NATIONAL BUREAU OF STANDARDS REPORT

8905

PERFORMANCE OF ROOFINGS IN COLD CLIMATES

by

William C. Cullen

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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Organic Building Materials Section
Building Research Division
Institute for Applied Technology

Sponsored by

Office of the Chief of Engineers
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1. INTRODUCTION

The National Bureau of Standards was requested by the Office of the Chief of Engineers, U. S. Army; the Directorate of Civil Engineering, U. S. Air Force; and the Bureau of Yards and Docks, U. S. Navy, to develop information on problems relating to the performance of roofing systems in cold climates and to provide technical assistance to engineering personnel in the solution of existing problems. In this connection, a survey of roofing systems was conducted on selected military installations in the State of Alaska during May 1965 as a task under Project 4210447, Performance of Roofings, Tri-Service Engineering Investigations of Building Construction and Equipment, National Bureau of Standards.

The conduct of the survey consisted of "on the roof" observations of typical roofing systems by an inspection team including representatives of the National Bureau of Standards; U. S. Army North Pacific Division; Office of the Alaska District Engineer; Headquarters, U. S. Army, Alaska; and Headquarters, Alaska Air Command.

Critical inspections were made at the following installations on the dates indicated:

a.	Elmendorf A.F.B., Anchorage	17 May 1965
b.	Fort Richardson, Anchorage	18 May 1965
c.	AC&W Site, Unalakleet	19 May 1965
d.	Fort Greeley, Big Delta	20 May 1965
e.	Tracking Station, Donnley Flats	20 May 1965
f.	Eielson A.F.B., Fairbanks	21 May 1965
g.	Fort Wainwright, Fairbanks	21 May 1965

In addition to the inspections, round-table discussions were held at each installation with engineering personnel experienced with the design, construction, maintenance and performance of roofing materials and systems in Alaska.

This report gives our observations of the performance of roofing systems in cold climates as well as our opinions and recommendations based on the observations and discussions. Further, this report discusses the effectiveness of the recommendations of the Alaska Roofing Board which convened in Anchorage, Alaska, in August 1957. The author was a member of this six-man board.

2. CLIMATOLOGICAL DATA

The climate of Alaska varies from extreme cold during the winter months to mild temperatures during the summer months. The extremes in the climates including temperature, wind velocity, snowfall, and rainfall are illustrated by the weather data for each installation visited (Table 1).

3. OBSERVATIONS AND COMMENTS

Various and sundry roofing materials and systems, both conventional and unconventional, were observed at each installation. These included bituminous built-up systems and fluid-applied elastomeric systems for flat decks, as well as metallic and composition roofings for sloping decks. A view showing the miscellaneous types of roofings which were observed on one installation is shown in Figure 1.

Historically, in Alaska the bituminous built-up roofs have presented the more serious and costly problems when compared to other roofings (this is also true for other areas). This fact is clearly illustrated by information furnished to us by one installation regarding roof repairs completed during a 7-year period which is reported in Table 2. Incidentally, the cost of repairs of built-up roofs on this station during the period amounted to about $900,000 Consequently, a large portion of this report is devoted to the performance, maintenance, and repair of bituminous built-up roofing systems.

3.1 Bituminous Built-Up Roofing Systems

3.1 1 Components

a. Waterproofing Membrane

For many years the conventional multiple-ply bituminous built-up membrane has been used to cover structures having low slope (usually flat) roof decks in Alaska. Prior to 1958, asphalt was the predominately used bitumen, but since then both coal-tar-pitch and low-slope (dead-level) asphalt have been used in the application of these roofs. Bituminous-saturated organic felts accounted for the large percentage of reinforcing fabrics employed although some asbestos and glass have also been used.

TABLE 1. ALASKA CLIMATOLOGICAL DATA[1/]

INSTALLATION	LOCATION	WIND VELOCITY mph	SNOWFALL in./year		RAINFALL in./year		TEMPERATURE °F	
		Max.	Max.	Mean	Max.	Mean	Max.	Mean
Elmendorf AFB	Anchorage	115	132.6	59.9	18.89	14.29	86	-38
Ft. Richardson	Anchorage	115	132.6	59.9	18.89	14.29	86	-38
AC&W Site	Unalakleet	77	82.7	33.7	19.76	13.69	86	-50
Fort Greeley	Big Delta	95	63.9	35.2	16.93	11.63	90	-63
Eielson AFB	Fairbanks	95	134.5	60.2	18.73	11.93	99	-66
Ft. Wainwright	Fairbanks	95	134.5	60.2	18.73	11.93	99	-66

[1/] Source: Report of Alaska Roofing Board, August 1957.

TABLE 2. ROOF REPAIR DATA

TYPE OF ROOFING	TOTAL NUMBER OF SQUARES	NUMBER OF SQUARES REPAIRED SINCE 1957	% REQUIRING REPAIRS SINCE 1957
Bituminous Built-Up	42,000	30,000	71.5%
Asphalt Shingles	3,000	350	11.7%
Metallic Roofings	350	10	6.7%

There was serious disagreement among engineering personnel regarding the use of a mineral surfacing (gravel) to protect bituminous built-up roofs. We were aware of this disagreement at the onset of the program and as a result both smooth-surfaced and gravel-surfaced roofs were observed during the survey and their performances were evaluated critically in terms of the surfacing employed.

b. Thermal Control Element

The temperature extremes experienced in Alaska make the use of a thermal control element in the roofing system mandatory. For economical considerations, the insulation was frequently located between the roof deck and the membrane although it was sometimes placed beneath the roof deck.

Prior to 1958, several types of insulating materials were used such as fiberboard, mineral board, fibrous glass and cellular glass. However, cellular glass has been used predominately for "on top of the deck" installations since that time.

c. Vapor Control Element

In cold climates such as Alaska, a vapor-control element, which is always placed on the warm (low-vapor pressure) side, is necessary to restrict the flow of moisture vapor from the interior of the structure into components of the roofing system. In roofing applications in Alaska, the vapor barrier was generally placed between the roof deck and the insulation and usually consisted of two plies of 15-lb. asphalt-saturated felt sealed with hot bitumen.

In cases where the insulation was placed beneath the deck, the vapor-control element was located in the structure and supplemented by ventilation.

d. Structural Roof Decks

Concrete decks, both poured and precast, have been used frequently as the structural platforms for roofing systems on low slopes. Wood decks, both plywood and T & G planks, have also been used to a large extent especially on family housing units. In many cases a wood deck was constructed over an existing flat concrete deck to provide a sloping surface. A case in point is shown in Figure 2 which proved to be most successful.

In some instances, metal decks were used with an insulation provided between the deck and the roofing membrane.

e. Flashing Systems

The function of flashings is to provide a water-tight junction between the roofing material and other parts of the structure. Flashings are the most vulnerable part of the roof since most leaks result from failure in these areas. We observed that, for the most part, conventional plastic (bituminous built-up type) flashings have been used in Alaska in areas such as parapet walls, skylights, ventilators, and other vertical surfaces. We also observed the use of "pitch pockets" and metallic flashings at vent pipes and stacks and other projections through the roofing.

Metallic flashings used alone or in conjunction with bituminous built-up flashing were found at expansion joints and edge flashings. In these cases the metal to bituminous transitions were frequently observed below the ponding water line.

3.1.2 Factors Affecting Roof Performance

a. Moisture

From our field observations, our experience gained by service on the Alaska Roofing Board, and from discussions with engineering personnel in Alaska, we are of the opinion that the most serious and costly problems with roofings resulted from moisture entering into one or more of the roofing system components. The invasion of water into the roofing system resulted from one or more of the following causes:

1. Failure of the watertight membrane.
2. Failure of flashings and appurtenances.
3. Moisture entrapped in the system prior to or during construction
4. Inadequate condensation control.

The moisture in the system contributed to premature failure of the waterproof membrane which was evidenced by blistering, wrinkle formation and subsequent cracking. Figure 3 shows the early indication of this type of deficiency. In addition, an appreciable accumulation of moisture in the insulation results in a reduction of its thermal efficiency.

b. Thermal Movement

Investigations, by the author, of roofing failures in cold climates over a period of many years have revealed that membrane shrinkage has been an important factor in both membrane and flashing failures. It was therefore anticipated that this factor would be a frequent cause of roofing failures in Alaska. However, our observations indicated that thermal shrinkage was of minor concern when compared to other factors. In fact, only three cases were observed in which thermal shrinkage was suspect. Figure 4 shows a serious failure attributed to thermal shrinkage in the form of a roof split which was observed on a cold storate warehouse. Figure 5 shows a repaired area which is again showing signs of a splitting failure due to thermal movement.

c. Roof Slope and Drainage

Our observations indicated that the performance of the built-up roofing system appeared to be related to the slope. The steeper the slope the better the performance. Even a slight slope (1/4-inch per foot) which provided positive drainage was reflected in an increased performance of the roofing membrane.

The ponding of water in low areas on roofs definitely contributed to premature failure and resulted in specific problems such as the chemical degradation of the bitumen, physical deterioration of any exposed felts and frequently the disintegration of the cellular glass insulation. These factors were observed on most level roofs and in particular on those unprotected with gravel surfacing. Figure 6 illustrates the many areas of one roof where water collected and stood. Many of these areas exhibited evidence of early membrane failure. Invariably the roof drains when present were located at high areas on the roof and, of course, contributed to the ponding of water.

Our observations of a gravel-surfaced coal-tar-pitch roof on the composite building at Unalakleet revealed that water, 2 to 4 inches in depth, covered most areas of the roof. Personnel at this station reported that this condition existed during most of the year. A slight rupture in this roofing membrane could result in serious and costly failures. It was the consensus of the inspection team that roof slopes and adequate drainage should be required in these areas.

FIGURE 1. TYPICAL ROOFING SYSTEMS USED IN ALASKA.

FIGURE 2. WOOD DECK APPLIED OVER A FLAT CONCRETE DECK TO PROVIDE A POSITIVE SLOPE.

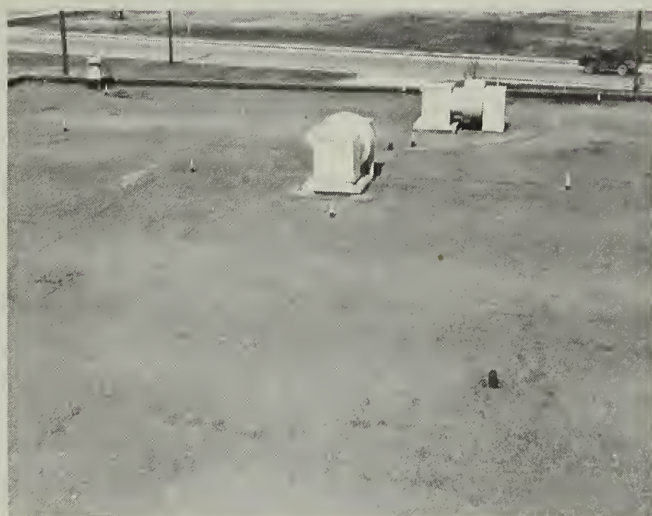


FIGURE 3. GRAVEL SURFACED ROOF SHOWING EFFECTS OF MOISTURE ENTRAPMENT IN THE ROOF SYSTEM.

FIGURE 4. ROOF MEMBRANE SPLIT ATTRIBUTED TO THERMAL SHRINKAGE.

d. Flashings

Inadequately designed, improperly installed and defective flashings were observed on roofs located at each installation. In our opinion, these deficiencies accounted for a large percentage of the reported failures. Figure 7 shows a serious failure which is typical of such a design at the flashing of an earthquake joint, which resulted in leakage. This was the only failure on a roof which otherwise provided good service for over 5 years. We believe this to ba a poorly designed flashing system for an expansion joint.

The unauthorized installation of antennae have also been the cause of leakage in many roofing systems. Figure 8 illustrates an extreme case where coping, roofing and flashing were punctured.

Metal to bituminous transitions in flashing systems should be avoided wheneven possible and should never be allowed beneath the standing water line. Figure 9 shows a typical failure at an edge flashing, while Figure 10 is an architectural drawing of the condition. We observed this type of failure more than any other single failure during the survey. The seriousness of this defect when it occurs below the standing water line is readily apparent.

e. Smooth Surfacing vs. Gravel Surfacing

Approximately one-half of the built-up roofs which were inspected were surfaced with gravel, while the remaining half were so-called smooth-surfaced roofs, i.e., coated with hot asphalt, hot coal-tar-pitch (one case only), asphalt emulsion, or a cut-back type asphalt roof coating. Our observations indicated that the better performance was obtained with the gravel-surfaced roofs, although adequate service was obtained with many of the smooth roofs. It should be pointed out here that there was disagrement even among the members of the inspection team regarding the merits of mineral surfacing. Nevertheless, we are of the opinion the evidence is in favor of mineral surfacing regarding the performance of the total system. Indeed in at least two cases, sections of gravel-surfaced roofing exposed side-by-side (on the same structure) with their smooth-surfaced counterparts appeared in better condition despite an age difference of a number of years. Figure 11, typical of many surfaced built-up roofs, shows the appearance after about 14 years exposure in the Anchorage area with little or no maintenance. On the other hand, many smooth-surfaced built-up roofs exhibited deficiencies common to this type of roofing, such as chemical degradation of bitumen, alligatoring, checking and surface cracking. These defects are not serious in themselves but do tend to shorten the effective life of the roof membrane.

FIGURE 5. UNSUCCESSFUL REPAIR OF A MEMBRANE RUPTURE ATTRIBUTED TO THERMAL SHRINKAGE.

FIGURE 6. EFFECTS OF PONDING WATER ON DEAD LEVEL ROOF. NOTE LOCATION OF DRAIN ON HIGH AREA (ARROW).

FIGURE 7. DEFECTIVE FLASHING AT EARTHQUAKE JOINT AFTER UNSUCCESSFUL ATTEMPTS TO REPAIR.

FIGURE 8. UNAUTHORIZED INSTALLED ANTENNAE WHICH RESULTED IN COPING, FLASHING AND MEMBRANE FAILURES.

Our experience with roofings in all areas has indicated that smooth-surfaced roofs require considerably more maintenance (recoating every 3 to 5 years) than their gravel-surfaced counterparts.

f. Insulations

The use of insulation in the roofing system has a direct effect on the durability of the roofing membrane. We observed that the performance of a membrane placed on the insulation was somewhat inferior to a similar membrane placed directly on the structural deck. Although this evidence would indicate that a "below the deck" location is desirable, we are of the opinion that this practice is not economically feasible in the majority of cases. Further experience in Alaska has shown that an adequate and serviceable roofing system can be constructed with the insulation located between the deck and the membrane if proper design, material and application specifications are enforced by construction inspection.

Various types of insulations were used in the Alaska area prior to 1957. However based on the recommendations of the Alaska Roofing Board, the cellular glass type has been used in the majority of installations since that time. In general, this material has performed adequately in service although some deficiencies were brought to our attention. The relatively poor resistance to wind uplift of the paper-backed type contributed to serious wind damage in one location. It was reported that the failure occurred at the interface of the cellular glass and its paper cover. In three cases, we observed indications of the disintegration of cellular glass extending down as much as 1/2 inch from the surface. In each case water had penetrated the membrane and we believe the repetitive freezing and thawing action of the water resulted in this disintegration. Figure 12 shows an area where this deficiency was observed.

The performance of other types of insulations such as fibrous glass, mineral and fiber board, cork, etc., was satisfactory as long as they remained dry.

g. Bitumens

Asphalt and coal-tar-pitch have been used for many years for the construction of built-up roofs in Alaska. In the survey we observed that each gave satisfactory service. We believe that other factors contribute much more to roof performance than the choice of bitumen.

FIGURE 9. COMMON FAILURE OBSERVED AT EDGE FLASHING WHERE A TRANSITION OCCURRED BETWEEN METAL AND BITUMINOUS MATERIALS.

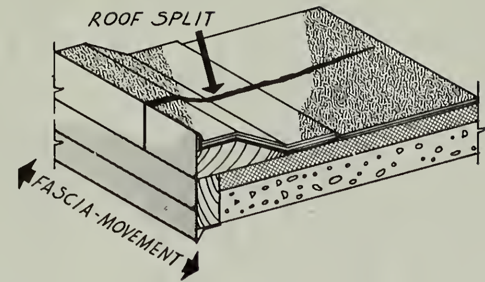


FIGURE 10. SCHEMATIC SKETCH OF FAILURE SHOWN IN FIGURE 9.

FIGURE 11. GRAVEL SURFACED ROOF AFTER 14 YEARS SERVICE, ANCHORAGE, ALASKA.

FIGURE 12. DISINTEGRATION OF CELLULAR GLASS INSULATION (EXTENDING 1/4 TO 1/2 INCH FROM SURFACE) ATTRIBUTED TO FREEZING AND THAWING ACTION OF ENTRAPPED WATER.

It was interesting to observe that a smooth-surfaced coal-tar-pitch roof was giving good service after many years exposure despite the fact that mineral surfacing is always recommended for this type of roof.

3.2 Roofing Systems on Sloping Decks

There was complete agreement that roofing systems on steep slopes have a history of excellent service in Alaska regarding watertightness and durability. Figures 13, 14, 15, and 16 show roofings which are typical of those which have served well. These include asbestos-cement, asphalt shingles, roll roofings, metallic shingles, and various other metal roofings. In fact, copper shingles which were observed in the Fairbanks area were still giving adequate service after 24 years service. This is considered excellent service for any roofing material in any climate.

Wind damage to asphalt shingles has presented some problems in the past but this deficiency has been largely overcome by specifying wind-resistant shingles or sealing down the tabs of free-tab shingles with an asphalt plastic cement.

Glaciation and formation of ice dams are problems common to steep roofs in cold climates. Glaciation, although not directly connected with roof performance must be considered in terms of the hazard it presents to life and property (including roof damage). On the other hand, the formation of ice dams at the eave of a roof frequently cause leakage where non-continuous roofings are involved (shingle type). A metal eave strip varying in width from 12 inches to 3 feet or more has been used (Figures 13 to 16) to reduce the potential hazards.

3.3 Fluid-Applied Organic Roofing Materials

Non-bituminous fluid-applied roofing systems were observed on flat concrete decks at Unalakleet and Donnley Flats. In two cases, Neoprene-Hypalon materials were used and in the other, an epoxy coating was applied. Although the performance of each material which was observed was considered to be satisfactory, we believe the Neoprene-Hypalon systems gave the better service in that they were less susceptible to rupture from discontinuities in the concrete deck, provided better adhesion to the deck, and exhibited the better weathering characteristics.

4. MAINTENANCE AND REPAIR

Inspection, maintenance, and repair procedures for roofing systems appeared to be well established for the installations included in the survey. In general, conventional methods, consistent with the climate of Alaska, were employed and the results were good. For example,

FIGURE 13. ASBESTOS-CEMENT SHINGLES ON A 6-INCH IN 12-INCH SLOPE IN EXCELLENT CONDITION AFTER 17 YEARS EXPOSURE.

FIGURE 14. ASPHALT SHINGLE ROOF ON FAMILY HOUSING BUILDING.

FIGURE 15. ASPHALT SHINGLES, SPOT-CEMENTED, ON FAMILY QUARTERS AFTER 5 YEARS EXPOSURE. NOTE METAL EAVE STRIP.

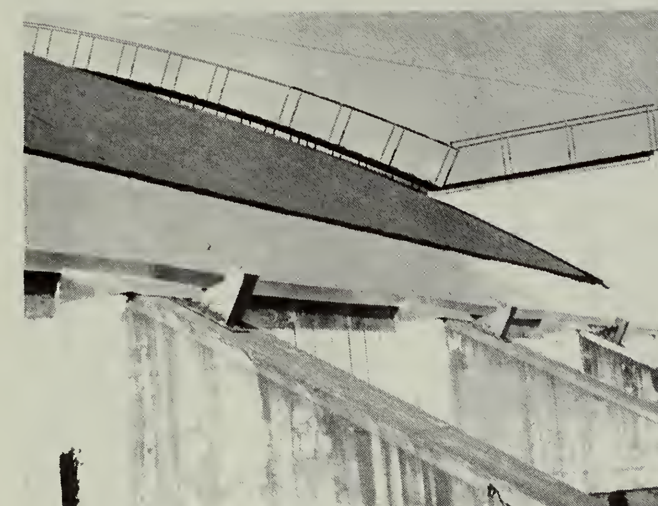


FIGURE 16. MINERAL-SURFACED ROLL ROOFING ON HANGAR ROOF AFTER 7 YEARS EXPOSURE. NOTE THE WIDE METAL EAVE STRIP USED TO SHED ICE AND SNOW.

Figure 17 illustrates the condition of a roof selected for the application of a repair membrane prior to a failure. Figure 18 shows a roof of a similar structure after repair was accomplished. We believe that this procedure will extend the useful life of the roof for many years. On the other hand, unconventional maintenance techniques were also observed. These in many cases compounded the failure rather than corrected it. Figure 19 shows the results of applying a glass fabric over a gravel-surfaced roof without removing the surfacing. Figure 20 illustrates cracking failures resulting from the use of thick surface coatings without the protection of gravel surfacing.

We were pleased with the results of the roof inspection and maintenance programs being conducted at each installation and it is our opinion that these procedures have contributed to the noticeable improvement of roofing performance in Alaska during the past 8 years.

We strongly believe that failure to recognize and correct minor defects and deterioration in their earliest stages are the greatest causes of premature roof failures and frequently result in costly repairs and replacement. We further believe that funds which are made available for inspection, maintenance and repair programs for roofing systems will ultimately result in enormous savings.

5. CONCLUSIONS AND RECOMMENDATIONS

A critical review of information and data, which were obtained during the survey and were based on histories, reports, discussions, and observations of roof performance, revealed a definite improvement in the performance of roofings in Alaska since 1957. The improved performance can be attributed to a large extent to the implementation of recommendations set forth by the Alaska Roofing Board. However based on the results of eight more years of experience, we do not concur with all the recommendations of the Board. These deviations are reflected in the suggestions which follow.

In conclusion, we submit the following suggestions regarding design, material and application procedures which we believe will mitigate many serious problems with roofing system performance in cold climates which were observed during the survey.

FIGURE 17. BUILT-UP ROOF IN INITIAL STAGES OF REPAIR AFTER 13 YEARS EXPOSURE.

FIGURE 18. BUILT-UP ROOF, SIMILAR TO THAT SHOWN IN FIGURE 17, AFTER REPAIR MEMBRANE WAS INSTALLED.

FIGURE 19. EXPOSED GLASS FABRIC WHICH WAS USED AS IN A REPAIR MEMBRANE OVER A GRAVEL-SURFACED BUILT-UP ROOF.

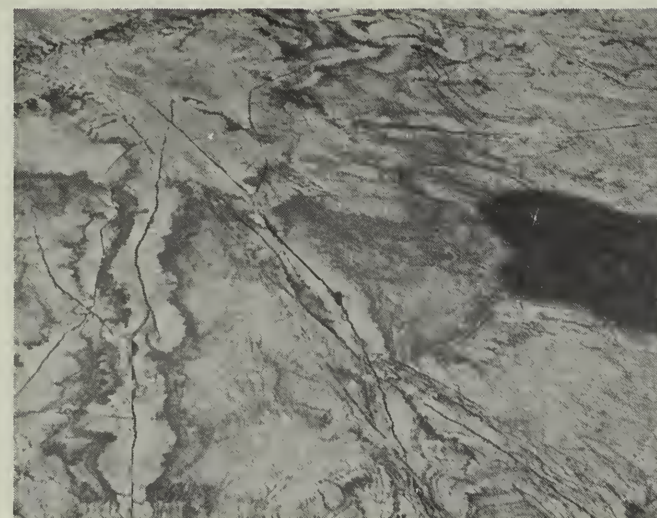
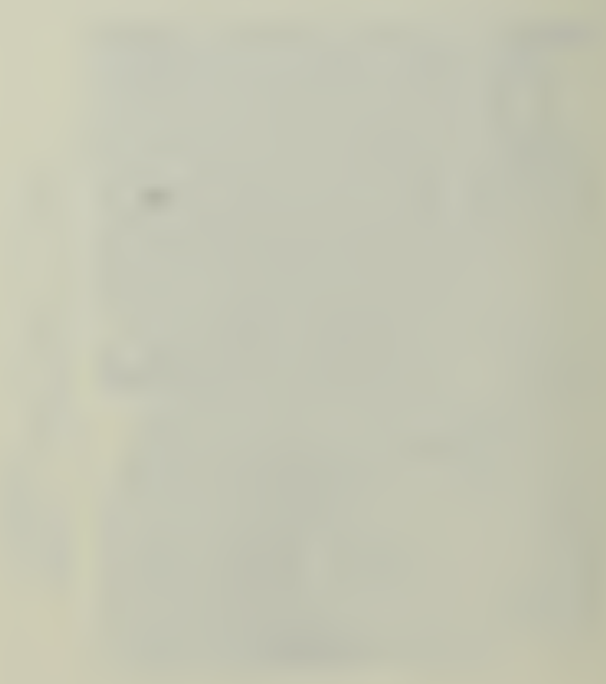


FIGURE 20. SURFACE CRACKING OF AN ASPHALT EMULSION ROOF COATING APPLIED OVER A THICK COATING OF HOT ASPHALT.



5.1 Built-Up Roofs

5.1.1 Design Considerations

a. Slope

Bituminous built-up roofs should be designed and constructed to provide a minimum slope to drain of 1/4 inch per foot (1/2 inch where possible) and to insure that no negative slope to drain will occur under any design load at any time.

Roof drainage systems should be designed so that drains are located at low areas of the roof.

b. Flashings

Figures 21, 22, 23, and 24 are flashing systems which are suggested for use at the locations indicated.

Wood backing when used in flashing systems should be fastened to the same structural system as the roof covering to preclude damage from differential movement between building elements.

Antenna installation should be made under the supervision of the post engineering personnel.

c. Insulation

We have seen no evidence to warrant the continued use of cellular glass on an exclusive basis for "on the deck" installations. Other insulating materials such as fibrous glass, mineral board, fiberboard, etc., will also give adequate service when properly installed in an adequate roofing system.

A vapor barrier having a ~~minimum~~ maximum vapor permeance rating of 0.5 perms should be specified for use between the deck and insulation.

d. Membrane

Low-slope asphalt (sometimes referred to as dead-level bitumen) or coal-tar-pitch conforming to applicable specifications is suggested for use in the application of all built-up roofs on a slope of less than 1/2 inch per foot.

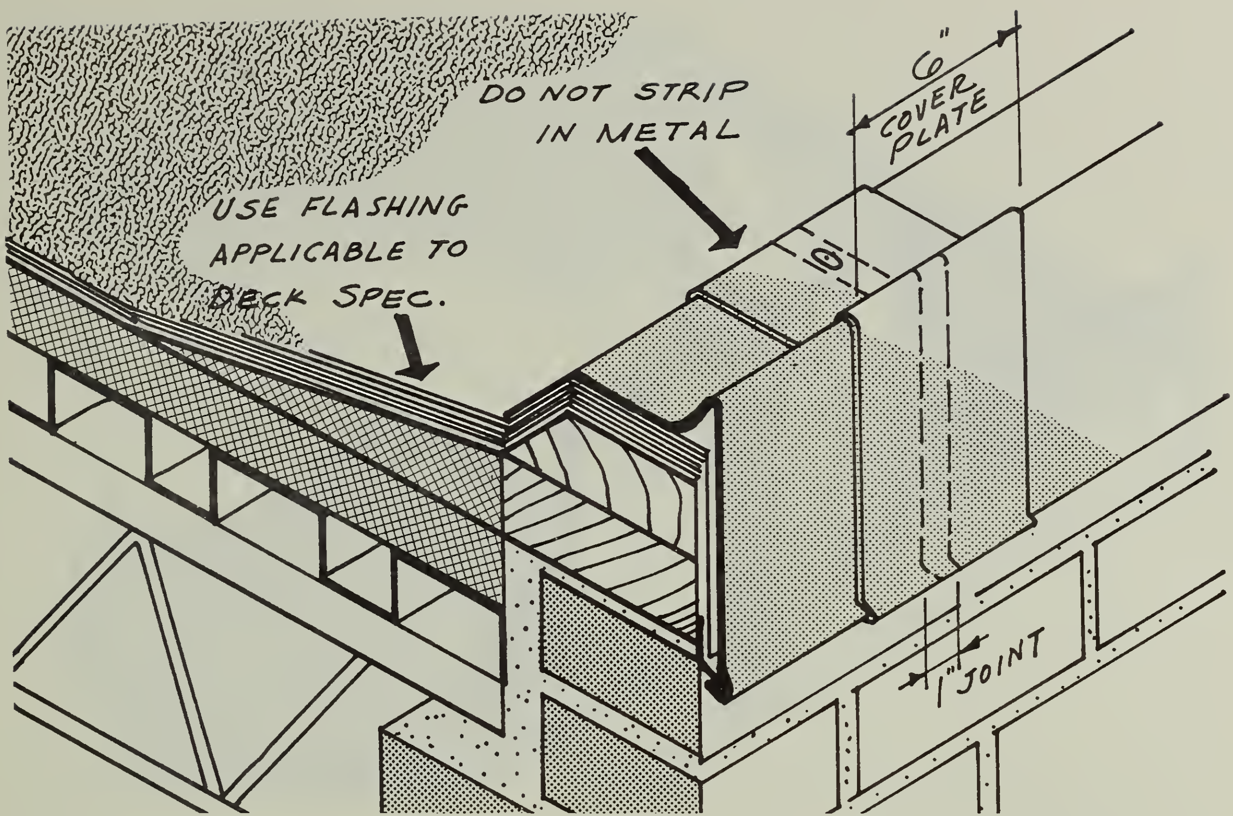


FIGURE 21. SUGGESTED FLASHING DESIGN
AT EDGE FLASHING.

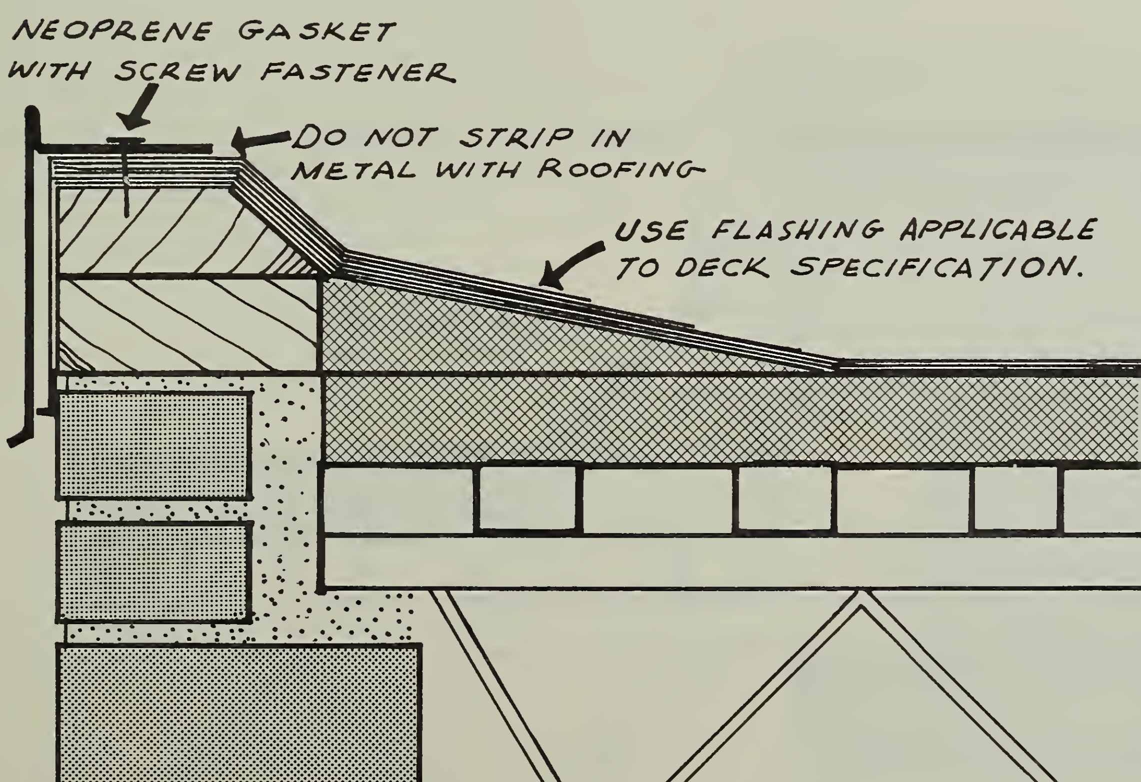


FIGURE 22. SUGGESTED FLASHING DESIGN AT
EDGE FLASHING. NOTE THAT THE METAL IS
NOT STRIPPED INTO THE BITUMINOUS
ROOFING.

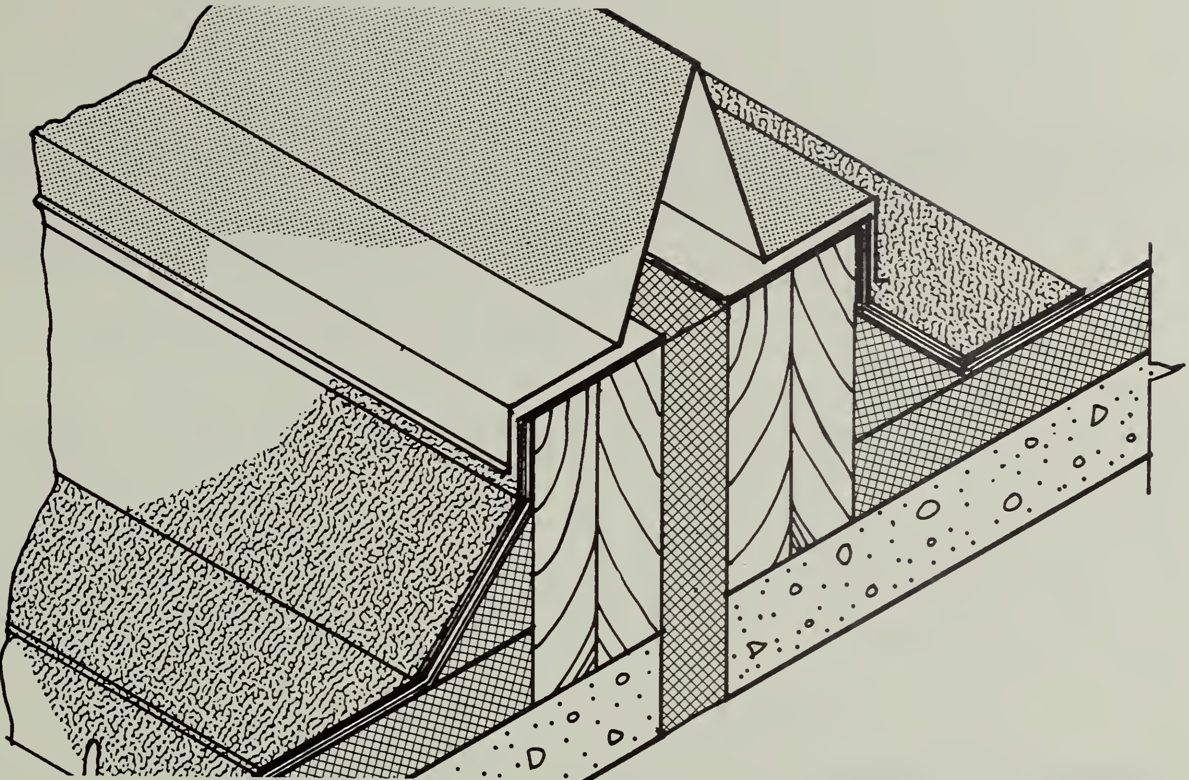


FIGURE 23. SUGGESTED FLASHING DESIGN
AT EXPANSION OR EARTHQUAKE JOINTS.

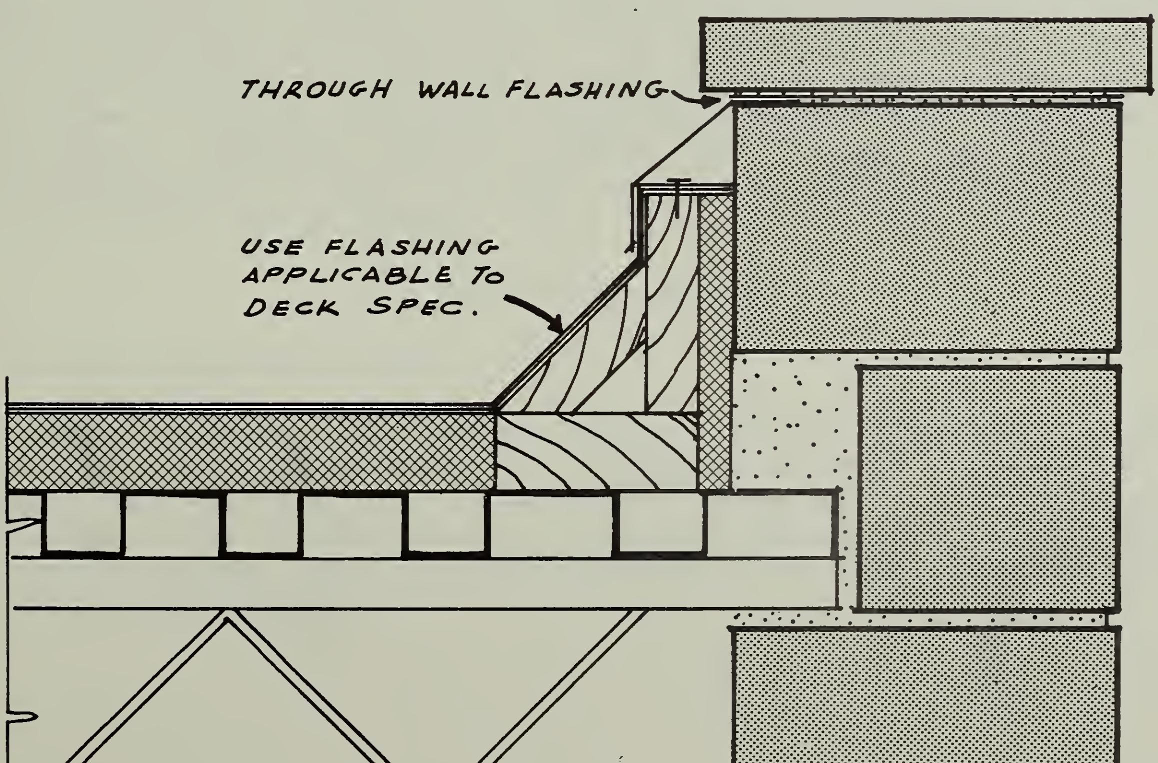


FIGURE 24. SUGGESTED FLASHING DESIGN
AT PARAPET WALLS.

Gravel or other suitable mineral surfacing should be used as surfacing on all bituminous built-up roofs on a slope of 1/2 inch per foot or less. The surfacing should conform as nearly as possible to the requirements of ASTM Designation D1863.

5.1.2 Application Considerations

The construction season in Alaska limits roofing applications to about 4 months or less each year. We believe that the waving of some of the conventional restrictions in application techniques due to temperature will actually result in improved roof performance. For example, roof application could be allowed when the ambient temperature is below the limit generally specified if other conditions are satisfactory for roof application or repair (dry weather, structure and materials). The judgment of the engineer in charge should largely govern in such cases.

5.2 Systems for Sloping Roofs

Roofing systems for sloping roofs have given satisfactory performance and it is predicted they will continue to do so as long as adequate material, design and application specifications are enforced.

In all asphalt shingle applications we suggest the use of wind-resistant shingles on all slopes to reduce wind damage. In addition, we suggest the use of a double underlayment of felt on all asphalt shingle installations on slopes of 5 inches in 12 inches or less. This method will prevent the infiltration of water due to the formation of ice dams. The underlayment should consist of two layers of 15-lb. asphalt saturated felt lapped 19 inches. The lap of the double underlayment should be sealed with a continuous layer of asphalt plastic cement from the eave extending up the slope to a line at least 24 inches inside the interior surface of the exterior wall.

5.3 New Roofing Systems

a. Fluid-Applied Systems

The neoprene-Hypalon fluid-applied roofing system is suggested for both exposed and unexposed concrete roof decks when the more conventional systems cannot be used. The system should be applied to a dry deck and should consist of a primer, 2 coats of a neoprene coating, and two coats of Hypalon coating. The dry film thickness of the system should not be less than 0.020 inches.

b. Elastomeric Sheet Roofings

Considerable interest was expressed in the utilization of some of the elastomeric sheet roofings in lieu of the bituminous built-up roofing system. Several of these roofings are currently available as follows:

1. Polyvinyl Fluoride film (Tedlar) factory-laminated to a felt of elastomer-bonded asbestos.

2. Chlorosulfonated Polyethylene film (Hypalon) factory-laminated to a felt of elastomer-bonded asbestos.

3. Polyisobutylene film factory-laminated to a felt of plastic-elastomer bonded asbestos.

4. Butyl Rubber Membrane.

A roof system can be considered adequate only when it has had a history of good performance exceeding 10 years in a climate such as Alaska. Obviously in the case of these materials this history is lacking. Therefore, we are unable to predict now their long-term performance in cold climates. We are of the opinion, however, that they possess good possibilities for special applications on small areas where the more conventional systems have not performed well. However, sufficient exposure data has not been developed to recommend their extended use in Alaska at this time.

6. ACKNOWLEDGMENT

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