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# NONCONVENTIONAL ROOF SYSTEMS FOR IN-HOUSE INSTALLATION AT AIR FORCE BASES

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Until 20 years ago, almost all nonresidential roofing in the United States was either built-up roofing or corrugated metal. New roofing materials and processes developed during World War II did not significantly affect the market. However, the Arab oil embargo in the 1970's drove up the price of bituminous roofing products, providing a new incentive to find alternate roofing materials. These new materials are now being used to replace damaged or failed low slope roofs.

Most Air Force buildings have low slope, or built-up roof (BUR) systems. Although repairs are generally completed by in-house crews, roof replacement is usually completed by contractors because most Air Force bases no longer have the asphalt kettle equipment needed to install or resurface BURs. However, for some conditions other than

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economical, managers at Air Force bases should consider in-house installation of nonconventional systems as a practical alternative for low slope roof replacement.

This report discusses the role of industry participants, sources of roofing information, and the factors to evaluate when considering reroofing, and lists procedural steps for the roof engineer and roof technician.

Based on the demonstration installations, in-house reroofing using nonconventional systems is a feasible option for Air Force bases. The installations were successful in that problems were easily resolved and the completed roofs did not leak. However, planning and support services were not adequate. It is recommended that extra planning effort be dedicated to each project and that training include system performance, detailed reference material, and hands-on experience.

## FOREWORD

This research was funded by Headquarters, Air Force Engineering and Services Center, Tyndall Air Force Base (AFB), FL, under Order Number F84-82, dated September 1984, titled "Durable Roof Systems for Remote Sites." The Technical Monitor was Mr. Dennis Firman (HQ AFESC/DEMM).

The work was performed for the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USACERL). Mr. William B. Rose is employed by the University of Illinois, Small Homes Council-Building Research Council. Dr. Robert F. Quattrone is Chief of USACERL-EM. The Technical Editor was Gloria J. Wienke, USACERL Information Management Office.

The cooperation of the Civil Engineering squadrons at Wurtsmith AFB, Oscoda, MI; Robins AFB, Warner Robins, GA; Gila Bend Air Force Station (AFS), Gila Bend, AZ; and McChord AFB, Tacoma, WA, is appreciated. The cooperation of the manufacturers of the demonstration roofing products is also appreciated.

COL Carl O. Magnell is Commander and Director of USACERL, and Dr. L. R. Shaffer is Technical Director.

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## TABLE

# NONCONVENTIONAL ROOF SYSTEMS FOR IN-HOUSE INSTALLATION AT AIR FORCE BASES

## 1 INTRODUCTION

### Background

Until 20 years ago, almost all nonresidential roofing in the United States was one of two types: built-up roofing, where layers of felt were embedded in hot mopped asphalt or tar, and often topped with gravel; and corrugated metal, where panels of galvanized steel were fastened to the structure with screws that pierced the panel.

New materials and processes developed during World War II led to the production of new roofing products and systems. The first wave of innovations came in the 1950's and 1960's; however, they failed to significantly affect the roofing market. Installers were too unfamiliar with new application procedures, and the products did not always perform as expected.

In the 1970's, the Arab oil embargo drove up the price of bituminous roofing products, providing a new incentive to find alternate roofing materials. Some products were resurrected from a decade earlier (Hypalon, for example), some were imported from Europe (modified bitumen), and some were created in the United States (ethylene-propylene-diene monomer [EPDM]). These new materials are now being used to replace damaged or failed low slope roof systems.

Many Air Force buildings have low slope, or built-up roof (BUR) systems. Guidelines for BUR management are contained in Air Force Manual (AFM) 91-36.[1] Although repairs are generally completed by in-house crews, roof replacement is usually completed by contractors because most Air Force bases no longer have the asphalt kettle equipment needed to install or resurface BURs. Replacement may also overextend the operations and maintenance manpower at many bases. However, for some conditions other than economical, managers at Air Force bases should consider in-house installation of nonconventional systems as a practical alternative for low slope roof replacement.

### Objectives

The objectives of this research are to:

- Provide information to roof engineers and technicians to help them decide how to meet base reroofing needs and whether the roof technicians and in-house personnel should perform this work.
- Provide guidance for roof technicians when preparing for an in-house roof installation.
- Demonstrate in-house installation of nonconventional roofing systems and document lessons learned.

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[1] Air Force Manual (AFM) 91-36, *Built-Up Roof Management Program* (Air Force Engineering and Services Center [AFESC], April 1989).

**Audience**

This document is specifically directed to the attention of the following:

- Roof Engineers--architects or engineers in the engineering branch (DEE) who are faced with reroofing needs.
- Roof Technicians--planners in the planning branch (DEM) who coordinate roofing activities.
- Roof Technicians--mechanics in the structures shop (DEM) who perform roofing maintenance and repair activities.

**Approach**

Information was requested from roofing manufacturers and from other sources. This information was the foundation of the guidance for roof engineers and technicians. This information was also used to select the roofing systems best suited to a particular climate and building condition. The selected systems and demonstration bases are:

- Ballasted PVC (plastic) at Wurtsmith Air Force Base (AFB), Oscoda, MI.
- Modified bitumen at Robins AFB, Warner Robins, GA.
- Standing seam metal at Gila Bend Air Force Station (AFS), Gila Bend, AZ.
- EPDM at McChord AFB, Tacoma, WA.

Training sessions and the system installations at the four bases were monitored for evaluation.

**Scope**

The four nonconventional roofing systems installed as part of this study are not representative of all single-ply and metal roofing systems. Rather, they are examples of systems that have been shown to be relatively easy to install. However, even systems that are easy to install have strict requirements and complex details. Physical tests of material characteristics were not conducted.

Although cost is important when choosing a roofing product, this report does not compare products in terms of cost. Cost of materials varies widely, as does cost of delivery and handling. Prices are not fixed, and generally vary from region to region. The nonconventional systems are commonly more expensive in terms of material, but are considered comparable to BUR when savings due to labor and performance are included.

This report also does not compare the costs of in-house versus contract installation.

## 2 ROOF SYSTEM PROCUREMENT AND SELECTION

### The Roofing Industry

A manufacturer considering participation in a military in-house installation is faced with conflicting aims. On one hand, the manufacturer wants to enlarge the market for the product. On the other hand, the manufacturer does not want to relinquish control over the installation.

Manufacturers prefer the term "roofing system," and avoid using the term "roofing product," because they produce and market a complete system. Although the successful performance of a roof does depend on the composition of the membrane, it depends to a greater extent on the quality of the installation. Some roofing materials (asphalt shingles, for example) are available as roofing products. For these products, the manufacturer provides only basic instructions and exercises no control over installation. However, the single-ply roofing industry prefers to control the installation. The principal means to achieve this control is through warranties.

A warranty of a roofing product is a contractual promise made by a manufacturer regarding the system performance. (The terms "guarantee" and "warranty" have almost identical legal meanings.) Although a complete discussion of warranties is beyond the scope of this report, any roofing system that is not experimental should be warranted.

Manufacturers typically grant warranties only when the installation (1) is conducted by certified installers, (2) uses only materials approved by the manufacturer, and (3) is inspected and approved for warranty.

#### *Industry Participants*

Managers intending to conduct reroofing should have a basic understanding of the structure of the roofing industry. Knowing the roles of manufacturers, technical representatives, sales representatives, suppliers, and contract installers, should help base personnel reduce the effort involved in in-house roof installation.

Manufacturers play a central role in the roofing industry. Most companies distribute nationwide and most employ engineers who provide technical services for the products. These services range from research and product development to monitoring field performance of the product and advising on particular installations. The technical representatives are generally available for phone consultation to answer particular problems. For site visits, the manufacturer will customarily bill for the representative's time and expenses.

The first contact that a roof engineer will have regarding a roofing product will probably be with a sales representative. This person can provide basic information about the product. Many sales representatives are also qualified to provide technical services. However, the engineer should not rely on technical information from a sales person unless the technical services office indicates that the sales representative is technically qualified.

Because most manufacturers are national, distribution is handled through local suppliers. Questions about material for a particular installation should be directed to the suppliers.

Most nonconventional roofing systems are installed by contractors certified by the roofing product manufacturer. This certification process allows the manufacturer to control the quality of installation.

Roof engineers should be aware that in-house installations may concern local installers, who may feel that their certification by the manufacturer confers certain installation privileges in a geographic region. If a manufacturer agrees to make the product available for in-house installation, that agreement should be in writing.

Roof engineers should also be aware of the various organizations and associations that may be helpful when planning and completing a reroofing project. The National Roofing Contractors Association (NRCA) is the principal professional association of the roofing industry. *The NRCA Roofing and Waterproofing Manual*[2] provides guidelines for roofing installations in general. The association also conducts training seminars and provides training materials. Regional Roofing Contractors' Associations are organized in most parts of the country. The Roofing Industry Educational Institute conducts seminars throughout the country to inform engineers, architects, specifiers, and contractors about up-to-date roofing products and procedures.

The manufacturers of roofing products have associations through which they provide information regarding their specific products. These associations include the Single Ply Roofing Institute (SPRI), the Asphalt Roofing Manufacturers Association, the Metal Construction Association, and the Roofing Council of the Rubber Manufacturers Association.

*Gathering Product Information*

The successful installation of a nonconventional roofing system involves close cooperation between the installer and the manufacturer. Manufacturers are quite protective of the reputation their product merits and they will take pains to see that the installation is relatively trouble-free. To become familiar with nonconventional roofing systems, roof engineers should contact the NRCA and SPRI. These organizations can provide the names and addresses of roofing manufacturers, charts that compare product characteristics, and guide books for roofing products. One such handbook is the *Commercial, Industrial and Institutional Roofing Materials Guide*[3] published every 6 months by the NRCA (1 O'Hare Center, 6250 River Road, Rosemont, IL 60018).

The engineer may also contact local roofing companies to see which products they carry. This information will help if contracts are to be let for the work. It will also indicate which products may be available locally for inspection.

### Roof Management—Establishing Condition and Priority

Guidelines for roof management are contained in AFM 91-36. This document gives base Civil Engineering the procedures necessary to develop and maintain an ongoing management program. The U.S. Army Construction Engineering Research Laboratory

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[2] *The NRCA Roofing and Waterproofing Manual*, 2nd ed. (National Roofing Contractors Association [NRCA, 1988].

[3] *Commercial, Industrial and Institutional Roofing Materials Guide* (NRCA).

(USACERL) has also published a manual to help determine the condition of BURs.[4] This report provides a method for determining the roof condition by quantifying the distress evident in the membrane and flashings.

When faced with a problem roof, the engineer must first decide whether to repair or to reroof. Because action is usually taken after leaks are noticed, patch repairs are quite common. Repair crews can be quickly dispatched to problem sites. Most patch repairs are temporary (remaining effective for 1 year or less) and often serve as indicators that planning for reroofing should begin. Reroofing requires a few months of planning and procurement.

## In-House Reroofing

Because many Civil Engineer (CE) roofing crews have neither the equipment nor organization to undertake large jobs, reroofing is seldom done in-house. However, some conditions under which in-house reroofing would be necessary or desirable include:

- Lack of qualified installers in the region.
- Exorbitant costs for available systems.
- Security.
- Remote location of the site.

One very important limitation on the scope of reroofing efforts for in-house installation is that reroofing even small buildings requires the work of an entire crew for at least 1 week. Consequently, those workers will not be available during that week for other jobs.

## Roof Procurement Sequence

The sequence described below is condensed into a checklist (Figure 1) for the roofing engineer.

### *Condition and Priority*

AFM 91-36 provides direction for the maintenance, repair, and replacement of all low slope roofs on Air Force buildings (including military family housing). The manual (1) establishes an in-house preventive maintenance program for roofs now in service and, (2) for contract work, it shows how to determine the best solutions, prepare construction documents, and hold suppliers accountable through contract management and coordination.

The roof condition is adequately determined only by an onsite inspection. The membrane, flashings, and insulation should be inspected individually, and assessed in terms of overall performance.

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[4] M. Shahin, D. Bailey, and D. Brotherson, *Membrane and Flashing Condition Indexes for Built-Up Roofs Volume I: Development of the Procedure, Volume II: Inspection and Distress Manual*, USACERL Technical Report M-87/13, Vols. I and II ADA190367 and ADA190368 (U.S. Army Construction Engineering Research Laboratory [USACERL], September 1987).

**Roof Engineer: Checklist for roof selection**

*Condition and priority*

Has the roof condition been established as being in need of repair?
What is the condition of the field?
flashings?
insulation?
Are the conditions light, medium or severe?
What priority is given to the work?
When must the work be completed?
What is the correct response--repair or reroofing?
Must the existing roof be torn off?
Are the drawings original construction, as built, revised, or up-to date?
Have the drawings been verified to conform to the existing building?
Do the drawings include roof plan?
building section showing roof structural support system?
edge detail?
other pertinent details?

*Building Factors*

Which roof details can be found ?
(plumbing vents, room vents, HVAC equipment, expansion joints, hatches, skylights,antennas, drains, scuppers, parapets, chimneys, etc.)
What is the roof slope?
What materials are present field?
flashings?
insulation?
deck?
roof framing?
eaves trim?
How will the building be used?
Will the insulation be upgraded?

*Other Factors*

What weather conditions will affect the work?
What are design conditions of temperature?
rainfall?
wind?

**Figure 1. Roof engineer checklist for roof selection.**

*Selection*

Which reroofing systems are available?
- Thermoplastic?
- Modified bitumen?
- Standing Seam Metal?
- Elastomeric?

Which roofing system should be chosen?
Which fastening system?
Which insulation system?
Should the construction be done by base personnel?
    Are the documents which describe the work prepared?
        Contract Documents
        Drawings
        Specifications
            Conditions
            Has a timetable been established?

*Contact with manufacturers*

Are you ready to discuss the following:
- Roof description?
- Training requirements?
- Procurement and payment?
- Warranties?
- Delivery dates?
- Equipment, accessories, tools?
- Special handling requirements?
- Site visits by representative?
- Technical supervision during installation?

*Execution*

Has the material been ordered?
Has training been scheduled?
Will a manufacturer's representative be on site?
What plans are made for weather or other contingencies?
Have the Roof Technician and the crew been briefed?

Has the material arrived? Is the order complete?

Is all of the equipment on hand?

Is the job ready to proceed?

**Figure 1. (Cont'd).**

*Design Considerations*

The critical building factors that influence the selection of a roofing system include: slope, deck material, dimensions, and number and nature of penetrations. These can be determined either by an onsite inspection or by checking documents on file. In addition to physical factors, the eventual use of the building must be considered.

The engineer should use design values for temperature, rainfall, wind, and incident solar radiation. Design values for climate are critical (threshold) values with a small likelihood of occurrence. These values often depend on the building's function.

*Selection*

The engineer should be aware that for most roofs, any one of many roofing systems would be adequate. If a number of systems are likely to perform equally well, the engineer should select the system with the longest "track record" or best record of success in the area.

*Contact with Manufacturers*

The first contact with manufacturers of the selected system should be to request product literature. It would be wise to request an installer's handbook at the same time. The detailed information contained in an installer's handbook can be very helpful.

*Execution*

The roof engineer prepares the documents that describe the present condition of the roof and what the final condition of the roof is to be. These documents generally include:

- General conditions of the contract.
- Drawings of existing conditions.
- Drawings of the work to be completed.
- Detail drawings.

Most roofing detail drawings are two-dimensional sections that identify the components and show their relative placement. Isometric (three-dimensional) roofing detail drawings help describe how corners and ends are to be treated. The engineer should contact the manufacturer's representative and make arrangements for procurement and training.

## Roof Selection Criteria

The weather, building structure, application, and material handling methods must be considered when selecting a nonconventional roofing system.

*Weather*

Roofing materials are tested for resistance to the weather by batteries of tests. If the material cannot accommodate thermal expansion and contraction of both the building and the roofing material, the manufacturer will incorporate a method into the system to allow for movement. The weather is pertinent not only during the service life of the product, but also at the time of application.

Depending on the roofing material being used, the temperature during application can greatly affect the quality of the installation. For example, metal roof application temperatures are governed by the comfort temperature for the installers who generally work without gloves. Black roofs, such as EPDM and some modified bitumens, become unbearably hot when the ambient temperature is above 100 °F. There has been little documented evidence of roof failure directly due to temperature extremes during installation. Elastomeric membranes (e.g., EPDM) remain flexible at very low temperatures and also retain much of their elongation capabilities at these low temperatures. Modified bitumens, on the other hand, generally require temperatures above 0 °F during application, but need special attention at temperatures between 0 and 32 °F. If installing modified bitumen at these temperatures, the rolls must be stored in a heated room before installation.

Wind uplift is best dealt with by using a fully or partially adhered roof system. For both of these systems, the insulation must be firmly attached to the substrate to overcome uplift. Partially attached membrane systems, using either mechanical fasteners or adhesive, are subject to billowing caused by wind. These membranes should be securely adhered around the perimeter. Scour is associated with ballasted systems. It occurs if the gravel ballast are moved or removed by high winds.

Ultraviolet (UV) exposure must also be considered. While some membranes are manufactured to resist damage from UV exposure, others may require aluminum paint or ballasting to achieve adequate protection and longevity. To reflect the heat, light color aggregates and membranes can be used.

If reroofing cannot be completed in 1 day, crew members must seal the membrane where work was terminated to protect the insulation from moisture and other environmental conditions. Only as much insulation as can be roofed over in 1 day should be installed.

*Building Structure*

The first thing to consider regarding the building structure is whether the system will be a new roof or a replacement. If the building is new, generally all structural considerations associated with a roofing system can be handled during the design phase. For reroofing, many of the properties are fixed, limiting the available options.

In reroofing, a roofing type that is comparable in weight to the old roof is preferable. A ballasted system may add too much weight. Wet insulation is also a factor; it should be replaced. Adding insulation to a building that previously was uninsulated is another weight consideration. Generally, a single-ply system weighs less than a BUR. Live loads such as snow loads and foot traffic must also be accommodated.

Building Movement. Building movement also requires consideration when selecting a low-slope roofing product. Because elastomers have high elongation properties, they are generally the best for accommodating extreme building movement. If extreme movement is evident, a loose-laid or partially adhered system is necessary. Any fully

*Conversion factors are listed on p 74.

adhered system, even an elastomer, can suffer from splitting and fatigue. The flashing method must also accommodate building movement.

Roof Slope. One serious consideration pertinent to low slope roofs is ponding water. Ponding water can penetrate lap joints and soak the insulation, thus destroying the roof. It is recommended that a 1/4-in. per foot slope be maintained (by tapered insulation, for example). If a gravel ballast is to be used, the slope should not exceed 2-in. per foot, or the gravel may move to low points in the roof creating excess localized load.

Substrate. When reroofing over a BUR, remove the existing roof, inspect the condition of the deck, and remove all damaged materials. Nonconventional roofing products must be applied over substrates that are compatible with the membrane and recommended by the manufacturer.

Reroofing membranes may be installed without removing the existing roof only if (1) the framing will permit additional dead loading, (2) the deck and insulation are in good condition, and (3) the deck is prepared according to the manufacturer's recommendations. Because modified bitumen products are compatible with the asphalt of BURs, they may be in direct contact with properly prepared BURs. Many other single-ply products are not compatible with asphaltic products and require careful surface preparation before application. All dirt and debris must be removed to allow the contact adhesives to seal properly. Standing water must also be removed before installing the new system. Often a primer and/or "recover board" (fiberboard or plywood) must separate the old roof from the new.

Insulation. Insulation is generally placed below the membrane but above the structure in a conventional assembly or above the membrane as in a Protected Roof Membrane (PRM) system. PRM solves the problem of condensation along the vapor retarder in conventional assemblies by using the low permeance membrane on the warm side of the insulation as the vapor retarder. This eliminates the need for a second vapor retarder. Insulation for the PRM system must be waterproof, such as extruded polystyrene. Most insulation types are compatible with single ply membranes.

Vapor Retarder. High relative humidities coupled with high indoor temperatures and low outdoor temperatures can create extreme vapor migration in a building. The vapor moves toward the outside and is trapped at the point where it reaches the membrane (generally of low permeance). This vapor condenses, soaking the insulation. Although some membranes possess relatively high permeance, the release of vapor is generally not rapid enough. The suggestion most often found is to use a vapor retarder on the warm side of the insulation to retard the flow of vapor toward the exterior. A PRM system may be used to minimize vapor and moisture problems. (See *Vents and Vapor Retarders for Roofs*[5] for vapor retarder selection criteria.)

Terminations. The number and type of penetrations through a roof may be one of the determining factors in selecting a roofing membrane. For example, metal roofing is a good material for roofs with few or no penetrations. Modified bitumens, on the other hand, are very convenient for roofs with many penetrations. The detailing of these modified bitumen terminations is relatively easy. The elastomers and thermoplastic membranes are used for roofs with an average number of penetrations and will generally be chosen due to one of their other characteristics.

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[5] W. Tobiasson, *Vents and Vapor Retarders for Roofs*, paper presented at Symposium on Air Infiltration, Ventilation, and Moisture Transfer (Fort Worth, TX, December 1986).

Exhaust. The single-ply products vary in their resistance to chemicals and other contaminants that may be exhausted onto the roof. Chemical exhaust can damage asphaltic products, and some elastomers. Oil-like products are damaging to asphalt, elastomeric, and thermoplastic products. Some membranes have been developed to withstand much more chemical stress.

Fire Ratings. Different buildings require roofing systems with different fire ratings. It should be noted that fire ratings apply to the assembly (deck, insulation, and membrane), not to individual products. Assemblies with different fire ratings may be achieved using the same products. Generally, ballasting and noncombustible decks are important elements in any system with high fire ratings. For further information, see the *Approval Guide*, Factory Mutual System.[6]

*Application*

Training Required. Because of their recent development, training is required to master some of the installation techniques associated with nonconventional roofing systems. The modified bitumens are most closely related to BUR technology, so experience in that type will help. Training is critical for EPDM roofing applications because of the special seaming technique. For metal roofing, some previous metalworking experience is beneficial. Because polyvinyl chloride (PVC) membranes often use a metal accessory for flashing, metalworking skills may also be helpful in these installations.

Ease of Installation. Installation directions are relatively simple. Care must be taken to prepare the substrate on which the membrane is installed. Thermoplastic membranes are normally heat or solvent welded and result in a joint that is stronger than the membrane. However, EPDM joints may require up to four separate steps and result in seams that are weaker than the membrane. The most important considerations in installation are lap joint strength and penetrations. If improperly installed, the system is almost certain to fail.

Verifiability. Verifiability is determining the integrity of the installation, particularly at the seams. It is important for single-ply membranes because they lack performance and design criteria and do not have a long history of use that would allow installers and specifiers to feel comfortable with the new technology. Unlike BUR materials, these products have only one ply; its failure can result in the failure of the roof. This fact requires close inspection and subsequent maintenance. Fully and partially adhered systems are relatively easy to inspect. Ballasted systems are difficult to inspect. Factory marked chalk lines allow installers to determine the accuracy of the lap joining techniques. In many applications, adhesive will squeeze out of the lap joint, indicating that sufficient adhesive or torching has been used. The inspector or installer can usually determine where more adhesive is needed by running a trowel along the seam. Lap joint and flashing seals are essential to ensure watertightness.

Installation Hazards. Many roof application procedures are inherently dangerous. The dangers are magnified in the hands of inexperienced personnel. Torch-welded modified bitumen systems that use open flame can set the structure on fire. The kettle of very hot asphalt used in asphalt systems can burn the workmen. Hot air welded PVC

[6]*Approval Guide*, Factory Mutual System.

systems can subject workers to similar hazards. Other single-ply systems use solvents that are both flammable and toxic. Metal roofs are a very "clean" installation, due to their lack of adhesives, but workers may be severely cut by sharp edges.

Tools and Equipment. Relatively few specialized tools are required for single-ply installations. Mechanical fasteners, which are used in most systems, can be installed using a variety of specialized tools. The modified bitumens may require torches or asphalt kettles and trowels. The metal roofing systems require equipment to attach fasteners. Metalworking tools are also needed for flashing installations. Heat welders and adhesive spreading equipment are needed for PVC and EPDM installations.

*Material Handling*

Moving large amounts of material to and about the job site may be a consideration for some installations. Torch applied modified bitumens are relatively easy to transport, and handle. Hot asphalt applications are more cumbersome because they require an asphalt kettle on the job site. Moving hot asphalt materials can be both difficult and dangerous.

# 3 ROOF INSTALLATION FOR IN-HOUSE REROOFING

## Crew

The roofing crew completes the installation. The individuals must exhibit certain skills and aptitudes. However, it is just as important that the crew function as a unit. To accomplish this, it is necessary to establish authority and communication. Crew characteristics such as pride, teamwork, and careful attention to detail will help make any installation successful.

### *Engineer*

The role of roof engineer is described in AFM 91-36. The engineer must: (1) decide how the work is to be conducted, and (2) describe the work in contract drawings, specifications, and instructions. Engineers have been trained to prepare drawings and specifications very carefully for contracts with commercial firms. It must be stressed that the same care should be shown in preparing for work to be done in-house.

### *Foreman*

The foreman of the roofing crew, usually a roof technician, assumes overall responsibility for the success of the installation. It is imperative that the foreman be trained in the roofing system. The foreman's principal tasks are to assign duties to crew members, delegate responsibility, and verify that the work is done in compliance with the drawings, specifications, and the manufacturer's instructions. The foreman serves as a liaison between the engineer and the crew and should devote attention to the reroofing effort until it is completed.

### *Lead Installer*

Like the foreman, the lead installer must be trained in the roofing system being installed. The lead installer must be in charge of any activity that is critical for successful installation. In many cases, the critical activity is field seaming; in others it is detailing.

Wherever judgment (rather than repetitive activity) is called for, the trained lead installer should assume the responsibility. The lead installer must answer occasional questions from crew members regarding details of how small items of work should be done.

If many crew members are trained, one lead installer should be designated among them. It is often very helpful to assign one trained crew member the responsibility for field seaming and to assign detailing and penetrations to another. For most non-conventional roofing systems, the work is quite neatly divided into field work and detail work.

### *Untrained Workmen*

Crew members who are not trained in installation of a selected system nevertheless are essential to the successful completion of the job. The responsibilities of untrained members include: handling and storing materials, job setup, cleaning, tearoff, procuring equipment and supplies, assisting trained crew members, maintaining equipment, and performing installation chores as their skills allow.

## Support

The success of the installation depends on good planning. The planning effort includes ensuring the participation of many of the following services.

### *Electrical*

Most reroofing efforts require the use of electrical machinery on the roof. The engineer or foreman must first determine the voltage and amperage required and should assume that all of the equipment will be in use at the same time in order to determine the required power. A heat seaming machine for PVC installations is one piece of equipment that operates at 220 volts. Second, the engineer or foreman should determine whether electricity is available at the job site, and at what size of service. Alternatively, he/she should provide power generation equipment sufficient for the expressed needs. The third item is to provide power distribution lines from the point of service to the most distant point of the roof. The lines should be of sufficient size that there is no voltage drop that would be harmful to the machinery that will be used. All connections should be grounded and they should be safe and rated for outdoor use. The power cords must be kept clean, dry, and must be inspected for defects regularly. The cords should lead to outlet boxes that will permit power activities at various distant locations on the roof. Ground fault circuit interrupters should always be used.

It was found during the demonstration installations that many delays and inefficiencies were associated with the failure to provide adequate electrical power. Fuses and circuit breakers were tripped in the building which served the power; cords were not sufficiently long to reach all parts of the roof; boxes did not permit the use of more than one or two pieces of equipment; often the tools performed poorly because of voltage drop.

### *Disposal*

All roofing activities produce debris. This is especially true when old roofing materials or insulation are torn off. The foreman must estimate the quantity of debris and must arrange for trash disposal equipment. Forming a low estimate is a common mistake.

### *Transport, Storage, and Handling*

Materials management is critical in the success of a reroofing mission. The effects of mishandling the material range from delays, to loss of or damage to materials, to damage to the project building. The instruction material for each reroofing system contains information related to storage and transport of the materials. It is very important to follow the manufacturer's instructions precisely.

Modified bitumen manufacturers point to the ease of handling their material. The field membrane comes in rolls, either 36 or 39 in. wide, which can be handled by one person. When one person is handling modified bitumen rolls, the roll edges must be protected from crushing. Rolls of PVC are approximately 5 ft wide and can be handled by two people. They require power equipment to lift onto any roof surface. Rolls of EPDM may be fabricated at the factory so that the largest possible surface area is covered with a single roll. Even the customary 40 ft maximum width of a roll has been exceeded where material transport allows. One crucial concern is the ability of the roof structure to accommodate the concentrated load of a giant EPDM roll. Standing seam metal roof panels require special handling. The panels may buckle if mishandled.

Materials must be stored in secure locations that provide the correct temperature and humidity ranges. Many solvents used in roofing are quite flammable and must be stored in a safe place.

If *heavy equipment* is used to transport the materials, the equipment must be operated by skilled personnel. Although most orders include from 5 to 10 percent overage in square footage of materials, this overage is necessary in order to cut and fit pieces on the roof; it is not intended to allow for damage during handling. If material is damaged during handling, the job will probably have to be postponed until additional material can be delivered.

Every shipment of roofing material will be accompanied by equipment, fasteners, sealants, information packets, bills of lading, and miscellaneous accessories. The person who receives the shipment from the supplier must first verify that the shipment includes all the material on the bill.

*Sheet Metal*

Most low slope roofing projects involve substantial use of sheet metal accessories, including edge trim, gravel stop, flashing, counterflashing, vents, and vent covers. It is most helpful during a roof installation to have access to facilities and raw material to fabricate necessary metal accessories.

*Carpentry*

There are many general carpentry jobs during any reroofing project. It is fortunate that most roofing crews are actually organized as part of the carpentry shop at most bases. Some carpentry duties are listed below.

- Remove and replace damaged sections of roof deck.
- Patch and close penetrations that are not in use.
- Remove and replace fascia, soffit, and eave trim.
- Construct hatches, curbs, and equipment stands.
- Provide temporary staging and scaffolding.
- Prepare jigs and templates.
- Construct edge barriers and implement safety features.

Many of the tools used in reroofing are standard carpentry tools, such as hammers, chalk lines, tape rules, electric drills, hammer drills, and saws. The crew should have ready access to carpentry tools. Time should be provided in the wood shop to fabricate wood roof accessories.

*Plumbing*

It occasionally may be necessary to move plumbing stacks when reroofing. An example of such a requirement would occur in a standing seam metal roof installation where the layout places a seam (rather than the flat of the panel) at a vent. It is often easier to move the vent than to try to correct a layout once it has begun. If roof drains must be repaired or installed, they fall into the domain of the plumbing trades.

## Training

Roofing crews on Air Force bases currently are not trained in single-ply roof installation. Because these systems differ significantly from familiar roofing and carpentry practices, training is essential. Most roofing manufacturers have instituted training programs for installers using their system. Some firms offer 2-day seminars consisting of literature review, audiovisual presentations, visits to job sites, hands-on experience and, at the end, evaluation and possible certification. The seminars may also include information on business management. Other manufacturers (especially smaller firms) have literature prepared and will send trainers into the field in a less rigorous training program.

Air Force personnel will not be able to control the conditions of the training, but they can explain to the manufacturer what they hope to achieve so that goals are set before training begins. Successful training programs involve the following factors.

### *Trainer*

Training involves communicating knowledge and experience. Thus a good trainer must know the product, must have experience with and confidence in the product, and must have good communication skills. During the demonstration installations, the quality of trainers varied.

Trainers should determine the level of expertise and knowledge of the trainees, solicit questions and discussion, conduct the sessions according to a clear and straightforward sequence of presentation, be prepared with supporting material, define any unfamiliar terms, and know how to regain interest if it wanes.

One skill of outstanding importance is the ability of the trainer to invite and elicit questions. It is not sufficient to state that questions are welcome. Instead the trainer must be able to determine if the trainees' understand the material and seek response with a few remarks or questions.

### *Trainees*

It is presumed that the foreman and at least one other trainee have had at least 3 years of technical experience in the sheet metal or carpentry trades.

Roofing system manufacturers differ on the value of prior training in roofing work. One EPDM manufacturer prefers to train those who have no prior background, while other manufacturers claim that previous experience is valuable. In this study, prior training and experience were quite valuable during the demonstrations. Prior training and construction experience permitted the installers to:

- Have a sense of the division of responsibility.
- Know how to use tools.
- Recognize simple matters of safety.
- Understand simple conveying and movement systems (lifting, carrying, etc.)
- Know how to work with parts of the building on the existing roof.

- Follow directions and communicate with one another.

- Understand the overall sequence of tasks.

No more than three individuals should be trained in a system for a given installation. These three may include the foreman, lead field installer, and lead detailer. If more were to receive training, it would tend to detract from the individual attention required. The foreman should select individuals for training based on their ability to learn and their ability to remain attentive to detail.

*Training Materials*

Reference Literature. The essential piece of training material is an instruction booklet. The booklet should explain the principles that govern the performance of the roof and explain the critical concerns at the outset. For instance, a metal roof booklet must emphasize throughout that the thermal expansion and contraction of the components must be accommodated. The booklet should be profusely and clearly illustrated. It should be contained in a sturdy binder so that is can be used as a reference on the site.

The format of the instruction booklet should follow the same sequence as the format of the training sessions. That will increase the trainees familiarity with the booklet and permit greater recall when using the booklet.

Each training session must begin with the trainer making certain assumptions regarding the levels of knowledge and skill among the trainees. It was found during the demonstrations that the trainees needed to be made more familiar with the products and their descriptions. Trainers familiar with their products often called accessories or sealants by their numbers, causing trainees to scramble through the installation booklets to find the appropriate name.

Audiovisual. Movies, video tapings, slide shows, and exhibits are very helpful in providing effective training. Audiovisual methods fill the gap between the fixed, linear qualities of written material and the loose, broad qualities of hands-on experience.

Hands-on Experience. The central part of the training is the hands-on experience. As with any of the practical arts, proficiency arises from "getting the feel" of the material or system being studied. Engineers should specify that hands-on training be an integral part of the training in any system.

*Training Procedure*

Principles, Performance, Behavior. The training sequence must begin with an explanation of the principles that govern the performance of the roof system. For standing seam metal, it may consist of explaining thermal expansion and contraction; for heat-welded thermoplastics, it may consist of explaining how to verify a seam. The trainer should make sure the trainees know what installation procedures to avoid.

Description of Materials. The trainer should make the trainees familiar with the roofing material by explaining what the material can do and what it cannot do. Samples should be passed among the trainees. If the physical properties of the material are described, they should be described graphically, not as test numbers.

Field. The description of the material should lead directly to a description of how the field material is applied and how the seams are finished. A typical seam should be described and its performance should be explained based on temperature, building movement, rain flow, standing water, snow, abrasion, and uplift.

Details. Trainers may choose to explain only how those details that occur on the project roof would be handled. The approach of one manufacturer--to describe three flashings: curb, wall, and pipe--appeared to be satisfactory.

Tools. Installing nonconventional roofing systems involves the use of both common and specialized tools. The operation and features of any specialized tools must be explained in detail, and hands-on experience with any new tool is necessary.

Safety. Each system has specific safety concerns. PVC and metal roofs are very slippery when wet. Torch-applied modified bitumen systems involve the use of open flames on the roof. Hot asphalt can cause serious burns and its fumes can be noxious.

Testing. Essential to the success of training and reroofing is the principle that any activity must be verifiable. The trainer must provide techniques that the trainee can use to assure that the activity (especially seaming) is carried out properly.

## Installation

### *Scheduling*

The organizational requirements of conducting a reroofing are great when compared to the typical operation of a carpentry crew. The roof technician must review the items on the checklist (Figure 2) to ensure that the work flows smoothly.

### *Notifications*

The major command that operates the building to be reroofed must be notified. The notification should give the expected start and finish dates, and a warning that parts of the roof may be exposed during the installation and that the occupants may wish to take measures to protect items inside. Generally, parking lots adjacent to the buildings will be put to use for delivery and temporary storage of materials. The occupants should also be notified that reroofing may create a mess around the perimeter of the building, (especially where a tearoff is involved), and that unpleasant odors may permeate the building.

### *Tearoff*

Tearoff of the original BUR is common in reroofing. Often, leaks have caused the insulation to become wet. Wet insulation should be removed. There is no advantage in saving it. A successful tearoff requires almost as much planning as the installation. The tearoff should be planned so that the area torn off can be reroofed and sealed by the end of the work day. Most roofing crews do not have the equipment, manpower allocation, and organizational structure to conduct a successful tearoff. Because tearing off is hard

| Roof Technician: Checklist for Roof Installation | |
|---|---|
| Has the crew been identified? | Lead installer<br>lead detailer |
| Has the work been scheduled? | |
| Is the material on hand? | Field accessories<br>sealants<br>solvents<br>fasteners<br>special equipment<br>insulation |
| Is the equipment on hand? | ladders<br>hoists<br>torches, kettles, etc. |
| Is safety equipment on hand? | fire extinguisher<br>first aid kit<br>goggles<br>hard hats<br>masks |
| Are all the necessary tools ready to use? | |
| Have arrangements been made for | electric service?<br>rubbish disposal?<br>delivery equipment?<br>plumbing?<br>sheetmetal services?<br>carpentry services,<br>inc. shop work? |
| Must the roof be torn off? | |
| What repair work will be done? | |
| Will insulation be installed? | |
| Have lines of authority been established? | |
| Has training been completed?Have safety measures been taken? | |
| Have safety precautions been reviewed? | |
| Ready to begin? | |

**Figure 2. Roof technician checklist for roof installation.**

and dangerous work, crew members should be equipped with safety goggles, hard hats, breathing masks, and gloves. Steel-toe safety shoes should be worn.

To tear off a roof, loose gravel should be removed. A mechanical broom greatly reduces the effort required for this step. After using a mechanical broom, the remaining loose gravel should be removed completely, using a stiff hand broom, before doing any other work on the roof.

The next step is to cut the membrane into approximately 3-ft square sections that can be carried by one worker. Mechanical cutters may be used, but they are dangerous for the inexperienced and they may damage the deck if set improperly. The spud bars that are typically used, do a poor job of dividing the roof into uniform sections. Using axes to cut the sections is tiresome and dangerous. The most effective device is a push cutter.

*Deck Preparation and Insulation*

If tearoff is not planned, check with the manufacturer to determine what deck materials can be used as substrates for the products. When reroofing over an existing BUR, all wet insulation must be located and removed. Loose gravel should be removed by brushing with a stiff broom or by mechanical equipment.

One method of overcoming the unevenness of the remaining gravel is to apply a flood coat of hot asphalt. A separator sheet of a material specified by the manufacturer can then be used as a substrate for the new membrane. The separator sheet may be mopped in place or mechanically fastened.

Another, more common, method of overcoming unevenness is to use a recover board. A recover board may be asphalt-coated wood fiberboard or pressed fiberglass, usually 1/2 to 5/8 in. thick. Recover boards may be mopped in place or mechanically fastened. They provide a smooth surface to which most membranes can be directly attached.

For reroofing after tearoff, remove debris from the deck and install new insulation. The fasteners must be selected so that the desired uplift rating will be achieved. The wind resistance of the assembly is only as strong as the weakest link. The fastening of the substrate to the deck must be as strong as the fastening of the membrane to the substrate.

*Materials Handling*

The importance of proper materials handling bears repetition. Directions from the manufacturer must be followed so that no damage occurs to the materials or to the building. Single panels of metal roofing must be carried on edge so the standing ribs do not buckle. The edges of rolled material must be protected from damage because of the importance of the edge in field seaming. Large rolls of EPDM must be placed on roofs only where the structure permits such a concentrated load. Volatile and flammable solvents and cleaning compounds must be protected from excessive temperatures and open flame.

*Laying Out*

Placement of the first roll or panel of roofing material is critical. While some materials such as modified bitumen allow some correction for misalignment as the work progresses, others, particularly standing seam metal, allow practically no correction. Installation of the field materials should be planned in advance to avoid seams at penetrations.

*Field Installation*

The principal criterion for the installation of the roof field is careful attention to seams. In all of the single-ply systems, installers get a sense that the application goes quickly. It does, but each seam should be completed properly and methodically and then verified.

The field work in single-ply systems is very clean. This property alone is a delight to roofers accustomed to working with hot asphalt. It is important to minimize the amount of traffic from the old section of the roof onto the new because the exposed surface can be abraded or torn by gravel on the bottoms of shoes and may be contaminated by the asphalt carried on the shoes.

*Details*

The measure of success of the installation is found in how details, terminations, and penetrations are handled. Manufacturer's literature should illustrate and explain how each termination is to be performed. Installers must follow these directions carefully. Detail work must be done slowly.

## 4 DEMONSTRATION INSTALLATION AT FOUR TEST SITES

Four systems were selected for demonstration. The locations represent a range of climate conditions. The four systems, locations, and installation dates are:

1. A ballasted PVC (plastic) roof at Wurtsmith AFB, Oscoda, MI, September 1987.

2. A self-adhering modified bitumen roof at Robins AFB, Warner Robins, GA, October 1987.

3. A standing seam concealed fastener metal roof at Gila Bend AFS, Gila Bend, AZ, January 1988.

4. A mechanically fastened EPDM (rubber) roof at McChord AFB, Tacoma, WA, July 1988.

Table 1 is an information matrix for the installations.

### Ballasted PVC

*Building Description*

The demonstration roof at Wurtsmith AFB was approximately 3200 sq ft. The deck was prestressed reinforced concrete. Prestressed concrete decks are hard (making the use of mechanical fasteners impractical) and strong (permitting additional loads). Because of the deck structure, a ballasted roof installation was selected (Figure 3).

The roof details included: edge flashing, one length of wall flashing, two plumbing vents and an expansion joint that required the reroofed section to be joined to an existing BUR.

**Table 1**

**Information Matrix for Four Roof Installations**

| site | system | area square feet | crew size | time work days | critical operation |
|---|---|---|---|---|---|
| Wurtsmith AFB | PVC thermoplastic | 3200 | 10 | 20 | heat seaming |
| Robins AFB | Modified bitumen | 7000 | 7 | 14 | sheet alignment |
| Gila Bend AFS | Standing Seam Metal | 4700 | 7 | 20 | termination detailing |
| McChord AFB | EPDM | 5600 | 9 | 21 | lap seaming |

*Product Description*

The PVC membrane installed was a reinforced thermoplastic membrane. Seams were made using forced hot air which melts and welds adjacent faces of the membrane. Field seaming was done using a self-propelled hot air seaming machine. The membrane was joined to the PVC-coated metal flashings and penetrations using a hand-held hot air gun.

*Training*

Training was conducted at Wurtsmith AFB on August 31 and September 1 (just before the installation) by a technical representative of the manufacturer. Three members of the carpentry crew received training.

The training focused on the use of hot air guns (Figure 4) to make acceptable seams. The technique requires dexterity and thoroughness. The trainee must insert the hot air nozzle between two surfaces of membrane for the proper amount of time until the surfaces just begin to melt, then move the nozzle slowly at the proper rate so that the melting is even and of the proper depth. Meanwhile, the other hand rolls a hand roller (Figure 5) back and forth across the seam at a certain angle to force the surfaces together (Figures 6 and 7). The trainees needed to learn how to perform these operations with alternate hands. (It was common to see the trainees rolling the hot air gun while

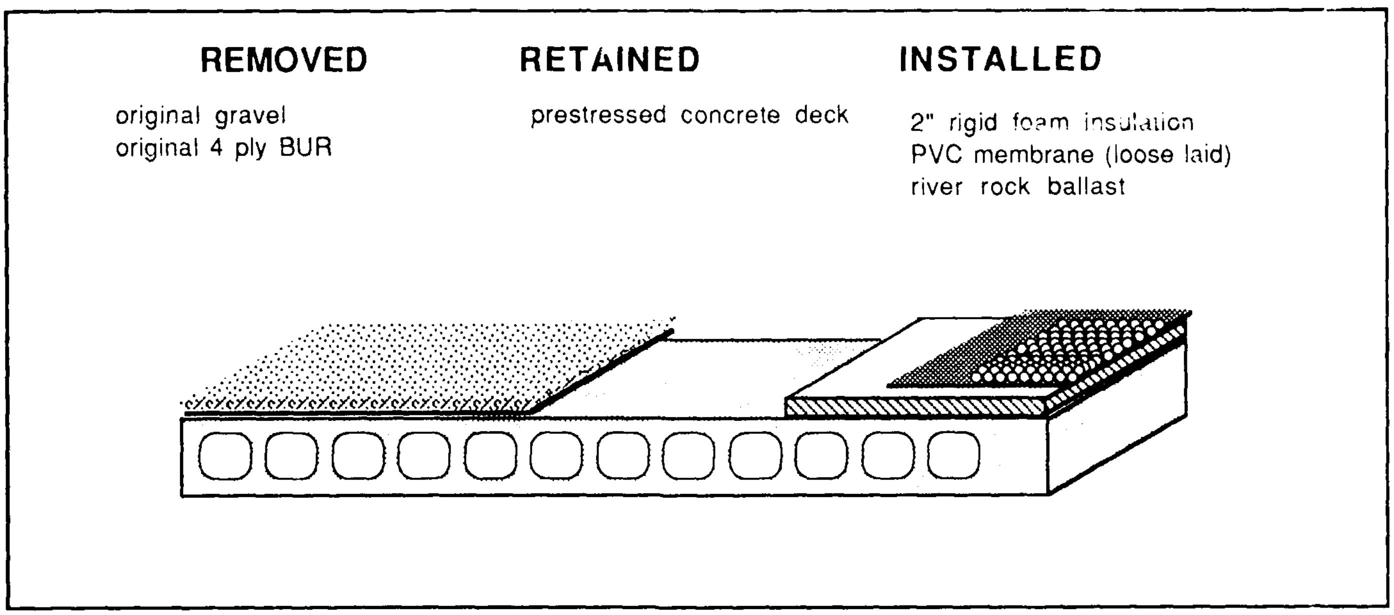


**Figure 3.** **Schematic of a ballasted PVC membrane installed over a prestressed concrete deck.**

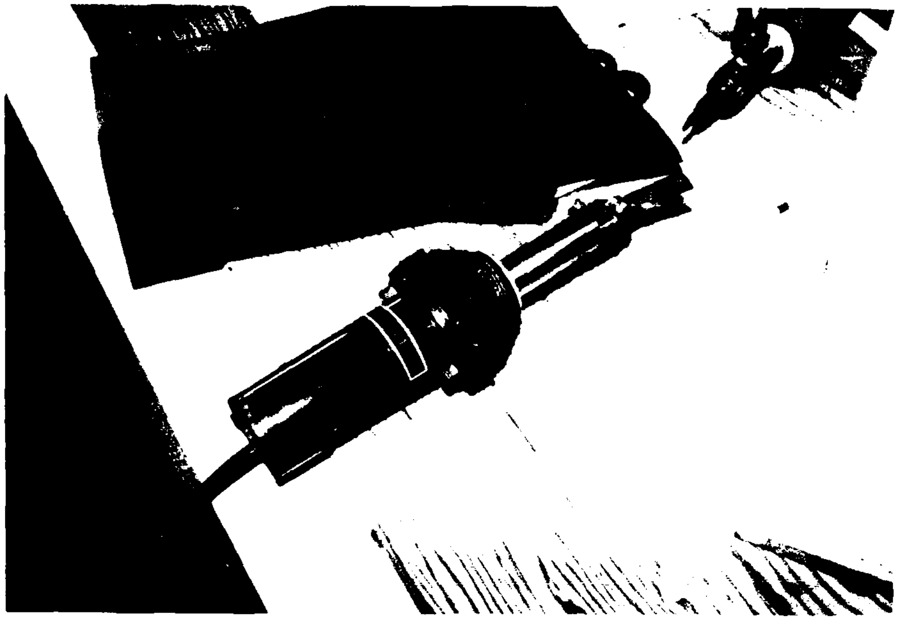

Figure 4. A hot air gun was used to weld PVC membrane seams.

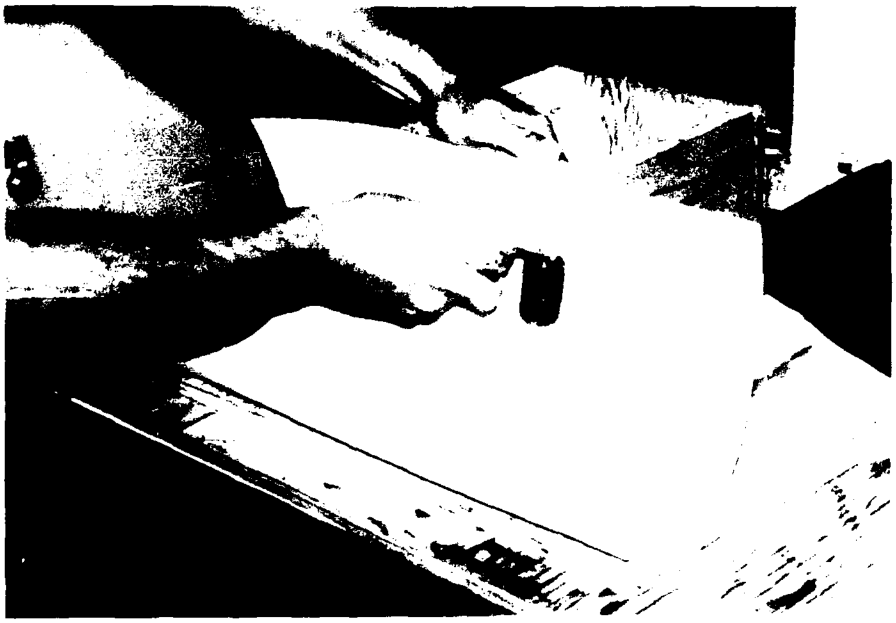

Figure 5. A roller was used to press heated membrane sections together.

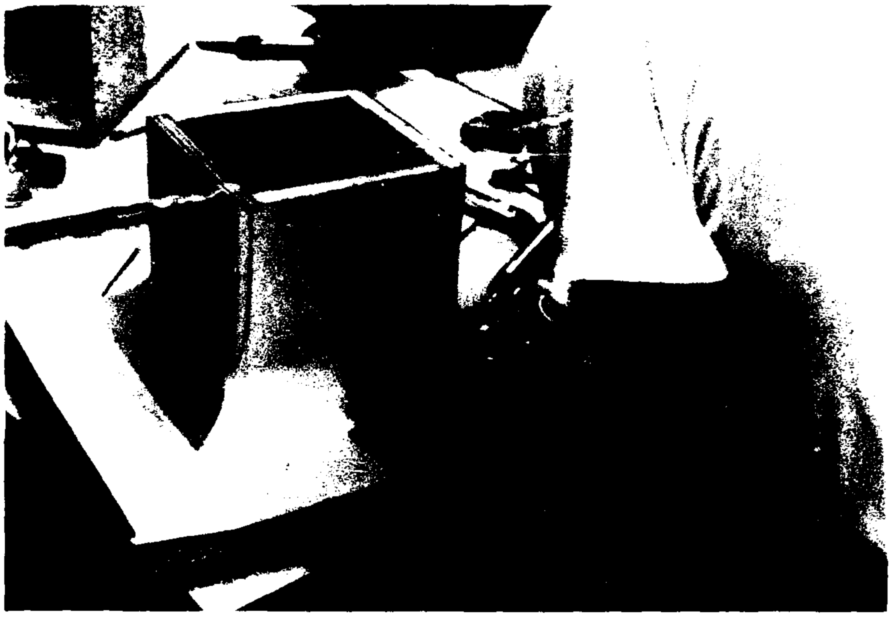

Figure 6. Hot air welds of the PVC membrane on a test curb.

Figure 7. Hot air techniques involve manipulating the hot air gun and roller simultaneously.

moving the roller slowly.) After 2 days of training, the trainees had mastered the welding techniques.

The trainees constructed pipe stems (Figure 8) and plywood forms for curbs, inside, and outside corners. Membrane material was adhered to the curbs with adhesive and seams were completed. The trainees learned to distinguish good welds from bad by the shape of the material that flowed at the seam. The underside of the membrane is a darker color than the upper side, so the presence of a dark, even line at the seam was expected. Poor welds were evident (Figures 9 and 10). The trainees also learned to tack material in place using the hot air gun and thumb pressure.

*Installation*

The existing roof was a gravel-topped BUR over high density fiberglass board insulation. The gravel was swept from the roof (Figure 11). A mechanical cutter was leased so the roof could be cut into sections and removed (Figure 12). The cutter was unreliable and was not used after the second breakdown. Further cutting was done by hand. Disposal of roofing materials was a problem. The quantity of gravel and other debris was much more than estimated. The dumpster was filled faster than it was emptied. The tearoff took much more time than expected.

The first step in the installation was to build up the perimeter edge with wood to the eventual height of the top surface of the insulation. A powder-activated fastening system was used to fasten 2 by 4s to the prestressed concrete panel deck. Then 1 by 4s

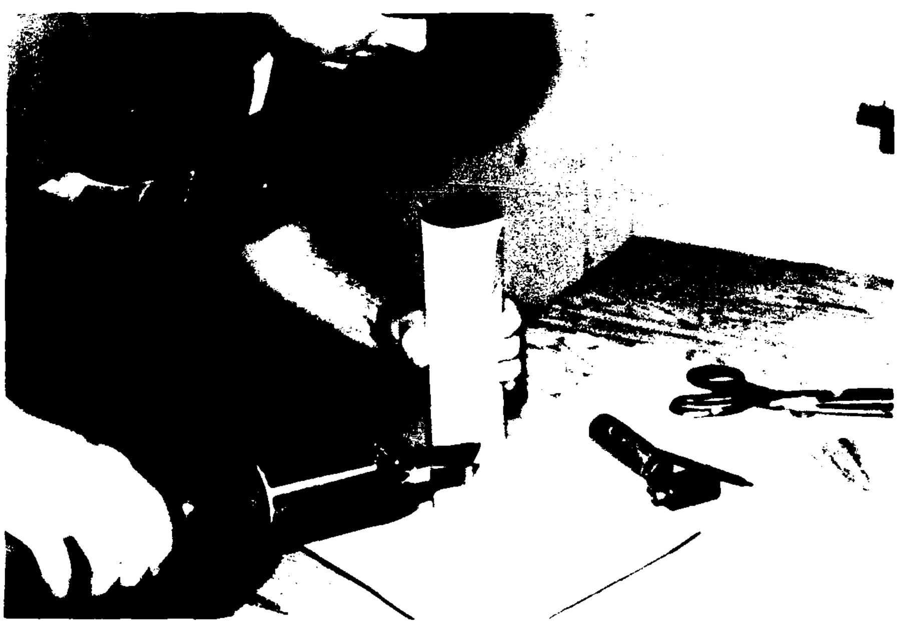

**Figure 8. A pipe stem constructed during training and later used for the installation.**

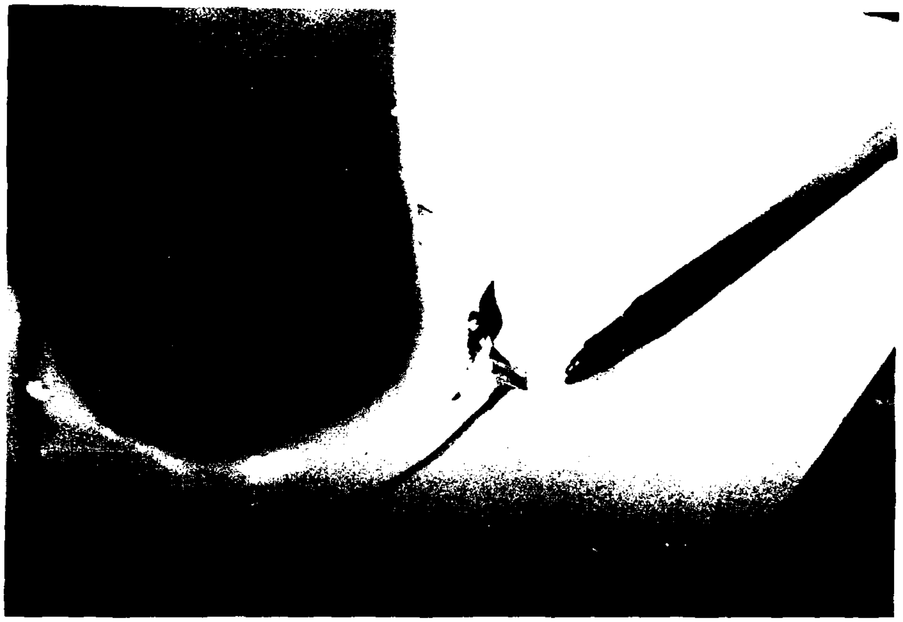

Figure 9. Poor weld due to local overheating of flange at the bottom of the pipe stem.

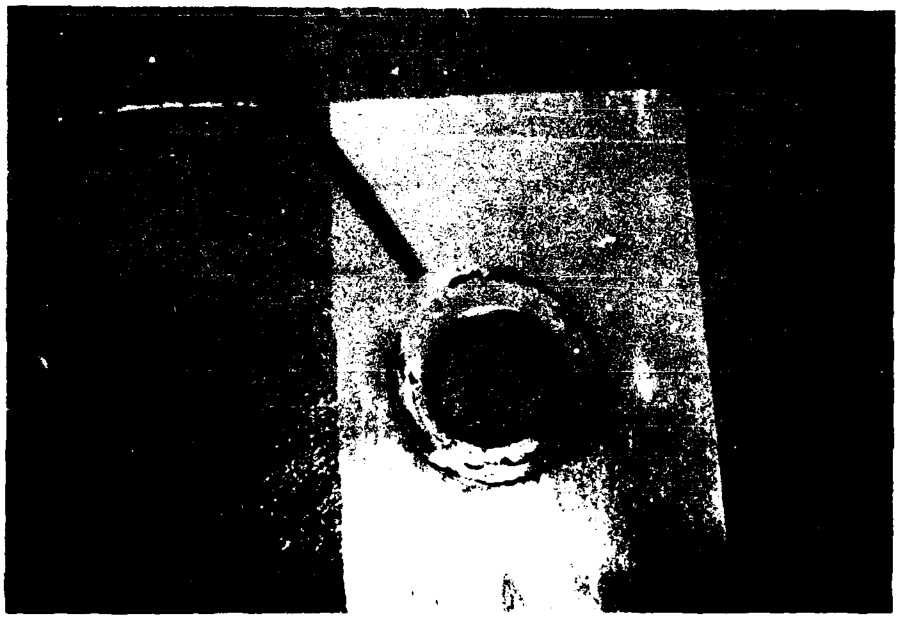

Figure 10. Poor weld in test pipe stem due to uneven application of heat at the flange.

Figure 11. Gravel being removed by shoveling and brooming.

**Figure 12. Mechanical cutter being used to separate sections of old BUR.**

were nailed to the 2 by 4s (Figure 13). Rigid foam insulation panels 2 in. thick were laid on the cleaned deck (Figure 14). They were not fastened in place because the weight of the ballast provides the uplift resistance for the entire system.

The roof was laid out carefully starting at the lower edge (Figures 15 and 16). The rolls of membrane were laid in place with a 3-in. lap. The edge was temporarily nailed in place at the fascia (Figures 17 and 18). Next, the seams were cleaned and dried (Figure 19). The machine seamer, a self-propelled device that blows a hot air stream at the lap, and which has a weighted roller wheel behind to compress the weld, was used for all lap seams. The machine rolls on specially prepared metal sheets laid directly on the membrane (Figures 20, 21, and 22).

The roof edge material consisted of 10-ft metal edging pieces with a PVC cladding which will accept heat welds to the plastic membrane. The metal was nailed in place at 3-in. centers (Figure 23) using nails with compressible washers. Each of the joints in the edge metal was reinforced using a patch cut from the membrane roll (Figure 24). The inside and outside corners were likewise reinforced (Figures 25 and 26).

Plumbing stacks were covered with pipe stems constructed during training (Figure 27). The wall flashing required the application of a thick fleece as a separator between the wall (which contained bitumen products and had sharp edges) and the roof membrane (Figures 28 and 29). Adhesive was applied to the fleece liner. The membrane was fastened to the wall through the fleece using a metal strip and screw fasteners (Figure 30). The metal strip was then covered with membrane material welded above and below the metal strip. New metal counterflashing was fabricated and installed to complete the installation.

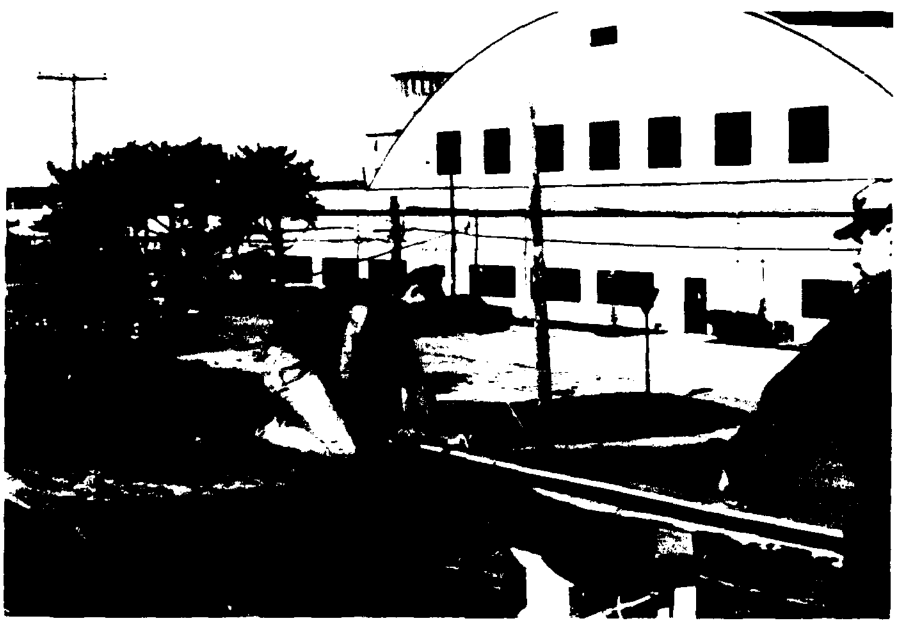

**Figure 13. Pressure treated lumber nailed to the roof edge.**

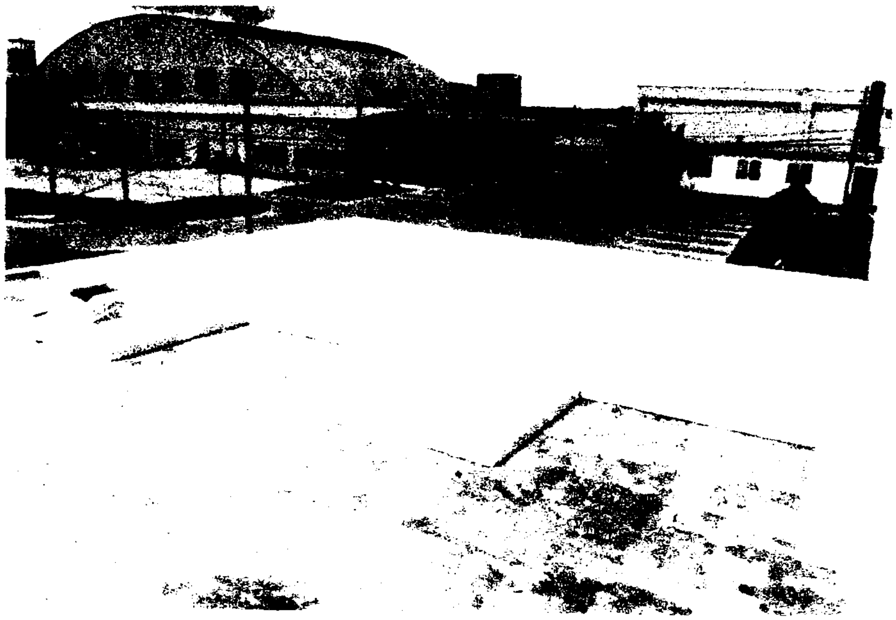

Figure 14. Rigid foam insulation laid in place.

Figure 15. Careful measurements are needed to place the first roll of membrane.

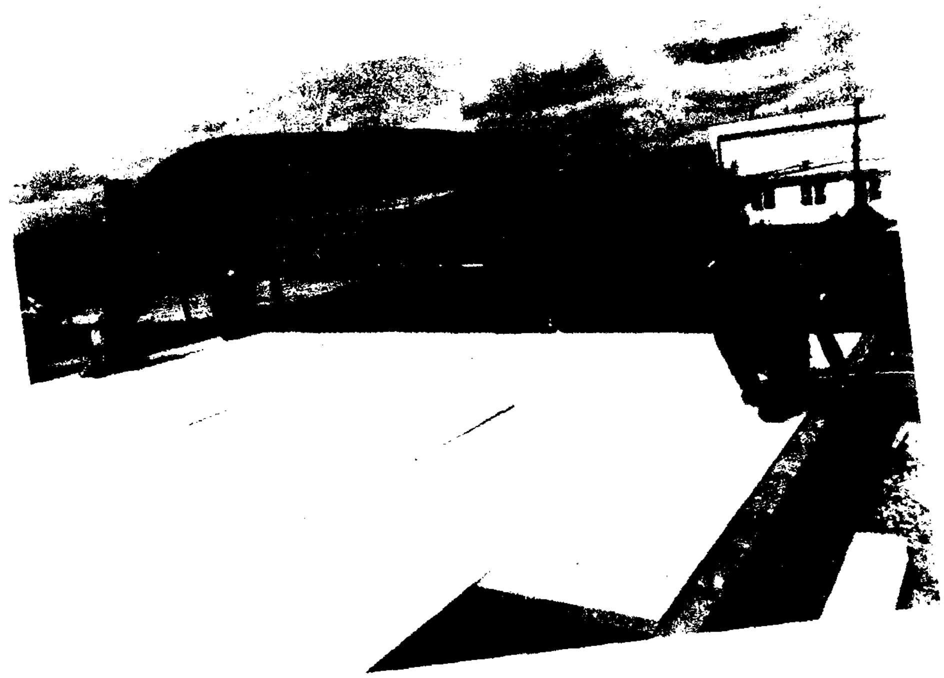

Figure 16. A chalk line is used as a guide for the first roll.

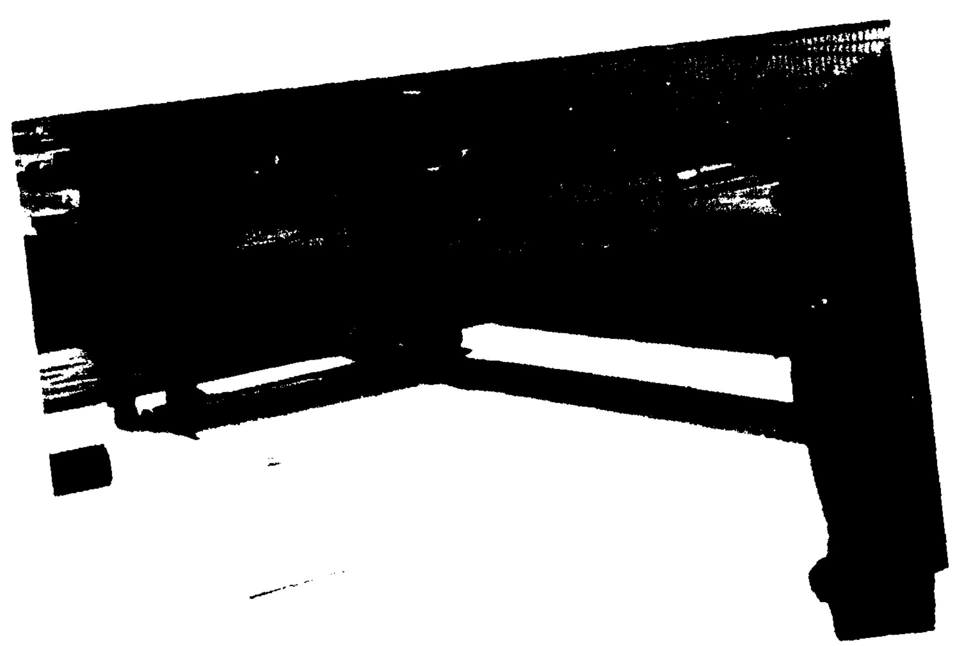

Figure 17. The first roll is laid in place and cut to length.

Figure 18. The membrane edge is temporarily held in place by nailing it to the wood fascia.

Figure 19. Seams must be dry before machine seaming.

Figure 20. Heavy gauge metal plates are laid next to seams.

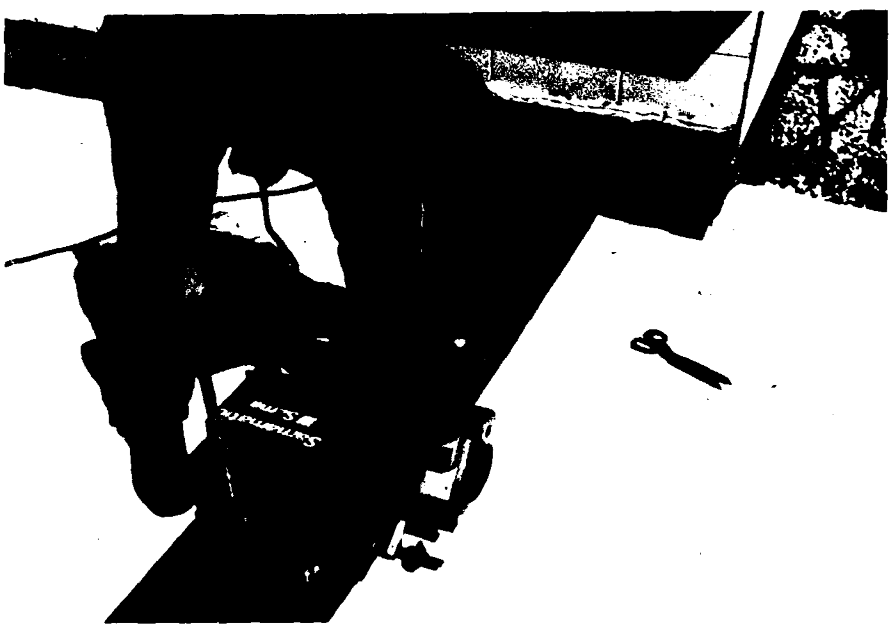

Figure 21. The seaming machine must be regulated for speed and temperature.

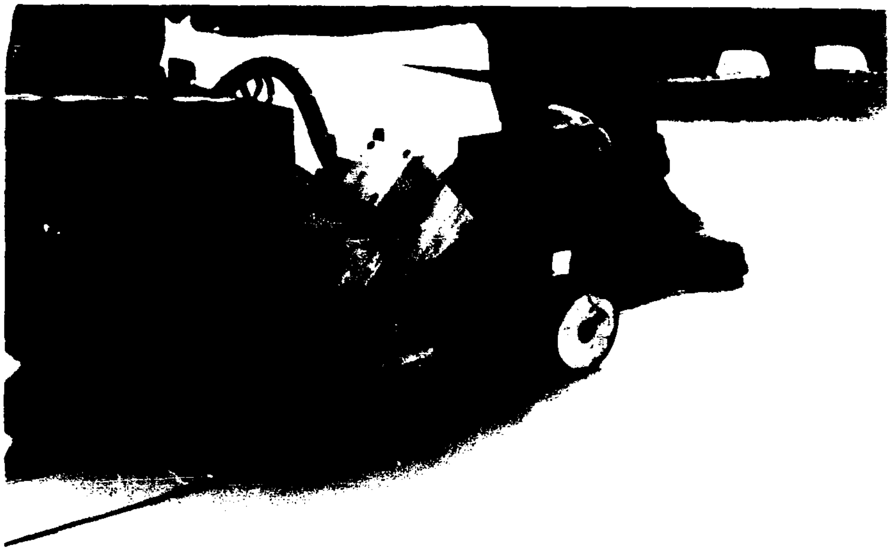

Figure 22. The seaming machine is self propelled.

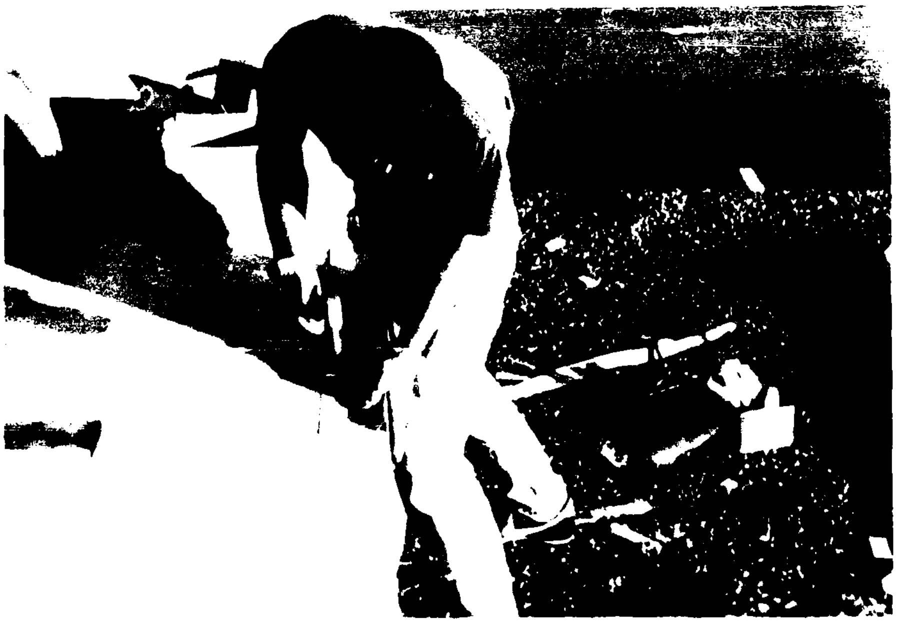

Figure 23. The edge metal is nailed in place.

Figure 24. Joints in the edge metal are reinforced with membrane scrap.

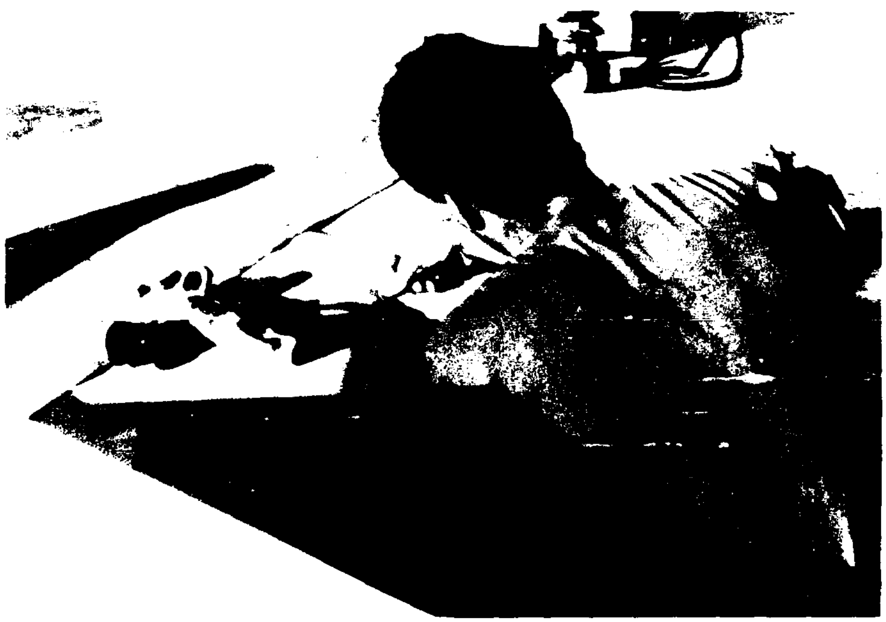

Figure 25. Inside corners are reinforced with membrane scrap.

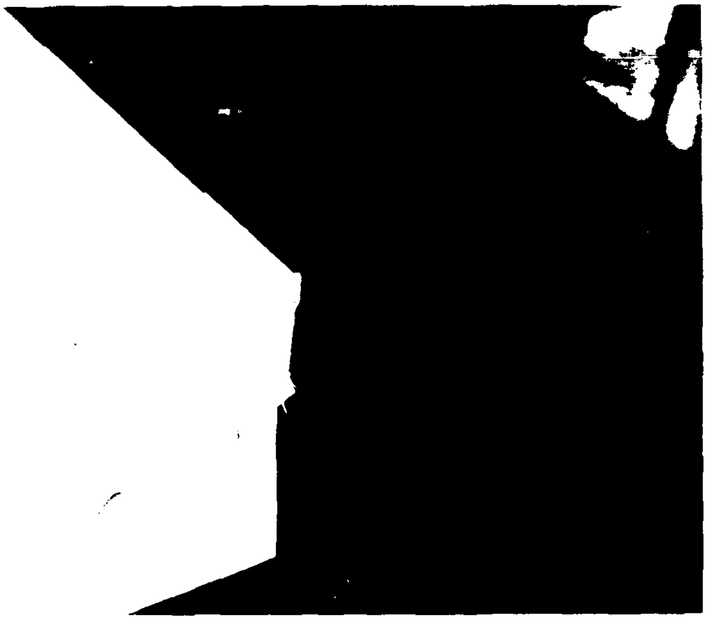

Figure 26. Outside corner of the edge metal is reinforced.

Figure 27. Pipe stem ready to be installed.

Figure 28. Adhesive is applied to the fleece liner before installing beneath wall flashing.

Figure 29. The fleece liner in place.

**Figure 30. A metal strip is fastened through the membrane to secure it.**

An expansion joint was required between the reroofed section and an existing BUR section. The section edges were built up to the membrane level with treated lumber (Figure 31). The membrane was run over the wood trim. Solid compressible foam tubing (pipe insulation cover) was placed in the joint and the foam was covered with a layer of membrane which was welded to both sides (Figure 32). The PVC membrane was embedded into the BUR with cold mastic adhesive.

Round river gravel, 1- to 2-in. diameter, was used as the ballast. This material may be difficult to locate in some regions but was readily available for this installation from a local supplier. (The gravel used for ballast must be smooth to avoid abrading or cutting the membrane surface, and must be large to avoid wind scour.)

*Results*

The installation was successful despite some difficulties encountered. A clear chain of command was not established and responsibilities were not well defined. The foreman did not exercise authority over the crew. Consequently, the work was done by unintended participants--primarily the manufacturer's representative and two very conscientious crew members.

Delays were frequent, and tearoff consumed a lot of manpower. The installation was scheduled to begin before the last half of the roof had been torn off.

A thunderstorm occurred with little warning and the roof was poorly closed in. There were several leaks into the building. Some of the insulation boards became wet and had to be removed and dried. Many of the details were not completed until the second week of installation.

Figure 31. Wood blocking is used to bring an expansion joint to membrane level.

Figure 32. Membrane material is used to form the expansion joint.

Because some of the lap seams could be pried apart, the temperature and speed of the machine seamer were adjusted so that the seams were more tightly welded. The completed seams were reinforced with membrane strips at the suggestion of the roof engineer.

Despite these difficulties, the two crew members who applied themselves during training displayed expert skills during installation. The manufacturer's representative concluded that their training had been a success.

**Modified Bitumen**

*Building Description*

A modified bitumen roof was installed on the tire shop at Robins AFB, Warner Robins, GA, in October 1987. The existing deck was wood, and there were no penetrations (Figure 33). The roof size was approximatley 7000 sq ft.

*Product Description*

A modified bitumen membrane is a blend of asphalt and polymer formed into a sheet. The membrane is usually reinforced and often has a coating. The sheets come in rolls about 1 yard wide and approximately 10 yards long. Modified bitumens may be applied to the roof by many methods including torch-applied, hot mopped, cold mopped, and self-adhering. In Europe, where modified bitumens were developed, they are applied to provide multiple coverage. In the United States, it is common to apply a single thickness of the membrane.

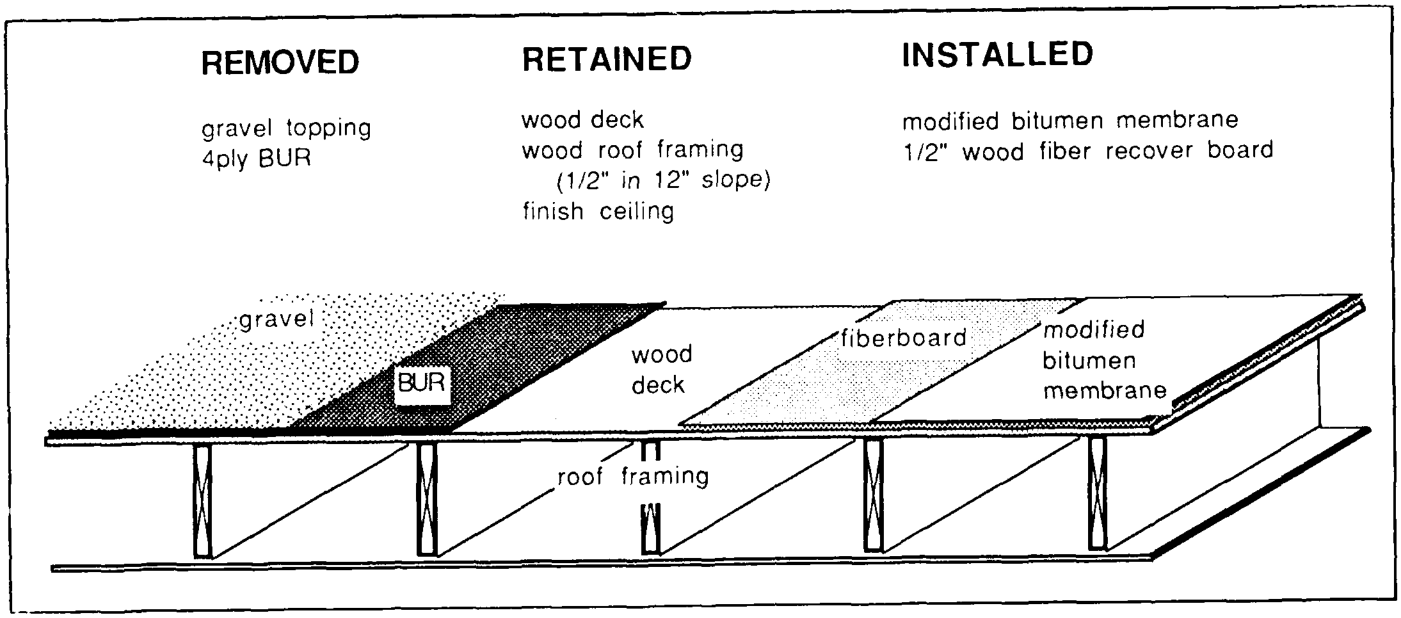


**Figure 33. Schematic of self-adhering modified bitumen installed over wood deck.**

The material used for this installation was a self-adhering Styrene-Butadiene-Styrene (SBS) membrane. The upper surface is a tedlar and aluminum facing. The product contains a polyester scrim. SBS itself is the polymer that serves both as product modifier and adhering agent. The product is applied by removing the release paper, exposing the sticky underside surface, and laying the membrane in place. Pieces and strips of the membrane are cut and used as flashing materials.

*Training*

Training for two workers was conducted at the company headquarters about 4 months before the installation. The training consisted of visits to two site installations and hands-on work with the roofing product in a shop space. The training session was not monitored.

*Installation*

The original BUR was removed to expose the deck (Figure 34). The deck was repaired and pressed fiberboard panels were fastened to the deck to serve as substrate for the roofing material (Figure 35). Edge metal was fastened around the perimeter with roofing nails at 12-in. intervals. (Figure 36). The bare metal was primed with a liquid SBS adhesive.

Rolls of the material were approximately 3 ft wide and 30 ft long. The sequence for installation described by the manufacturer and shown during training is as follows: (1) unroll the entire roll then reroll half, (2) slit the release paper near the middle of the roll with a roofing knife, (3) have one person stand on the sheet while a second pulls the

**Figure 34. Gravel is swept and the old BUR is removed.**

Figure 35. Fiberboard panels are fastened to the deck to serve as recover board.

Figure 36. Edge metal is nailed in place.

release paper away from the slit and a third guides the roll into position, (4) use a broom to "sweep" the roof material into adhesion. The material is quite sticky, but it still may be lifted up from the substrate if necessary.

After several tries with this method, it was found to be inadequate. The rolls did not unroll in a straight line and the guide lines printed on the sheet were inconsistent. The rolls had to be lifted and replaced a few times before the edges formed a straight and consistent line. As a result, the adhesion was reduced. The ends of the rolls were buckled and left a poor quality surface. One crew member developed a method that overcame these difficulties. Using this method (1) a line was snapped on the substrate as a guide at the uphill edge for each roll (2) the release paper was removed from the first 1 ft of the roll, and that first 1 ft was put in place, forming an overlap of at least 6 in. (3) the membrane was rolled into place. Unrolling was done by three crew members: one held the roll and walked backwards and placed the new membrane along the snapped line in 3-ft increments; the second, walking on the new surface, held the 3-ft lengths of release paper; the third followed behind and pressed the membrane in place (Figure 37). In this way, alignment of the roll could be assured every 3 to 5 ft.

Full adhesion at the seam and adhesion of the membrane to the deck was obtained by rolling with a small roller (Figure 38). The person who pushed the roller also gathered the torn-off sections of release paper and disposed of them.

This method made excellent use of the manpower, provided a sure method of alignment, and overcame difficulties associated with irregularity in the material. It is much to the credit of the crew that the method was a result not of training, but of their ingenuity.

**Figure 37. The membrane is pressed into place after removing the release paper.**

**Figure 38. A small roller is applied to increase the membrane's adhesion to the deck.**

*Results*

The reroofing was begun as tearoff was continuing upwind from the new membrane installation. Because tearoff creates so much dirt and debris the adherence of the membrane to the substrate was unquestionably affected, despite continuous efforts to sweep the substrate before installation.

The rolls of modified bitumen material were not of consistent quality. A guide line was marked on the upper surface of the membrane to assure proper lapping of the sheets. However, the distance of this line from the edge varied as much as 2 in. from roll to roll (Figure 39). Installers had the choice of maintaining either an even line from one roll to the next, or an even edge, but not both.

The rolls were not all of uniform thickness. Production errors resulted in large buildups of bitumen along some edges (Figure 40). This made it difficult to obtain clean lap seams. The ends of the rolls were not flat. The upper surface was badly bunched and it was often cut off because it was so "crinkled."

Although the product was not of consistent quality and the quality of the installation was compromised because of the presence of much dust following the tearoff, the installation was conducted very conscientiously. It demonstrated that the aptitudes of the crew exceeded the expectations of the manufacturer.

Figure 39. Membrane edge showing uneven application of guide lines on different rolls.

Figure 40. Buckles in product thickness made even application difficult.

## Standing Seam Metal Roof

### *Building Description*

The project building at Gila Bend AFS, AZ had a BUR with gravel topping. The deck was wood with a slope of approximately 1/2 in. to the foot. A ridge was part of the original deck construction. The building structure was sufficient to allow the gravel to remain on the roof while bearing the additional weight of the new metal roof. There were only two plumbing stack penetrations (Figure 41). The installation was conducted in January 1988. The roof size was approximately 4700 sq ft.

### *Product Description*

The standing seam metal roof system used for this installation was made of medium-gauge steel with an electrolytically applied coating of zinc and aluminum (Zincalume). The panels are 16 in. wide and are sent to the job site in specified lengths. Accessories include Z-purlins, ridge members, eave trim, and sealants.

The panels are joined at the panel rib using a series of bends that permit triple lapping at the seam (Figure 42). The line where the panels meet is 1-1/2 in. above the plane of the roof. A bead of sealant is compressed within the rib. The seams are joined temporarily using a crimping tool (Figure 43) and are finished using an electric seaming machine. The panels are held to the roof by panel clips. The demonstration roof product used a two-part clip. The bottom part was fastened with screws to the metal substrate while the upper part of the clip was embedded in the rib. The two parts can slide with respect to each other, permitting elongation and shortening of the panel under thermal changes without compromising the hold-down of the fastener (Figure 44). The panels were ordered in exact lengths (Figure 45). This required accurate measurement of the roof dimensions to within 1 in.

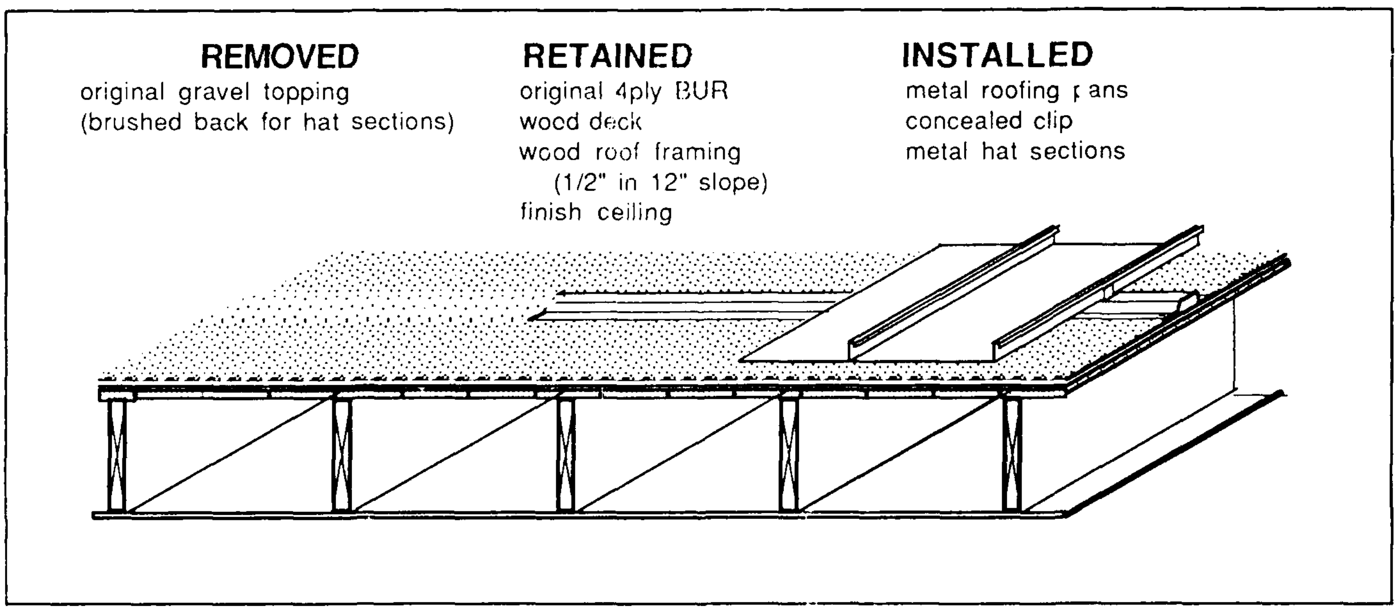


**Figure 41. Schematic of standing seam metal roof installed over wood deck.**

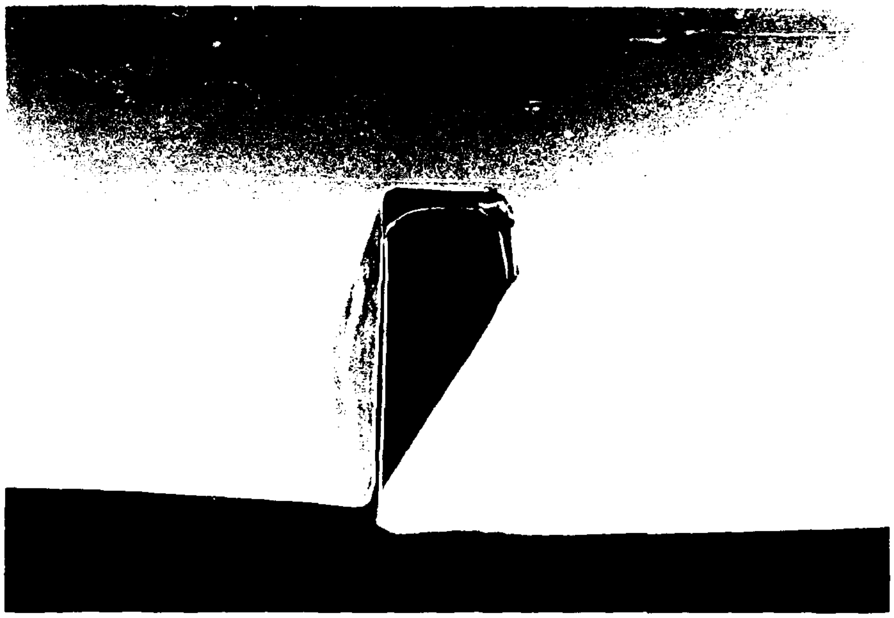

Figure 42. Standing seam metal roof rib.

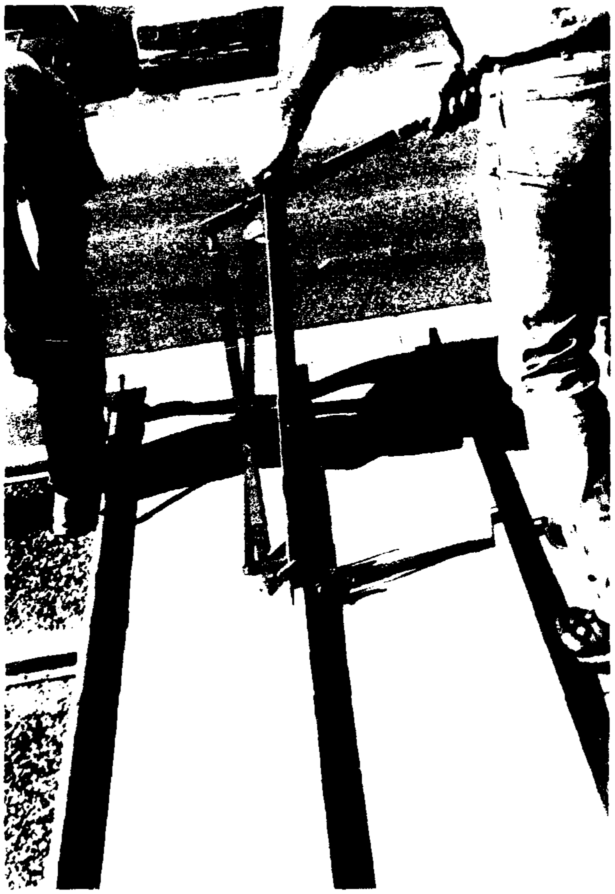

Figure 43. A hand crimper is used to temporarily join the panels until machine seaming.

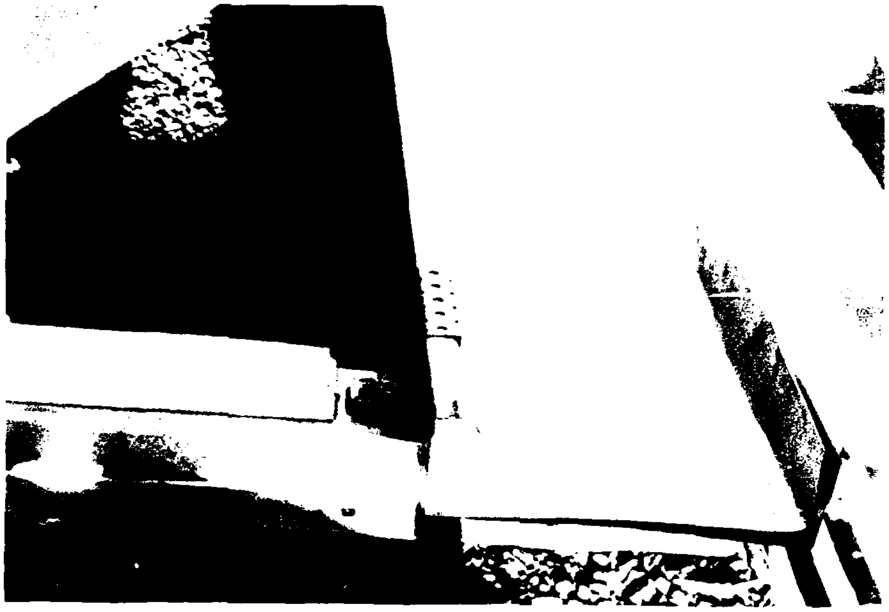

Figure 44. The metal roof uses a clip screwed to the substrate.

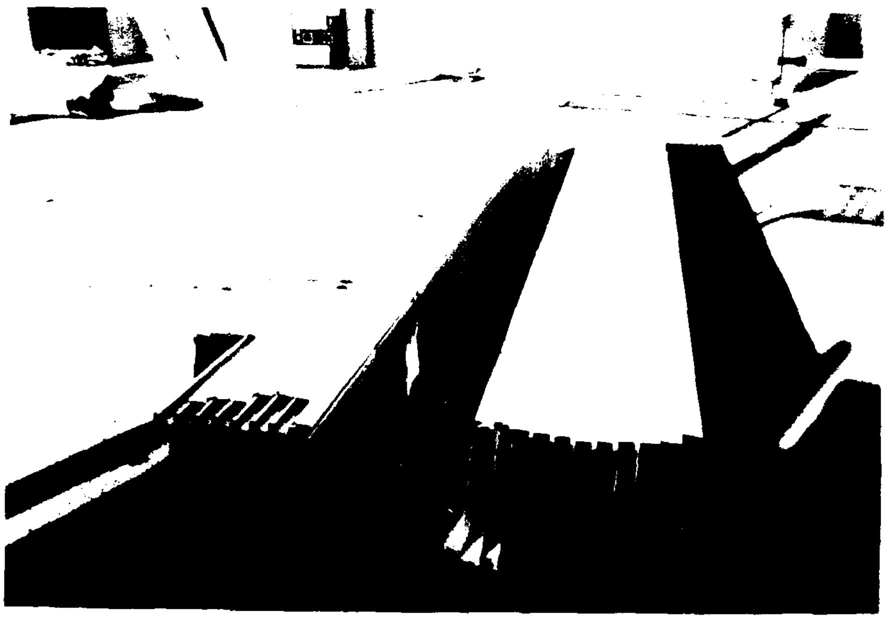

Figure 45. Roof panels are delivered to the site already cut to length.

*Training*

Training was conducted in a conference room on the base for the entire 8-person crew. Reference materials were distributed but there were no audiovisual aids and no product available during the training. Training lasted only 3 hours and installation began immediately afterwards.

A technician was sent by the manufacturer to provide instruction and to oversee the construction. By chance, one crew member had previous commercial experience with installation of the same roofing system.

*Installation*

Gravel was removed from the roof at strips running across the slope located 5 ft apart (Figure 46). Purlins were installed in these strips by screwing 10 ft lengths of U-purlins directly to the roof deck. The roof panels span the 5 ft between purlins.

Placement was planned before setting the first panel to ensure that the panels terminate correctly. (Figure 47). This placement allowed the plumbing stacks to penetrate the centers of panels so that the ribs did not need to be cut and allowed the final panel rib to be included in the wall flashing. Styrofoam spacers were used between the purlins and panels, primarily to prevent noise from thermal expansion.

The field installation (Figure 48) went very quickly. Two workers carried the individual panels by grasping the rib so that the panel did not buckle. They hooked the rib of each panel to the previously installed panel and rolled it downward into place. Then they placed clips at each purlin and fastened them with two screws. They used a hand crimper to lock the panels together (Figure 43). Each panel was securely fastened at the ridge (Figure 49), allowing it to move freely at the eaves. Close tolerance was required in placement of the ridge ends of the panels to allow proper alignment of the ridge cap (Figure 50).

The roof was relatively simple to install because there were few penetrations. The only details were: ridge, edge (Figure 51), two pipe stacks (Figure 52), and wall flashing (Figure 53). The most difficult detail to execute was the wall flashing. The roof was laid out such that 12 in. remained between the rib of the last panel and the counterflashing at the wall. Generally, the panels must be hooked and rolled into position. But in this case, rolling was impossible because the flashed end had to be installed first. This led to some distortion in the final rib, which was effectively closed by machine seaming.

The reentrant corner shown in Figure 54 proved quite troublesome. The cut at the reentrant corner propagated into a tear because of the lack of a supporting substrate beneath and because the panel was forced into place. A serviceman proposed cutting a quarter section from a rubber boot and using the remaining boot to cover the flat of the panel and the corner at both walls.

*Results*

The roof installation was considered successful by the manufacturer's representative and by the roof technician.

The training session was brief, delivered to a large crowd, and lacked instructional materials. The trainer was quite familiar with the products, but sometimes described them in ways that the trainees could not comprehend. The principal benefit of the

Figure 46. The surface is prepared by scraping the loose gravel so that steel purlins can be screwed to the deck.

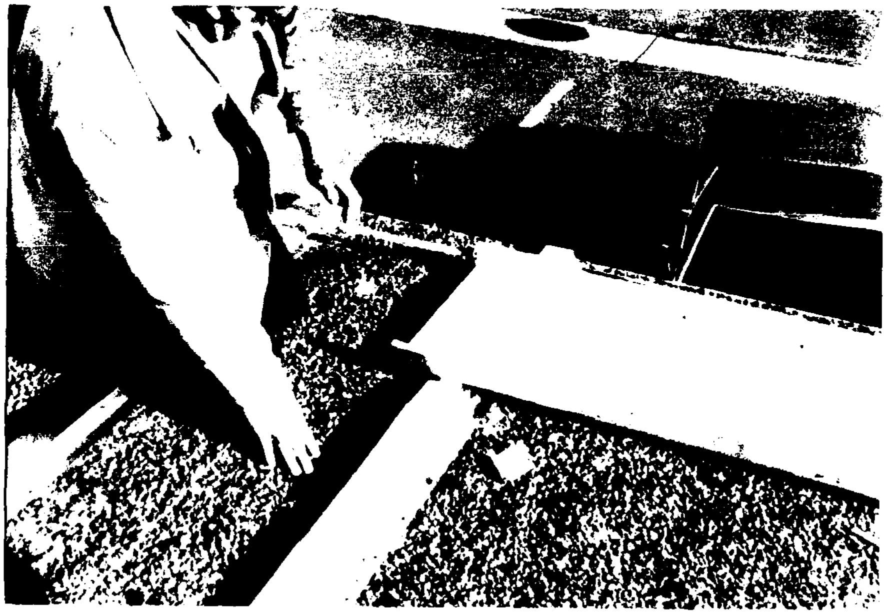

Figure 47. Placement of the first panel determines where each later panel will fall.

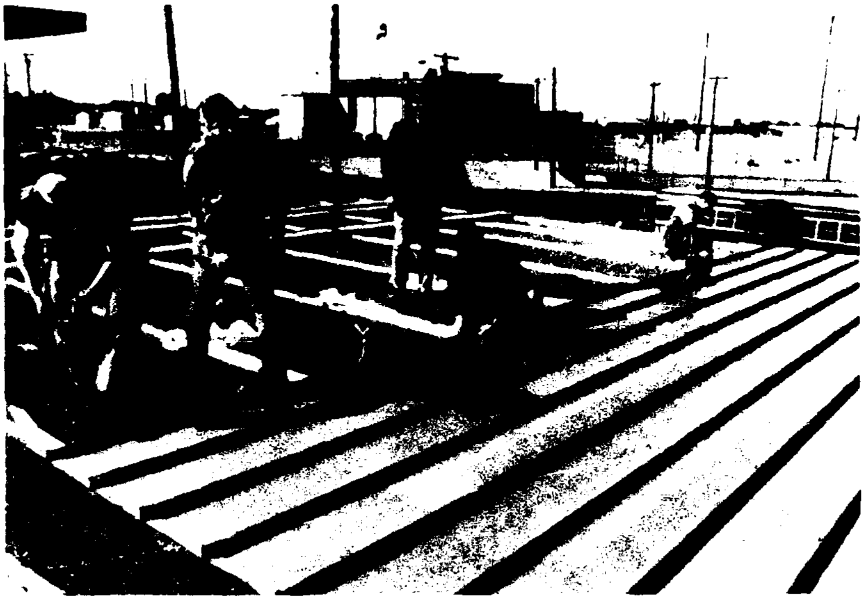

Figure 48. Once the installers become accustomed to field seaming, work progresses quickly.

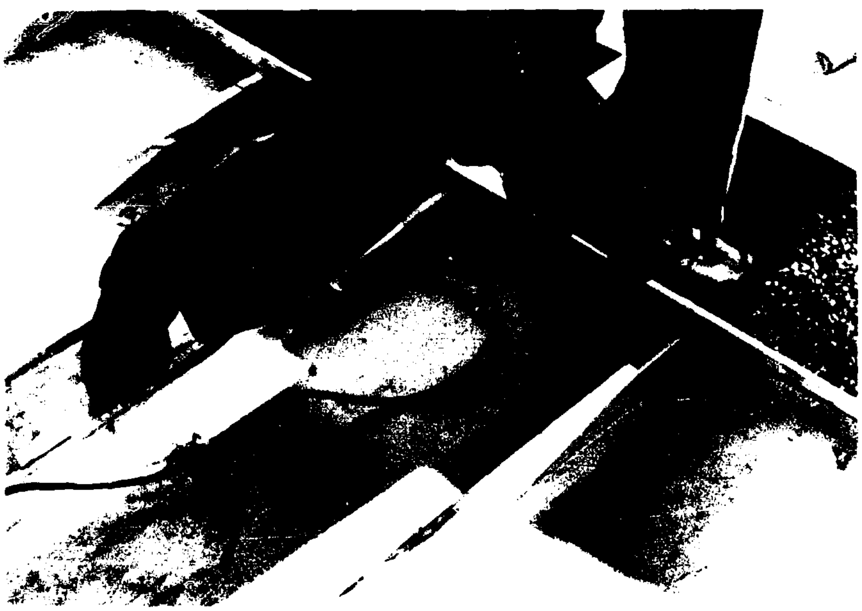

Figure 49. Panels are fastened rigidly to the roof only at the ridge.

**Figure 50. A ridge cap is installed.**

**Figure 51. Edge trim is installed at the gable edge.**

Figure 52. A rubber boot that can be cut to fit pipe of different diameters is used for pipe flashing.

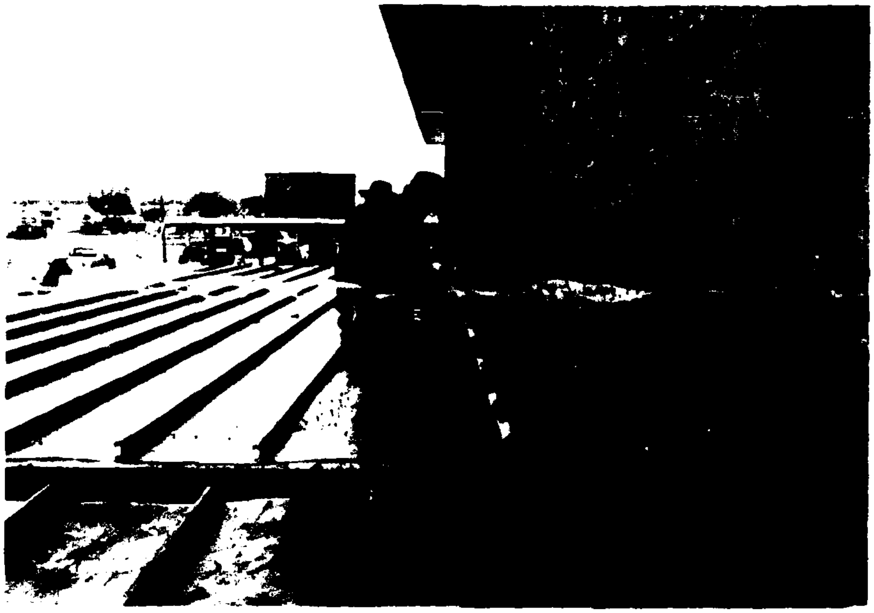

Figure 53. The wall flashing uses a 4-in. turned-up panel edge beneath existing counterflashing.

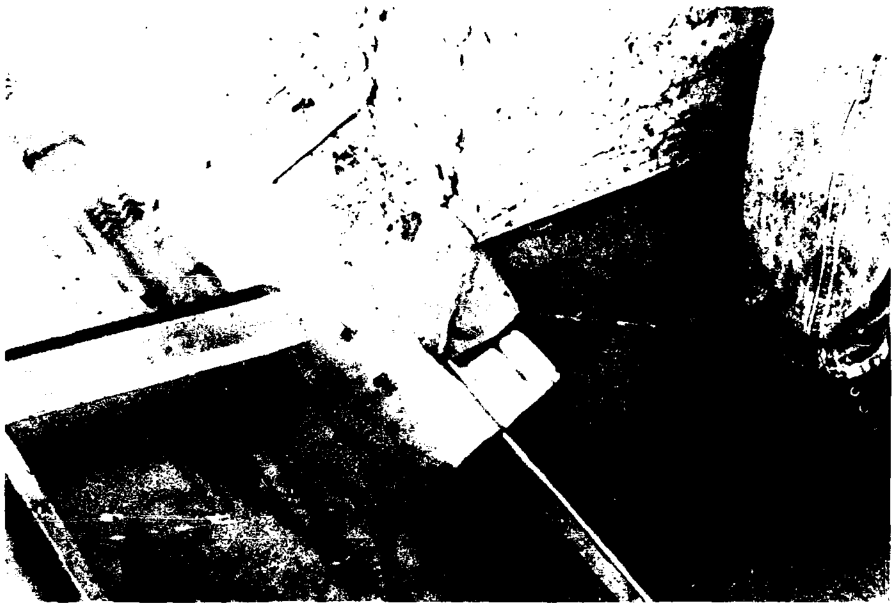

**Figure 54. Reentrant corner detail.**

training session was that it put the well-written installation manual into the hands of the roofing crew and allowed them to become familiar with the contents. Trainees asked many questions during the session and the questions revealed a very astute understanding of the products and processes.

The action of the roofing crew was quite professional. The foreman was technically prepared for the work and showed a great amount of confidence in the system. The duties on the roof were well distributed. This crew had the distinct advantage of having a crew member who had installed the system in the past. Nevertheless, the crew members acted with an understanding of their role.

Typically in the industry, the placement of hat section purlins is done carelessly, because maintaining a strict 5-ft spacing is not critical. This crew took special care in neatly laying out the purlins, thus establishing a standard of care that carried through the entire installation. Planning for laying the panel was thorough, enabling the crew to avoid many potential difficulties. Installation of the panels went quite smoothly, and the detail work was very carefully done. The one exception, the reentrant corner, was actually brought on by haste.

The correct application of sealants is essential to a successful installation. Sealant application is described in detail in the manufacturer's literature. One crewman suggested a change in the sequence (not in the sealant or location) which made the application much easier and neater, and more likely to result in proper sealant placement. The ridge cap installation detail calls for a continuous 3/8-in. bead of specified sealant applied on the inside of both legs of the ridge cover. However, these legs are precisely the hand-holds that must be used when spreading the cap to fit. Thus, application of the sealant as illustrated made ridge cover placement messy, compromising the integrity of the continuous sealant bead. The suggestion by the crew member was to apply the sealant to the fixed surface that mates with the ridge cover, resulting in an undisturbed continuous bead of sealant between the two specified surfaces. The suggestion by the crew did indeed constitute an improvement in standard application.

The standing seam metal roofing system is designed to be useful especially where there are few or no roof penetrations. Detailing is exceptionally difficult on standing seam metal roofs. This particular roof system is well suited to application by in-house personnel. The instruction manual is clearly written and contains helpful information.

Workers must learn to: (1) apply the correct sealants to the proper surfaces and (2) snap the panels in place correctly. Snapping panels is easily verifiable, but working with sealants involves careful attention to the instruction manual and a complete understanding of the principles of water movement. Crew members readily mastered the techniques involved. Because of the high level of organization before application, the installation proceeded quite quickly and without great difficulty.

**Mechanically Fastened EPDM (Rubber)**

*Building Description*

An EPDM roof system was installed on the 5600-sq ft supply building at McChord AFB, Tacoma, WA during July 1988. The deck was 3-1/2-in. thick tongue-and-groove wood and was exposed in the rooms beneath. Wood fiberboard insulation existed above the deck, with electrical conduit running within this insulation. A BUR with gravel topping was the original roofing system. The roof slope was approximately 1/2 in. per ft (Figure 55).

Leaks were present both around the edge and in the field. The leaking at the edge was due to the fact that the original installation lacked a wood nailer as was specified in the original drawings. This caused the edge metal to be only loosely attached to the roof and the movement of the metal led to water penetration. Leaks in the field had soaked some of the insulation which needed to be replaced.

The only penetration in the roof was a plumbing vent. The detail at the lower edge of the roof contained a built-in gutter system with drains built into the BUR membrane.

*Product Description*

The mechanically fastened EPDM roofing system used a reinforced membrane of EPDM rubber obtained in 5- and 10-ft rolls. This membrane is elastic and is able to expand and contract under temperature stresses without deforming the deck to which it is directly fastened.

The membrane is fastened to the roof deck at the edges using screws and washers every 1 ft. Those fasteners are then covered by the lap from the adjoining sheet. The fasteners are not exposed. The lap seams are cemented together using a splicing cement. A bead of sealant is applied within the seam to form a secondary water barrier should any water penetrate the cemented seam. Sealant is also applied to the exposed edge after the surfaces are mated together. This sealant is "buttered" in place.

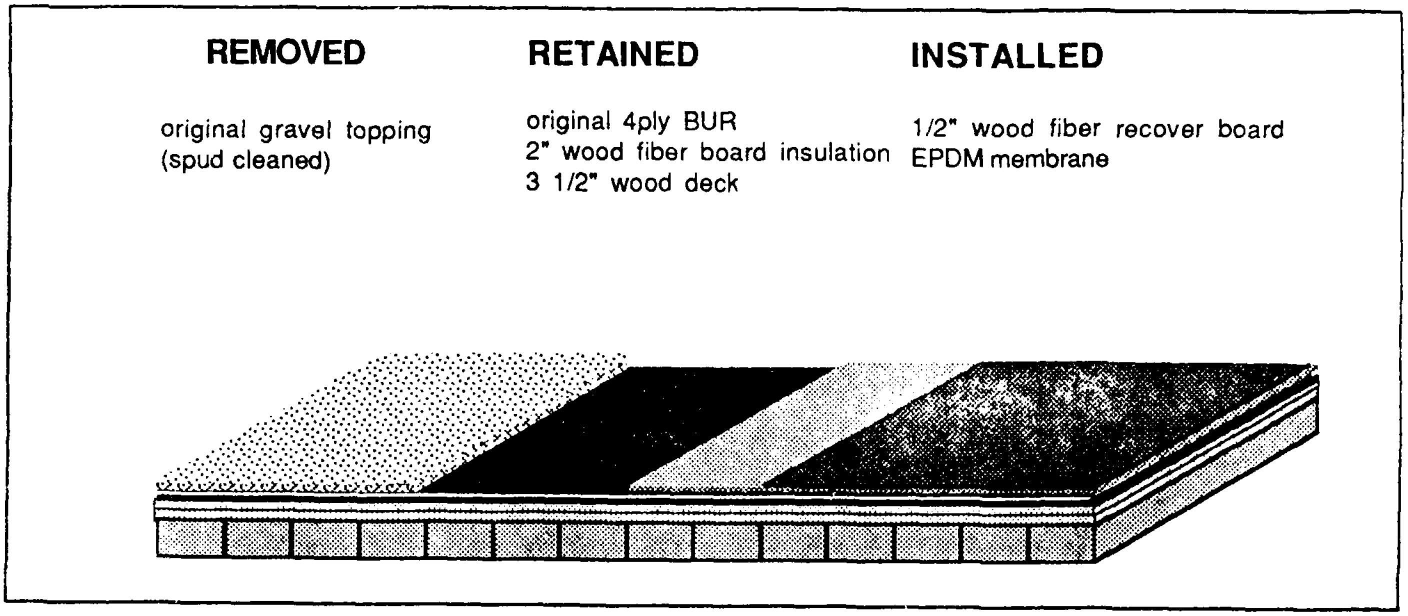


**Figure 55. Schematic of an EPDM membrane installed over wood deck.**

Critical to the performance of this system is, first, cleaning the mating surfaces using clean rags to remove all traces of talc and dirt and, second, using the proper cleaning solvents, cements, and sealants.

Edge metal is applied around the perimeter of the roof and nailed into the wood nailer below. The exposed metal on the roof surface is covered with a strip of membrane cemented in place.

*Training*

Training was given in a standard format at the manufacturer's headquarters. The session lasted 2 days and was quite rigorous. Trainees divided their time between review of the product literature and hands-on experience. Although 1 year elapsed between training and installation, the trainees remained familiar with the requirements of the system and made frequent use of the training literature.

*Installation*

This installation was conducted without a manufacturer's representative present. The crew foreman was equipped to make decisions in the field.

The roof was prepared by spudding off the loose gravel (Figure 56). Broom cleaning of loose gravel is often sufficient when a sturdy recover board is being used, and, in this case, the spudding was probably an unnecessary effort. However, with all of the gravel removed, removing loose insulation and patching was a much cleaner operation. The

**Figure 56. Loose gravel is spudded off the existing BUR.**

effort required to replace rotted edge nailers (Figure 57), and wet insulation on about 20 percent of the roof surface (Figure 58) was unexpected and disrupted the schedule. As in the other installations, the time necessary for proper preparation seemed very long.

A recover board of medium density fiberboard was applied over the existing BUR with large fasteners that went through the membrane into the wood deck (Figure 59). Some of the fasteners had been carelessly installed with the washers upside down so that sharp edges were in contact with the membrane. The fasteners were removed and the washers were turned around.

The proper application of an EPDM roof depends on the proper use of various solvents, adhesives, and sealants provided by the manufacturer. Solvents are necessary for cleaning. Sealants differ depending upon the anticipated amount of movement and the degree of exposure.

When rain showers interrupted the work, proper steps were taken to cover the exposed fiberboard with polyethylene. The roofing system was designed for temporary terminations in case of such interruptions.

The installation procedure involves laying the membrane at the perimeter first, then across the field. Curiously, the recommended procedure was to begin at the top of the roof and work downwards. The apparent advantage of such a system is that, if rainstorms interrupt the work, water will not drain to the underside of the new membrane. The disadvantage, of course, is that lap seams point uphill.

Figure 57. Rotted wood edge nailers are removed and replaced.

Figure 58. Wet insulation is removed and replaced.

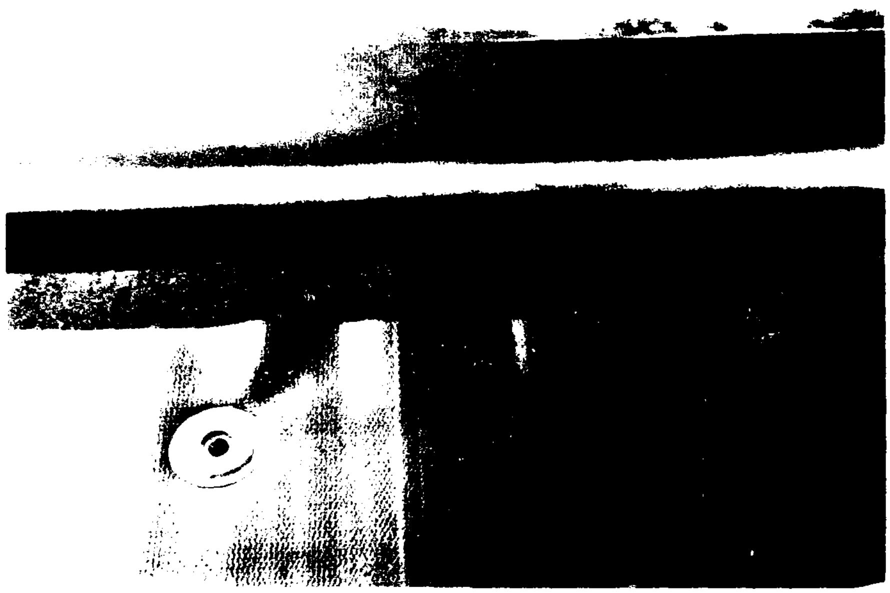

**Figure 59.** **Mechanical fasteners are long screws that penetrate through the recoverboard to wood deck beneath.**

The installation procedure involved the following steps:

1. Lay the membrane in place

2. Fasten the edge to the deck (Figure 60)

3. Install fasteners so that no burrs protrude from the metal (Figure 61)

4. Carefully clean the surfaces to be mated (Figure 62)

5. Apply an even amount of splicing cement and let it dry correctly (Figure 63)

6. Apply the in-seam sealant per the manufacturer's directions (Figure 64)

7. Carefully lay the membrane in place to avoid wrinkles (Figure 65)

8. Seal the trailing edge and "butter" the sealant (Figures 66 and 67). It is important that the edges be properly "buttered" to prevent the reinforcing scrim from wicking water into the membrane.

An early difficulty in getting the fastening screws to seat properly in the deck material was overcome by using a standard screw gun, rather than a hammer screw gun.

At the lower edge of the roof, the built-in gutter was simply framed over to create a flat surface, and a stock gutter was installed.

Figure 60. Sheets are unrolled and fastened to the edge nailer.

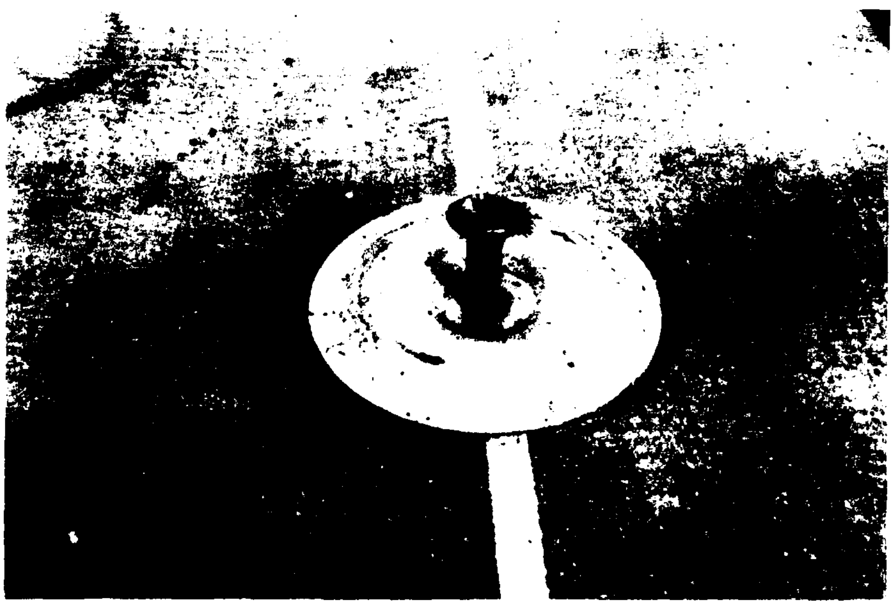

Figure 61. Proper tools must be used to install fasteners.

Figure 62. The first step in proper seaming involves cleaning the two mating surfaces to remove all talc from the membrane.

Figure 63. Splicing cement is applied with a roller and allowed to dry so it is no longer tacky.

Figure 64. Secondary sealant is applied following manufacturer's directions.

Figure 65. The two membranes are laid in place and rolled so cement bonds the two surfaces.

Figure 66. Lap sealant is applied to membrane edge.

Figure 67. Sealant is "buttered" in place.

*Results*

The installation was completed in 2 weeks. It was considered a success to the extent that those involved would like to do future reroofing using the system on other buildings at the base. The product was well designed and the building, because of its small size and few penetrations, was suited to the product. The crew benefited from the formal training and demonstrated appropriate care during the installation. Crew members must pay attention to careful cleaning of the surfaces to be cemented together and to using the correct sealants where specified by the manufacturer.

# 5 CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

When conducting in-house installation of nonconventional roofing systems, the roof engineer should be familiar with the roles of roofing manufacturers, technical and sales representatives, suppliers, and contract installers. The engineer should conduct an onsite inspection to determine the roof's condition and establish a priority for the work. The engineer should then evaluate the weather, the building structure, and the building use. Based on these factors, the engineer should select a roofing system and contact manufacturers to obtain detailed information. The final steps should be to prepare the necessary documents, procure the materials, and arrange training.

The foreman for in-house installations is usually a roof technician who assumes responsibility for the success of the installation. The foreman should identify the crew members, plan for support services, and oversee the preparation tasks. The foreman also notifies the major command of the reroofing, and supervises the tearoff, material handling, and layout.

Based on the demonstrations discussed in this report, in-house reroofing using nonconventional roofing systems is a feasible option for Air Force bases. All four demonstration installations resulted in successful (not leaking) roof systems.

The four roofing products studied (ballasted PVC, self-adhering modified bitumen, standing seam metal roof, and mechanically fastened EPDM) were all relatively simple to install. Crew members were sufficiently skilled to follow the instructions. The PVC roofing system was the most difficult, requiring new manual skills to be developed and judgment to be exercised. The standing seam metal system was well developed. The instruction and reference material was thorough and concise, which compensated for some of the inherent complexity of the system. The self-adhering modified bitumen was the simplest of the four products, which compensated for the underdeveloped training materials. The mechanically fastened EPDM system was a well-developed product, had excellent documentation, and required a moderate amount of skill.

The demonstrations showed that the in-house roofing crew members have the aptitude necessary for successful installation. Moreover, they were able to improve on installation methods that were demonstrated during training. The PVC roofing crew succeeded in installing a roof that would be approved for warranty by the manufacturer. The standing seam metal crew installed the system exactly as required, simplified one operation (at the ridge) by changing the sequence of sealant applications, and overcame an unfortunate condition at the reentrant corner by creative use of a rubber pipe boot. The modified bitumen crew conducted a good installation and developed a method that improved the sequence of field installation. Each installation had certain crew members who showed interest in the use of the nonconventional system; these members were crucial to the success of the project.

All four of the installations suffered from lack of planning. Responsibilities were not well described or apportioned. Essential services such as electricity or disposal were not adequate. Some of the poor planning can be attributed to the fact that the roofing technicians were unfamiliar with the system. However, each manufacturer had supplied necessary information regarding the materials shipped, equipment necessary, and storage and handling. Instead, the poor planning must be largely attributed to the fact that the installations made demands on the manpower far in excess of what such crews customarily undertake. The work was completed by crews of 6 to 10 workers. Roofing managers must seriously consider whether it is cost effective to dedicate manpower in this way.

**Recommendations**

Although products and aptitudes permit base personnel to install nonconventional roofing systems, the Engineering Office and roofing crew may not be sufficiently well organized to undertake even simple reroofing. It is recommended that extra planning effort be dedicated to each project.

A successful installation requires training in the system to be used. It is recommended that training include (1) hands-on experience with the system, (2) product information for reference during the installation, and (3) information on the performance of the system, so that field decisions may be informed decisions.

METRIC CONVERSION TABLE

°C = 0.55 (°F - 32)
1 ft = 0.305 m
1 in. = 2.54 cm
1 sq ft = 0.093 $m^2$

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