much as a 4-ply bituminous built-up roof membrane.[5] If the loose-laid inverted system does perform as expected and substantially increases the useful life while decreasing the frequency of repair, this roof may be cost-effective on a life-cycle basis.

Construction techniques of the loose-laid inverted system are not complicated and application is not as dependent on favorable weather as conventional built-up roofing. The field lap splicing is the only portion of the procedures that should be done under dry conditions.

Literature Cited

Aamot, W.C. (1971) Review and analysis of warm roofs in cold climates. U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL) Technical Note 374, July. (unpublished)

Bailey, A.P., Design climate information for Anchorage and Fairbanks, Alaska, and Hanover, New Hampshire. USACRREL Technical Note 384. (unpublished)

Brotherson, D.E. (1965) Studies on movements of built-up roofing membranes. University of Illinois Small Homes Council -- Building Research Council, Research Report 65-2. December.

Brotherson, D.E. An investigation into the causes of built-up roofing failures. University of Illinois, Small Homes Council -- Building Research Council, Research Report 61-2.

Cullen, W.C. (1965) Performance of roofing in cold climates. National Bureau of Standards Report 8905, June.

Dept. of the Army (1966) Roofing Design. Technical Manual 5-804, March.

Johnson, P.R. Fairbanks temperature patterns and frequency of days in various temperature ranges. IAEE, University of Alaska.

Johnson, P.R. and C.H. Hartman, Environmental atlas of Alaska. IAEE and IWR, University of Alaska.

Moselle, G. (Ed.) National construction estimator, Eighteenth Edition. Craftsman Book Company. Los Angeles, California.

Robert Snow Means Company, Inc. (1970) Building construction cost data 1970.

Schaefer, D. (1970) A proposal for evaluation of arctic designs incorporated into new classroom building, University of Alaska. IAEE University of Alaska, July. (unpublished)

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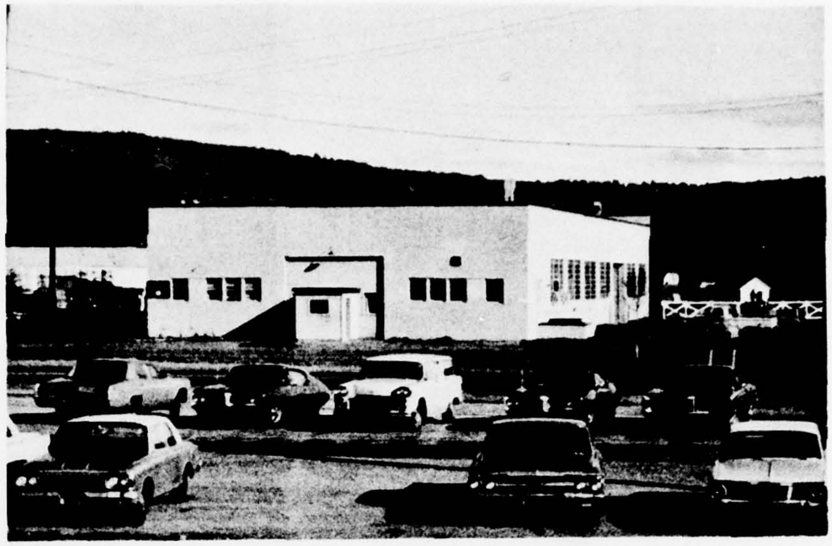
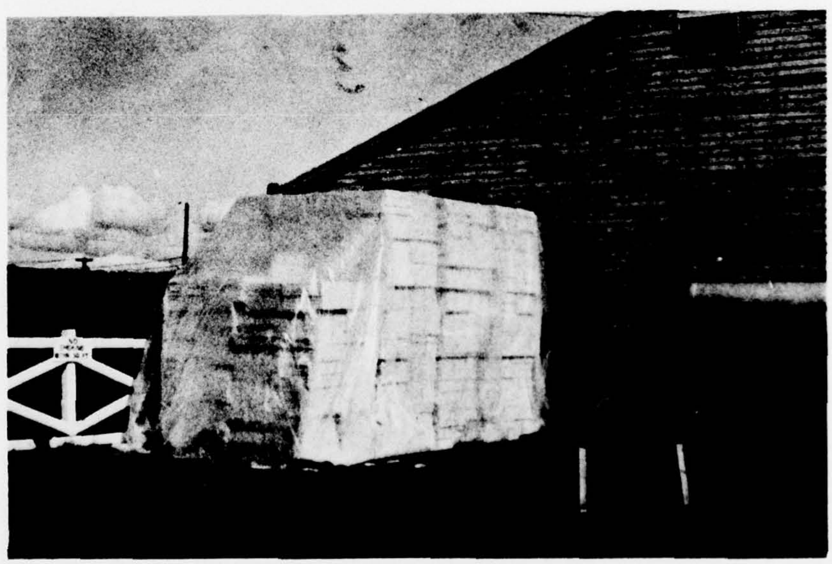


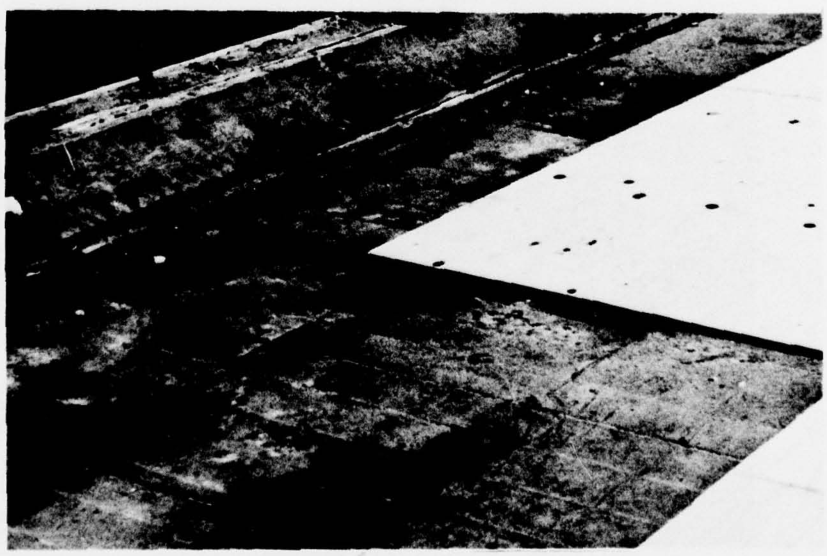
1. Building 1053, Ft. Wainwright, Alaska. Motor vehicle repair and warm storage.



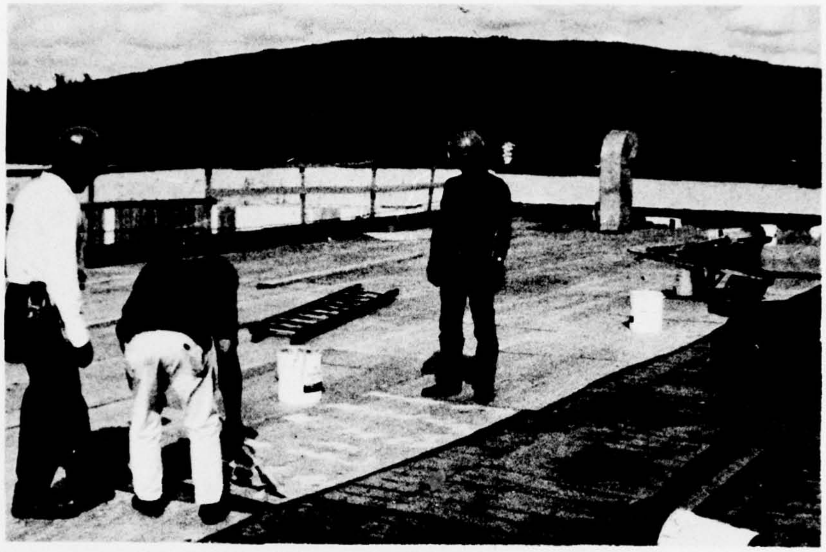
2. Stockpiled materials for loose-laid inverted roofing system.

3. Contractor began removal of existing BUR on 6 July 1971.

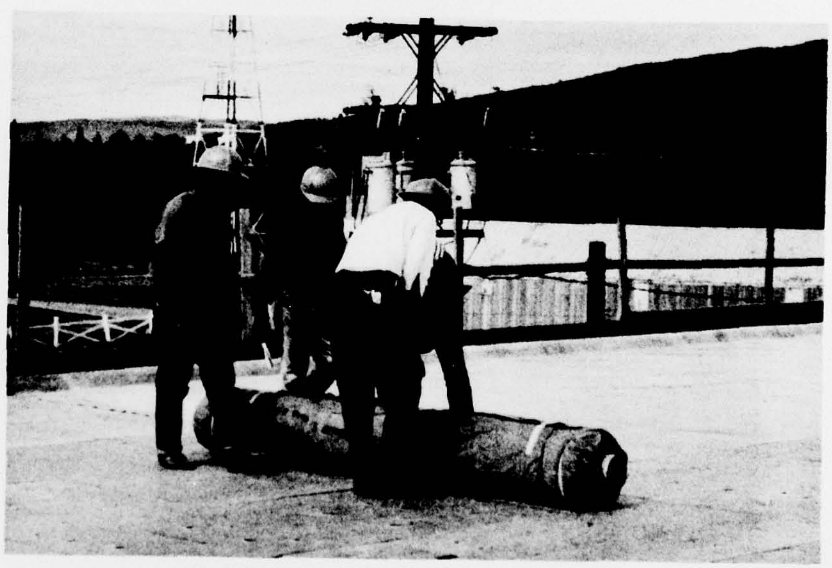
4. Metal deck, insulation and metal deck at ridge vent.



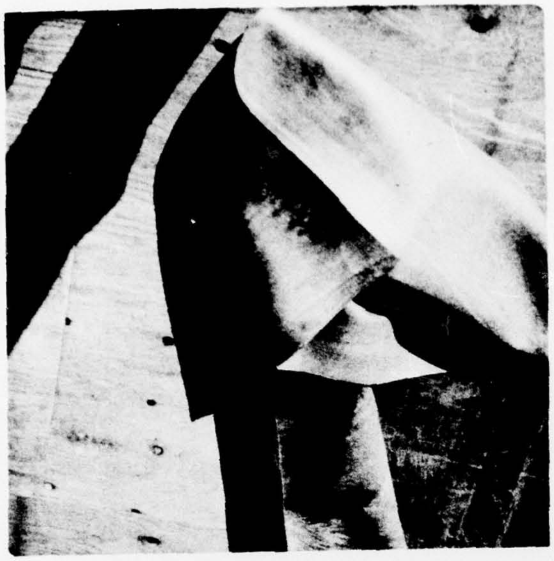
5. Condition of metal deck after stripping existing BUR. Note that the corrosion has penetrated the steel deck.



6. Application of 1/2 in. plywood sheathing to prepared metal deck. Plywood was glued to deck.

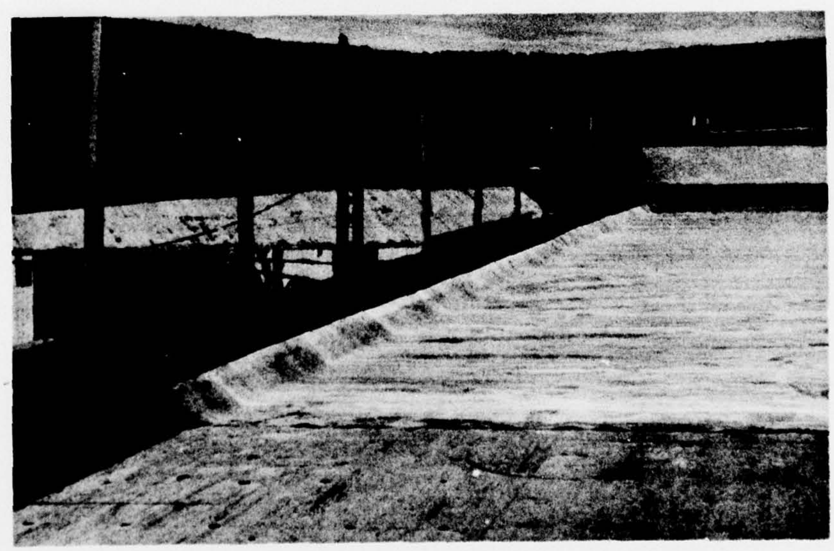


7. Rolling butyl rubber membrane on plywood deck.

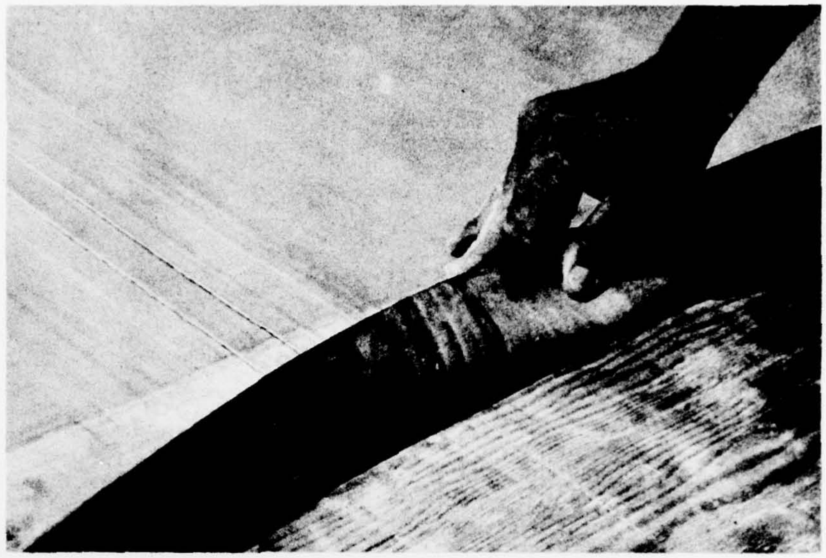


8. Close-up view of butyl rubber membrane.

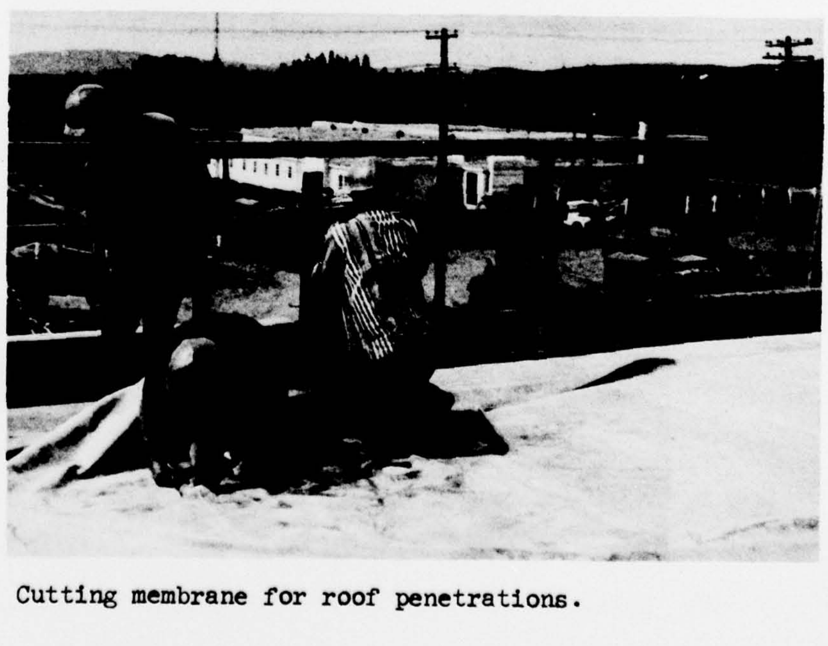
9. Placement of the butyl rubber membrane on the plywood deck. The placement took 3 hours.



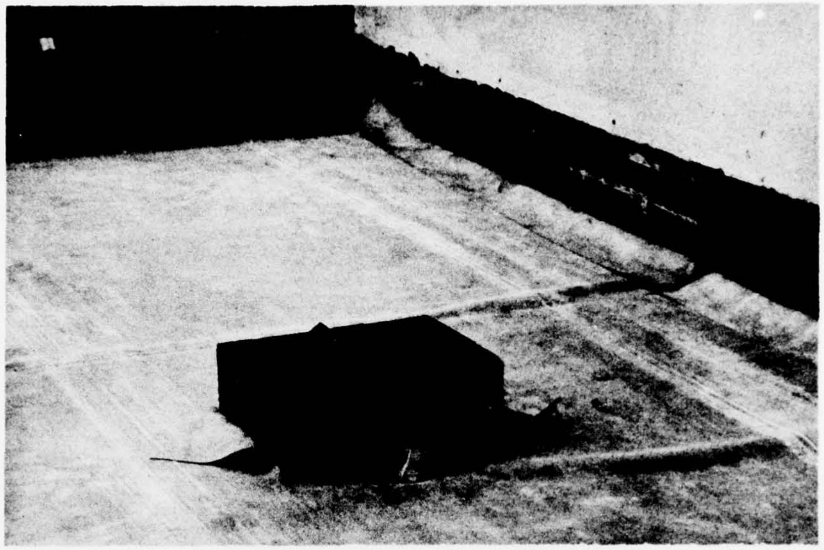
10. Membrane at the edge of the roof.



11. Close up of membrane showing factory splice.



12. Cutting membrane for roof penetrations.



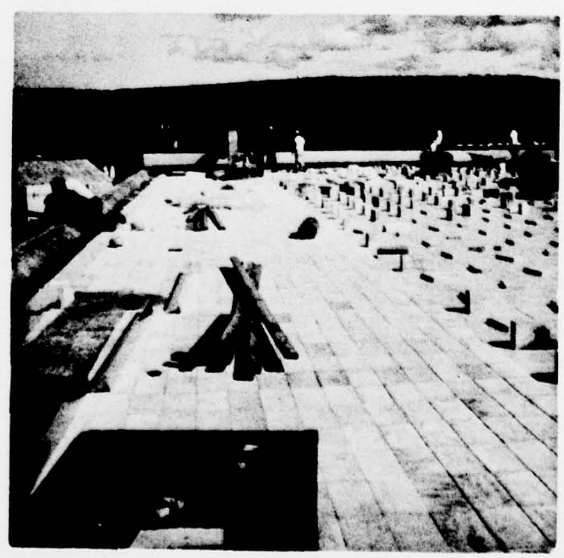
13. Duct penetration.

14. Exhaust stack and waste vent penetrations.

15. Field lap splicing. This was done on 15 August, after several days of rain.

16. Polystyrene laid over the membrane and temporarily held with pavers.

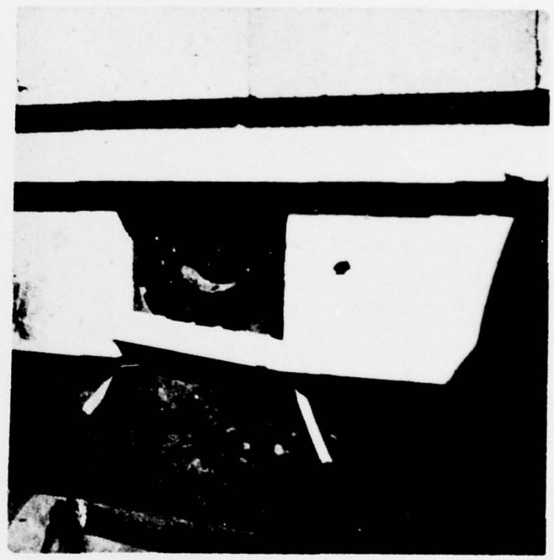
17. Portion of roof showing finished concrete paver placement.



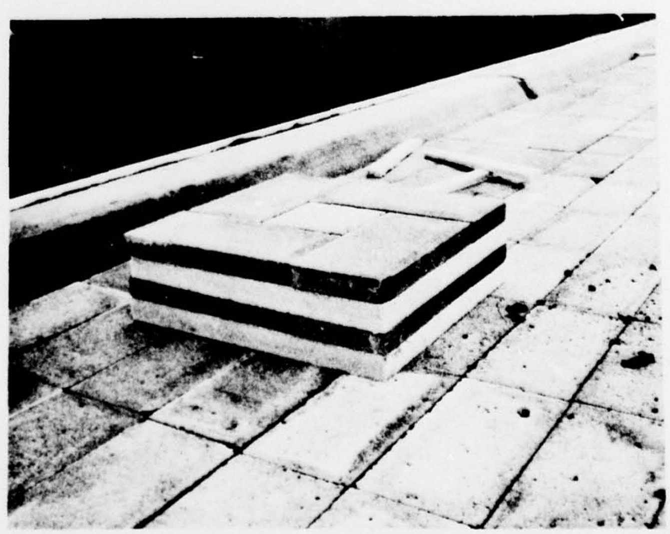
Drain Details

18. Drain after lowering to membrane level and bonded in place.

19. Placement of polystyrene insulation at drain.



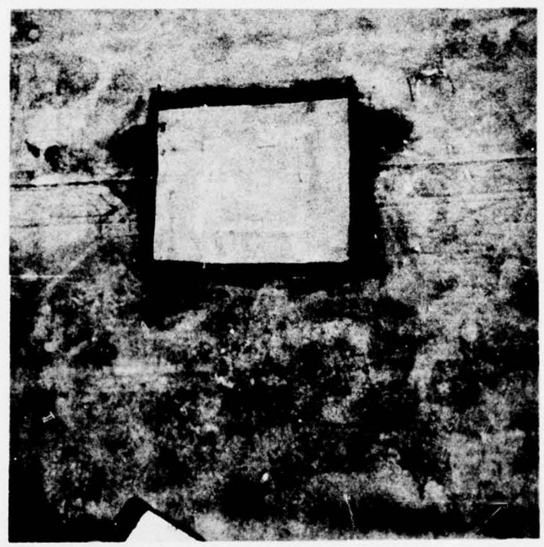
20. Completed drain cover. This prevents freezing of drain annulus during extreme cold periods.



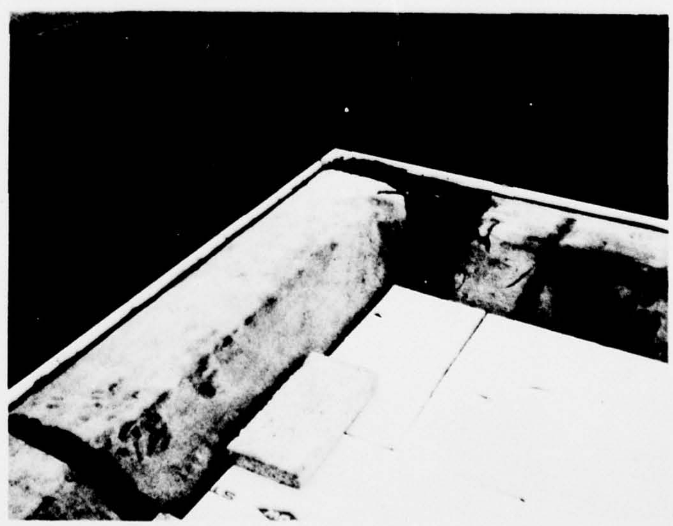
Flashing Details

21. EPDM flashing at roof edge. Also note field lap splice.

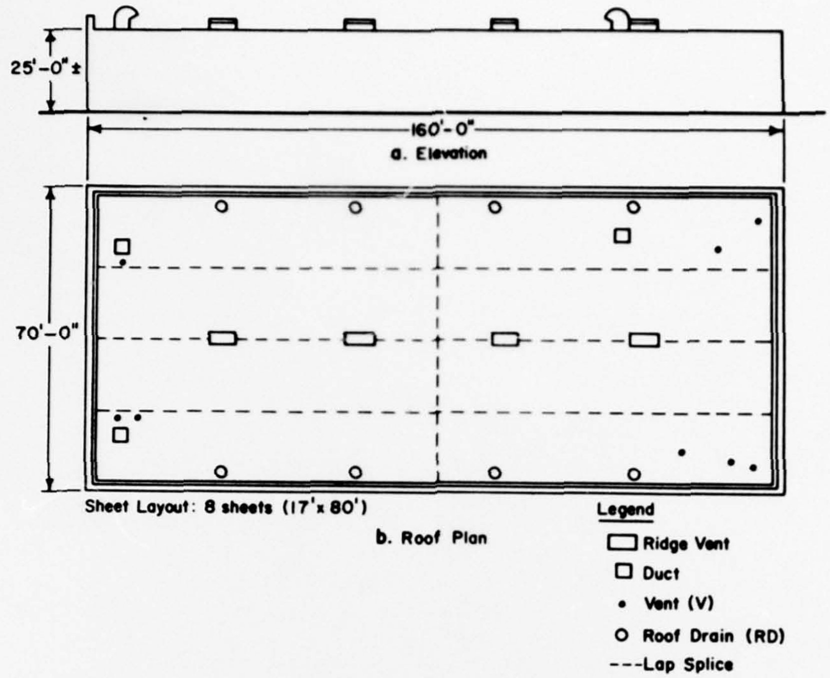
22. Typical patch.

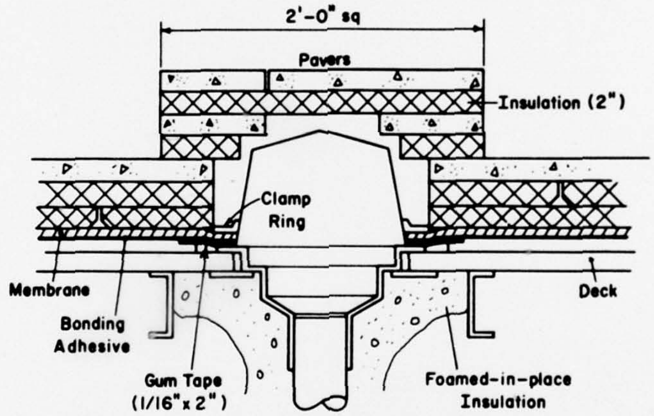


23. Completed flashing at a building corner. Insulation in place ready for pavers.

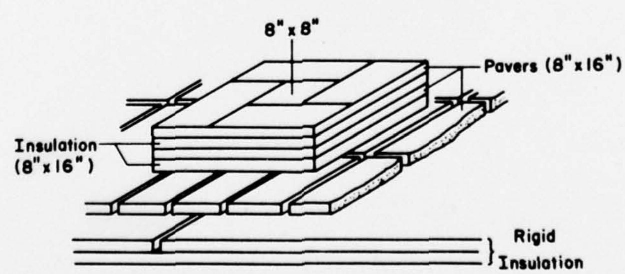


APPENDIX A: Roof Plan and Drain Details.



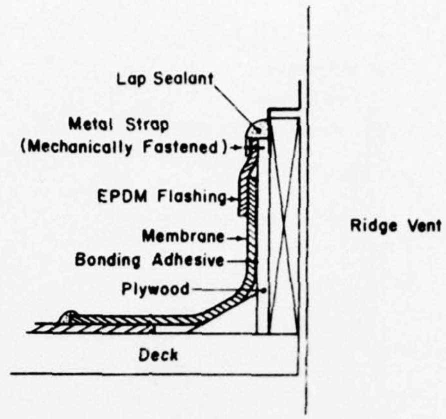


Drain Detail

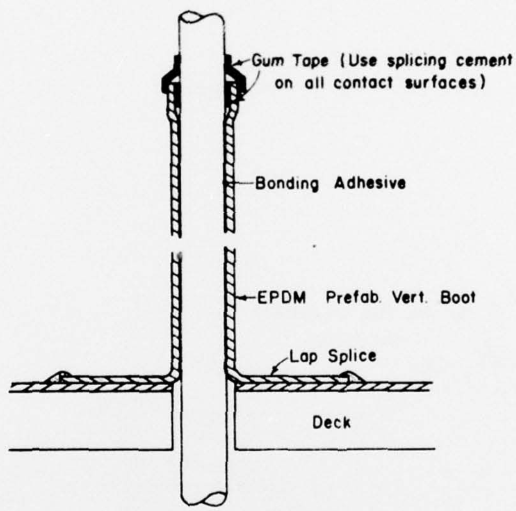


Oblique View at Drain

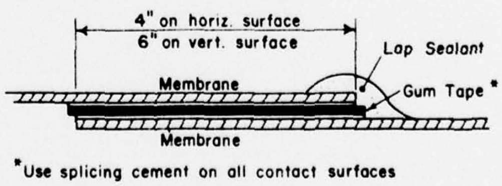
APPENDIX B: Details from Manufacturer's Shop Drawings.



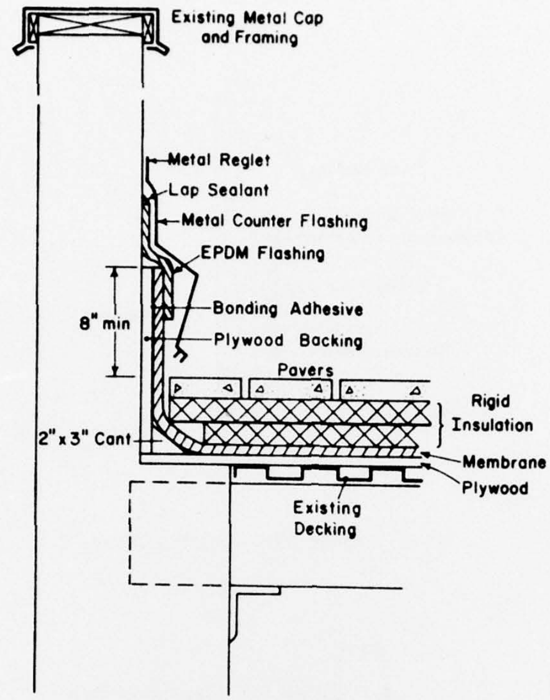
Ridge Vent Flashing Detail



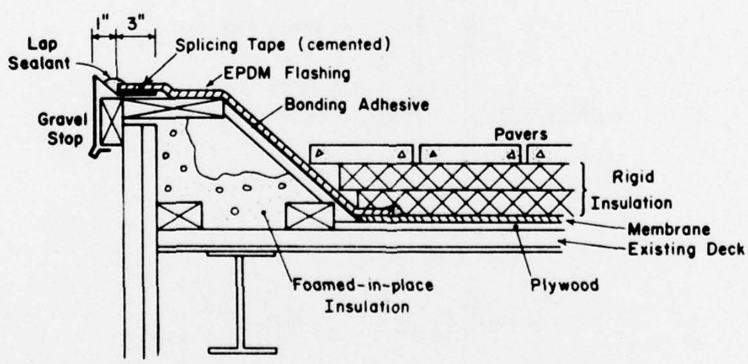
Roof Vent Details



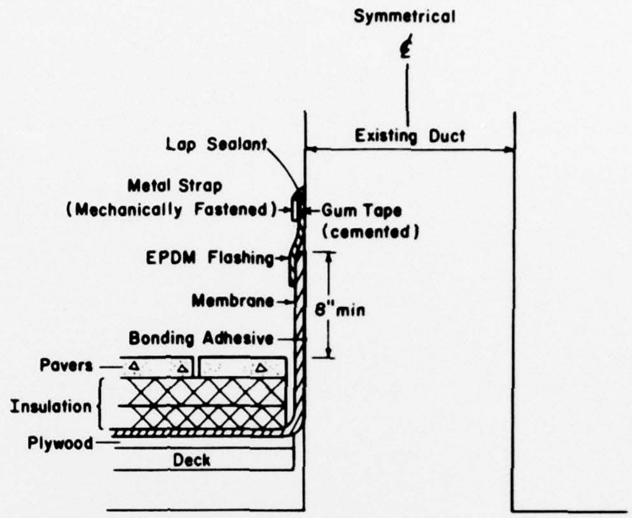
Typical Lap Splice



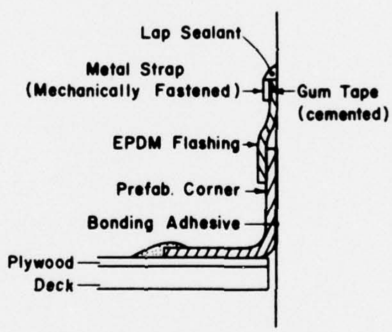
Section Through Existing Firewall



Eave Detail



Duct Penetration



Corner Detail