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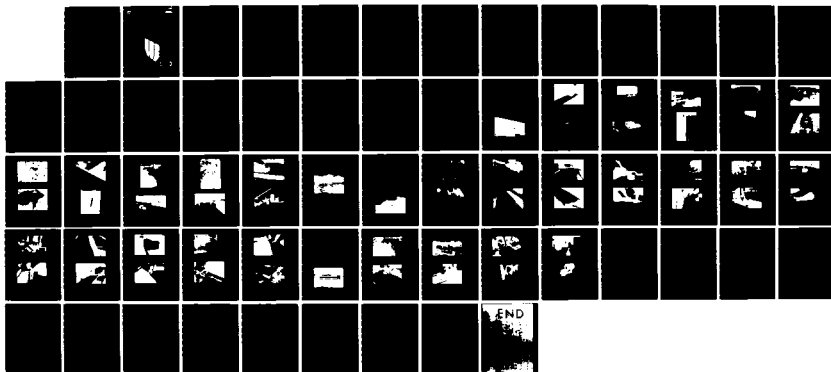
CONSTRUCTION OF EXPERIMENTAL POLYVINYL CHLORIDE (PVC)
ROOFING(U) CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY)
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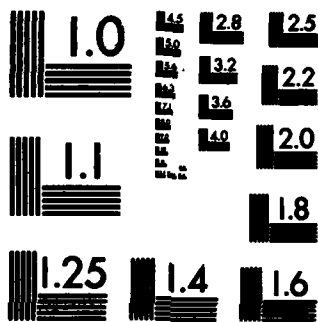
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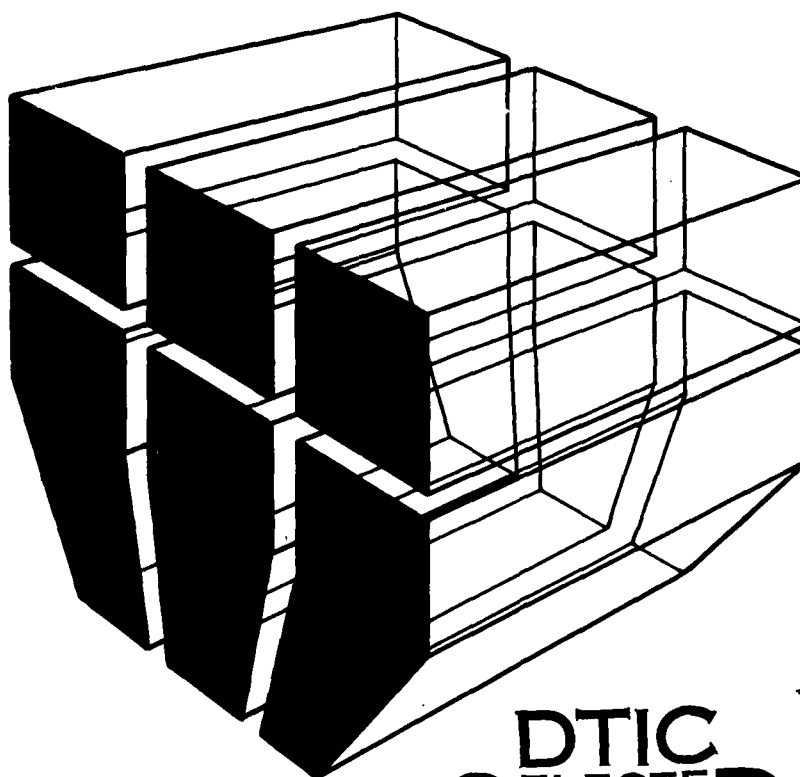
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TECHNICAL REPORT M-343
April 1984

CONSTRUCTION OF EXPERIMENTAL POLYVINYL
CHLORIDE (PVC) ROOFING

by
Myer J. Rosenfield



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Polyvinyl chloride (PVC) single-ply roofing systems have been installed at three U.S. military facilities for long-term evaluation (10 years) in three environments. Commercial PVC systems previously had been shown to offer an alternative to conventional built-up roofing (BUR) for new installations or for reroofing failed systems. (Cont'd)		

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Three PVC roofing systems are being field-tested in different combinations at Chanute Air Force Base, IL; Fort Polk, LA; and Dugway Proving Ground, UT. These tests will document the systems' performance for the various weather extremes and building types at each site. In addition, the manufacturers' estimated lifetime for the roofs will be compared with actual service.

As predicted in an earlier U.S. Army Construction Engineering Research Laboratory (CERL) study, reinforced PVC membranes were easier to install due to less shrinkage upon unrolling. Each membrane type was isolated carefully from the others to avoid interference that might affect results or any interaction between the different materials.

Independent contractors installed the systems. The contractors' methods in placing the roofs will no doubt have major impact on long-term performance. Thus, it may be difficult to obtain a true performance picture for systems installed with less care than demanded under certain conditions.

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FOREWORD

This work was performed by the Engineering and Materials (EM) Division of the U.S. Army Construction Engineering Research Laboratory (CERL) for the Directorate of Engineering and Construction, Office, Chief of Engineers (OCE), under Project 4A162731AT41, "Military Facilities Engineering Technology"; Task A, "Facilities Planning and Design"; Work Unit 044, "Improved and New Roofing for Military Construction." The OCE Technical Monitors were John Ichter, DAEN-ECE-S and Joel Seifer, DAEN-ZCF-B.

Appreciation is expressed to Charles Benzie of Inspec, Inc., who monitored the installation at Chanute Technical Training Center; to William McCormish of Inspec, Inc., who monitored the installation at Fort Polk; and to William Schultz of Soils and Materials Engineers, Inc., who monitored the installation at Dugway Proving Ground.

Dr. Robert Quattrone is Chief of CERL-EM. COL Paul J. Theuer is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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CONSTRUCTION OF EXPERIMENTAL POLYVINYL CHLORIDE (PVC) ROOFING

1 INTRODUCTION

Background

Most Army facilities use conventional roofing systems, such as built-up roofing (BUR), that are sometimes complicated to construct and expensive to maintain. In addition, these conventional roofing systems are often comparatively short-lived, resulting in high life-cycle costs that are difficult for already overburdened Army operation and maintenance (O&M) budgets to absorb. Therefore, the Office, Chief of Engineers (OCE) asked the U.S. Army Construction Engineering Research Laboratory (CERL) to attempt to identify alternative, easy-to-install roofing systems that can improve the performance of Army roofing while reducing life-cycle costs.

Previous work at CERL had identified and evaluated alternative roofing systems that would be less susceptible to installation error or misapplication and that would not be as sensitive to storage, handling, and weather considerations.¹ A second report described an investigation into properties and application of polyvinyl chloride (PVC) single-ply roofing.² As a result of this investigation, it was determined that PVC single-ply membrane roofing should be installed and evaluated in actual service at military installations in different climates in the continental United States.

Objective

The overall objectives of CERL's roofing studies are to (1) evaluate innovative roofing systems and materials as alternatives to BUR systems, (2) provide a way to improve Army roof performance and reduce life-cycle costs, (3) improve contractor quality control of BUR construction, and (4) develop guide specifications for selected alternative systems. The specific objective of this report is to document the

construction phase of a 10-year field evaluation of PVC single-ply membrane roofing.

Approach

A test plan was developed using standard test methods published by the American Society for Testing and Materials (ASTM), when available, and other tests developed by Government or private agencies when needed. Test sites were selected, and test guide specifications were developed. Installation of the test roofing systems was monitored.

Mode of Technology Transfer

It is recommended that the results of this study be issued as a Corps of Engineers Guide Specification.

2 PROCEDURE

Test Plan

Although only one generic material PVC was selected, it was determined that different manufacturers' products should be installed side by side in different climates using different installation techniques. Reasons for this were three-fold.

1. No two manufacturers formulate their product to the same composition or make the sheets the same way. Some products are solid PVC without reinforcement; others contain a fabric or scrim of fiberglass or synthetic fibers. Therefore, it was necessary to test a variety of products. Those selected for testing were from Plymouth Rubber Company, USM Weather-Shield, and Sarnafil (U.S.), Inc.

2. Single-ply membrane can be installed many ways: loose-laid and ballasted, mechanically fastened, spot adhered, or fully adhered. Different manufacturers have different recommendations for installing their products. Therefore, it was necessary to evaluate different installation methods.

3. The test plan was designed to determine how weathering would change the physical and mechanical characteristics of the membrane materials, and to compare results between the different types.

The initial set of tests was designed to establish the membrane's physical and mechanical characteristics at the time of application. Subsequent tests are scheduled at 6-month intervals over a 2-year

¹ E. Marvin, et al., *Evaluation of Alternative Reroofing Systems*, Interim Report M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory [CERL], June 1979).

² M. J. Rosenfield, *An Evaluation of Polyvinyl Chloride (PVC) Single-Ply Membrane Roofing Systems*, Technical Report M-284/ADA097931 (CERL, March 1981).

period and at 1-year intervals over the subsequent 8 years, accompanied by a visual inspection once each year. Two reports will be issued, one after the 2-year period and one after the following 8-year period. Test characteristics of interest to this study are in Table 1.

Test Site Selection

To ensure that the systems would be subjected to identical exposure, site selections were based on:

1. The availability of buildings that were structurally divided into three parts or that were large enough to divide into three parts.
2. The availability of a local (in-house) engineer staff that could prepare contract drawings and administer the construction contract.
3. The availability of local (site) funding for the construction work.

Three military installations representative of the geographical and climatic variations in the continental United States were chosen as test sites: Chanute Technical Training Center (Air Force), IL; Dugway Proving Ground (Army), UT; and Fort Polk (Army), LA. These provided a temperate mid-west climate, a high desert environment, and a sub-tropical Gulf Coast climate, respectively.

Test Guide Specification Development

A previous investigation led to an understanding of PVC membrane manufacture and installation practices.³ Test guide specifications designed specifically for this program were prepared in accordance with a format recommended by OCE. The guide specification was written on a generic, nonproprietary basis, although it was realized that contract specifications would have to be specific if selected

³ M. J. Rosenfield.

Table 1
Test Characteristics for PVC Membranes

Test at Beginning of Exposure Program

Property	Test Method	Remarks
Xenon arc aging	ASTM D 2565	"Property" refers to physical properties of interest. This group of tests will be used to estimate weathering performance. The tests will be useful for comparison to see how well they predict the actual conditions of the membrane materials.
Heat aging	ASTM D 3045	
Volatile loss	ASTM D 1203	
Dimensional stability	ASTM D 1204	

Test at Beginning and Intermittently During Program

Tensile strength	ASTM D 412, D 751, D 882	These are tests to establish the basic mechanical and physical characteristics typical of roof membranes. Any changes in these characteristics during service would signal aging, deterioration, and a reduction in life expectancy. Abrasion resistance is necessary if the roof will experience regular foot traffic; seam strength is essential in single-ply systems; changes in hardness indicate a loss in plasticizer, oxidation, and a decrease in resistance to mechanical damage; absorption and permeability are necessary characteristics if the membrane is used over existing roofing systems with possible moisture entrapment. Glass transition, brittleness, and bend tests quantify decreased resistance to mechanical damage. Thickness and specific gravity quantify plasticizer and volatile loss.
Elongation	ASTM D 412, D 751, D 882	
Seam strength		
Shear	ASTM D 412, D 751, D 882	
Peel	ASTM D 1876	
Tear resistance	ASTM D 751, D 1204	
Abrasion resistance	ASTM D 3389	
Thickness	ASTM D 1593	
Specific gravity	ASTM D 792	
Hardness	ASTM D 2240	
Water resistance		
Absorption	ASTM D 570	
Permeability	ASTM E 96	
Glass transition	ASTM D 3418	
Brittleness	ASTM D 1790	
Low-temperature bend	ASTM D 2136	
Gas chromatograph/ Mass spectrograph	USBR	
Outdoor exposure	USBR	

materials were to be compared. This action is permitted for research and development (R&D) work by Defense Acquisition Regulation (DAR) 3-211.

Material specifications were based on ASTM D 3083, *Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal and Reservoir Lining*. ASTM specifications for PVC roofing membrane materials did not exist at the time.* Drafts of the proposed guide specification were reviewed by manufacturers of the materials selected for the tests, and many of their comments were incorporated into the final document. The text of the test guide specification appears in the appendix.

Contracting Procedure

Technical specifications for insulation and roofing membranes were prepared at CERL for use in the construction contracts. Each installation prepared the remainder of its own contract document. Normal advertising procedures were followed, although a bidder's list of manufacturer-approved applicators was provided to each installation.

After contracts were awarded, but before the actual work began, a preconstruction conference was held at each site. Representatives from CERL as well as the contracting officer, manufacturers, contractor, and any subcontractors were present. Local engineering inspectors also attended. All specifications and drawings were carefully reviewed, with experimental goals of the program explained and

*ASTM is in the process of reviewing such specifications for approval.

discussed. In particular, it was emphasized that these projects were to serve as demonstrations for future material and specification selection, that requirements for application procedures and materials would be monitored very closely, and that nonconforming work would be rejected. An important point of discussion was the requirement for periodic sampling in the future and its effect on the manufacturers' warranties for the system. A procedure was developed by which the manufacturers would be notified when samples were to be taken. If they were to be cut by installation personnel, the manufacturers would send a representative to supervise the work. If they were to be taken under contract, the installation contractor would do the work. In both cases, this would preserve the warranty. Total contract costs and unit costs for each of the three materials are in Table 2.

3 INSTALLATION AT TEST SITES

Chanute Technical Training Center

Building 96, Jackson Hall, was selected by the Base Civil Engineer for application of the experimental PVC roofing systems. Jackson Hall is used to train technicians in maintaining and servicing jet engines and certain missiles. The building is divided longitudinally into a high bay, with a metal roof deck, and a low bay, with a concrete roof deck. The low bay is divided into three parts by two transverse expansion joints. A penthouse in the center part has

Table 2
Total Contract and Unit Costs

Location	System	Application	Contract \$	Sq Ft (m ²)	\$/Sq Ft (\$/m ²)
Chanute	Complete	Ballasted	127,687	28,125 (2,612)	4.55 (48.90)
	Flexhide	Ballasted		6,932 (644)	
	Plyroof	Ballasted		7,551 (701)	
	Sarnafil	Ballasted		13,642 (1,267)	
Dugway	Complete	Smooth	109,018*	27,150 (2,522)	4.01 (43.23)
	Flexhide	Mech. Fast.	34,436	9,000 (836)	3.83 (41.19)
	Plyroof	Mech. Fast.	30,707	9,150 (850)	3.36 (36.13)
	Sarnafil	Adhered	43,875	9,000 (836)	4.88 (52.48)
Polk	Complete	Smooth	148,497	27,448 (2,550)	5.41 (58.23)
	Flexhide	Mech. Fast.	54,943	12,000 (1,115)	4.58 (49.28)
	Plyroof	Mech. Fast.	49,005	7,700 (715)	6.36 (68.54)
	Sarnafil	Adhered	44,549	7,700 (715)	5.79 (62.31)

*Dugway contract included \$18,292 more for bituminous treatment of continuous window canopies.

a steel roof deck and contains the HVAC equipment. The minimum slope for all roof decks is 3 percent. Figure 1 shows the building arrangements.

Materials and Method

The installation method at Chanute was loose-laid and ballasted. Membranes selected were Plymouth Rubber Company's Plyroof PVC 45, USM Weather-Shield's Flexhide 45, and Sarnafil's G21 442. The Plyroof and Flexhide are both unreinforced. The Sarnafil is reinforced with a glass fiber scrim.

The contract for reroofing Building 96 specified complete removal of the existing BUR system down to the deck. The only components reused were the existing gutters and downspouts. After cleaning, the concrete deck was primed as needed and a two-ply felt and asphalt vapor retarder was applied. A commercial vapor retarder consisting of two plies of kraft paper laminated with a flame-extinguishing adhesive was adhered to the penthouse metal deck. Two layers of urethane foam board insulation complying with Interim Amendment 4 to Federal Specification HH-I-530A were installed. The board was classified as Type 1, Grade 2, Class 2. Both layers under the Plyroof and Flexhide and the bottom layer under the Sarnafil were Style B, with aluminum facing on both sides. The top layer under the Sarnafil was Style E, with a 3/4-in. (19-mm) layer of perlite on one side and aluminum foil on the other. The perlite side was installed up, in contact with the membrane. Insulation thickness was calculated to provide a value of R20 for the complete roof construction under winter conditions. The Plyroof membrane required a reinforced kraft paper slip sheet between it and the insulation.

Discussion

The different PVC membranes were separated at the building expansion joints to avoid bonding to each other, a possibility that had concerned the manufacturers. Although the original roof's membrane expansion joints were flush with the surface, raised ones were installed to completely isolate one system from another. The bellows was preformed neoprene with aluminum angle flanges, sealed at the joints with a strip of uncured neoprene.

Construction began with removal of the existing BUR on 21 September 1982, on the roof part designated Area A. Each area was completed before the next was started. Area C, the final one, was com-

pleted on 24 November 1982. This long time for completion was due to several rainy periods of 2 or 3 days duration each, during which work could not proceed.

Specifications were written to allow each manufacturer's installation methods to be followed. Specific instructions were written into the contract only when manufacturers' instructions were vague or when specific differences were desired. One such requirement was to stagger end joints in the sheets. One manufacturer's practice was to place all end joints in a single line so that four layers occurred at each corner. Staggering eliminated one of these layers, resulting in a joint with less disturbance to the membrane material.

The contractor elected to use a self-propelled hot-air gun to weld all sheet seams and, in accordance with the contract, demonstrated this technique by forming and submitting 20-ft (610-cm) seam samples (Figure 2). The method worked very well for the demonstrations. However, during actual installation, the self-propelled hot-air gun welder worked well only for the reinforced membrane; problems occurred with the unreinforced membranes. The machine tended to cause wrinkles in the seams (Figures 3 and 4), which had to be cut out and patched by hand. Also, some seams on one membrane were not thoroughly welded due to improper heat setting and opened spontaneously 2 days after they were made (Figure 5). Manufacturer's instructions require immediate sealing of all seams with a special sealant, and this had not been done. Therefore, the contractor had to rip the faulty seams apart and reweld them with a hand-held hot-air gun and hand roller.

The contract required temporary ballast in the form of rubber tires or some other method to be used on the membrane before the permanent aggregate ballast was applied. For the most part, the contractor did not meet this requirement, although it was repeatedly pointed out. One day the wind was strong enough to penetrate under the membrane and disturb the extremely light insulation boards, with the result shown in Figure 6. This membrane had to be cut apart to straighten the insulation, with extra strips of material installed to seal it again. If the insulation had been specified to be fastened in place, this would not have happened.

None of the above problems were caused by deficiencies in the membrane material. However, there

were two problems with installing the unreinforced materials. One was related to shrinkage. Specifications and manufacturer's instructions both required relaxation time after unrolling the sheets. The contractor was somewhat lax in following this requirement, with the result that he was instructed to cut the membrane loose, allow it to relax, and then seal it again. The rolls of membrane shrank up to 7-in (18 cm) after being cut from the sheet metal to which they had been attached (Figure 7).

The other problem related directly back to manufacture of the membrane. When the membranes were unrolled to relax, wrinkles in the sheet were noticed (Figures 8 through 10), and these persisted into the completed membrane. They undoubtedly resulted from excessive stretching during processing on a calender, with the material unable to recover completely when tension was removed.

Building 96 is protected by a system of lightning rods. These were originally installed by setting the base plates in plastic cement (Figure 11) and putting the cable into the roof through a pitch pocket. For final installation, the bases were cleaned and fastened to concrete paver blocks. The pitch pockets were eliminated and PVC membrane was formed around the cable penetrations (Figure 12).

Since these membranes were installed loose, a requirement was included in the contract to conduct a smoke test before ballasting to check the integrity of the seams and sheets. A chemical smoke from smoke grenades was proposed. Because of this smoke's potential toxicity, the test was performed on a weekend when the building was deserted. A tank-type shop vacuum unit was used, its discharge nozzle piped to a sleeve installed in the roof membrane (Figure 13).

The only smoke leakage was around the perimeter, where it was expected (Figure 14), indicating that all seams were sound and that the membrane was free of holes. Figure 14 also shows PVC pipe used as a gravel stop. This piping was installed so that water could drain between it and the membrane and flow into the gutter.

Most problems were caused by the contractor's poor housekeeping practices and failure to exercise proper techniques in the work. This lack of care began with the demolition work and continued almost to the end of the project. For example, the

contract required a covered chute or other device to be used when removing debris from the roof. The contractor attempted to comply by installing a chute made of two Sonotubes that led from the roof to a truck (Figure 15). In a short time, the lower section of the chute was removed, and the workmen did not use it anyway. Figure 16 shows a piece of BUR being thrown over the side, and much debris on the ground around the truck.

After membrane installation began, the contractor used a prefabricated hoist to move materials from the ground to the roof. As seen in Figure 17, he placed this hoist directly on the newly installed PVC membrane without any protection boards and left it this way for most of the project's duration. Of necessity, all materials used, including buckets of hot asphalt, had to be carried across the membrane to the place of use. No protection boards were used as walkways, and the membrane rapidly became contaminated with asphalt from drippings and footprints (Figure 18). This condition persisted during application of the first two types of membrane. Several attempts were made to clean the membrane with ethyl acetate, tetrahydrofuran, and industrial strength detergent. The tetrahydrofuran is used as a solvent to weld pieces of membrane together, so it only served to attack the sheets. The affected membrane was never restored to its original cleanliness. Asphalt and concrete primer were tracked across or splashed onto the surface on three occasions. The area that received the worst asphalt contamination was removed and replaced, and the rest of the splash area was cleaned. Following this, the contractor used damaged insulation boards for protection.

Access to the low roof over the entryway (see Figure 1) was by a ladder from the main roof deck. After the membrane was installed, the contractor failed to put protection boards under the ladder feet, again placing stress on the new roof (Figure 19).

Ballast was installed after the smoke test. Although it was specified as smooth, water-washed round stone, dry and dust free, it was delivered with a high fines content and with many broken pieces that had flat faces and sharp, jagged edges. A call to a local roofing contractor (not associated with either the installation or any of the materials used) indicated that the quarry from which the ballast came was the only local one approved by a different major PVC membrane manufacturer, and that it had proven acceptable for use. Ballast was delivered to the

site in a lift truck and dumped into a bucket (Figure 20). This was, in turn, hoisted to roof level by a crane and dumped into a motorized gravel spreader (Figure 21), from which it was applied to the roof (Figure 22). Close checks were made when the gravel spreader tires ran over a single stone. No punctures in the membrane were observed, but a definite dimple was caused in the underlying insulation. At first, the contractor had a workman continually sweeping errant stones from the path of the spreader, but as manpower dwindled, this was phased out.

Fort Polk

The installation chose Building 1411, the Post Field House, for application of the experimental PVC roofing systems. The main building is of World War II vintage; squash and handball courts were added in 1966. The entire structure is of wood construction, with 1 x 8 in. (25 x 200 mm) tongue and groove wood sheathing as the deck. The deck was not insulated, and the bottom ply of the BUR was nailed in place instead of set in asphalt. Although the BUR had leaked extensively during the previous 11 years, only isolated areas of the deck were found to have deteriorated. This was probably due to the steep slopes of the Lamella arch and those of the sloped roofs over the dormers and side wings. Also because of the slopes, the Field House roof was smooth-surfaced, without aggregate cover. The squash and handball courts had a gravel surface. Figure 23 shows the building arrangements.

Materials and Method

The installation method at Fort Polk was unbalanced because of the slopes involved. Membranes selected were Plymouth Rubber Company's Plyroof PVC 45 FR White, USM Weathershield's Flexhide LR-50, and Sarnafil's G21 410. The Flexhide is reinforced with a polyester fabric and the Sarnafil is reinforced with a glass fiber scrim; the Plyroof is unreinforced. The Sarnafil membrane was installed fully adhered. The Flexhide and Plyroof were mechanically fastened.

The contract for reroofing Building 1411 specified removal of the existing BUR and all guttering, and installation of the new single-ply systems with new gutters and downspouts. Removal of the BUR was not difficult, as it was nailed to the deck. Isolated areas of deteriorated deck were found, with complete deterioration of the structural wood joists in some cases. The deteriorated decking was removed and replaced with new treated 1 x 8 in. (25 x 200

mm) T&G wood plank. In areas where structural joists had deteriorated, sections of 2 x 6 in. (50 x 150 mm) treated lumber were spliced to both sides of the damaged member.

Nailers were installed around all roof penetrations larger than 1 ft (300 mm) diameter. Most of these penetrations are between joists, and the arched roof has no penetrations. Prior to insulating the deck, any loose planks discovered were nailed down, but gaps between planks were not filled. A vapor retarder was not installed. Two layers of polystyrene foam board insulation complying with Federal Specification HH-I-524C were installed. The board was classified as Type III, faced with aluminum foil. The top layer under the Sarnafil was faced with 1/2-in. (13-mm) fiberboard, to comply with Sarnafil requirements. Insulation thickness was calculated to provide a value of R20 for the completed roof under winter conditions. The Plyroof membrane required a reinforced kraft paper slip sheet between it and the insulation, and the Flexhide required a fiberglass slip sheet.

Discussion

Polystyrene insulation was selected instead of urethane or polyisocyanurate because it is more flexible and can conform to the curvature of the arch more easily. Each layer was mechanically fastened independently, avoiding difficulties of trying to handle two layers together on the curved surface of the arch. Eight fasteners were used for each board in the first layer (Figure 24) and for the second layer under Flexhide and Plyroof membranes (Figure 25). Sarnafil requirements specified 10 fasteners per board (Figure 26).

As at Chanute, complete physical isolation was maintained between the different PVC membranes. The Field House was constructed without expansion joints, so a dummy joint was installed across the roof as a divider. Figure 27 shows the completed divider joint, covered with copper sheeting. This divider separated the arched roof and two dormers into two sections, designated Areas B and C. Area A consisted of the lean-to wings on each side, the canopy over the entrance, the racquetball and squash courts, the boiler room, and the hallways.

Construction began on 29 November 1982 with removal of the existing BUR from the roof part designated Area C. Each area was essentially completed before the next was started. Area B was

started on 5 January 1983, followed by Area A on 28 January 1983. Work was completed on 11 March 1983. This long time for completion was due to so many days of rain that the contractor requested and was granted a time extension. Completion originally had been scheduled for 20 February.

The contractor used a self-propelled hot-air gun to weld the Sarnafil membrane seams, as this is required by the manufacturer. Plymouth Rubber Company and USM Weather-Shield permit either solvent or hot-air welding, and the contractor elected to use a self-propelled solvent welder for these two membranes. Techniques were demonstrated by forming and submitting 20-ft (610-cm) seam samples. As at Chanute, these worked very well for the demonstrations, but sometimes gave different results during actual installation. For example, flow of the solvent to the brush was satisfactory for the test, which was level on the ground, but could not be controlled on the sloped surfaces. As a result, most of the seams on the slopes were solvent-welded by hand.

As stated previously, two of the membranes were mechanically fastened. One was a system in which steel battens covered with PVC were fastened to the deck through the insulation with screws and the membrane was solvent-welded to them. The other used rectangular washers fastened along one edge of each sheet, through the insulation with screws, with the next sheet lapped over them and then welded to the first sheet. The membrane used with the batten system was not reinforced, and severe shrinkage was noted as the sheets were allowed to relax after unrolling. The membrane used with the washers along the edge was reinforced, and no shrinkage was observed.

The batten system was installed at the north half of the parabolic roof. This area consists primarily of the parabolic arch with a narrow rectangular flat area at the east and west sides. The entire area was free of penetrations.

The required kraft paper slip sheet was rolled over the completed insulation substrate, parallel to the roof slope. All end and side laps were lapped to a minimum of 4 in. (100 mm) and were terminated at the perimeter nailers with a 1 in. (25-mm) lap. As the slip sheet was rolled over the parabolic roof section, "spot" fastening of the batten strips was used to hold the slip sheet in place. Over the com-

pleted slip sheet, the 8-ft (25.4-cm) batten strip sections were fastened in continuous rows parallel to the roof slope. The batten strips were placed 12 in. (305 mm) from the perimeter and the successive rows were placed at 24 in. (610 mm) on-center. The strips were screw-fastened through the prepunched holes, at 24 in. (610 mm) on-center (Figure 28). The strips delivered to the site had no pre-punched holes at the immediate strip ends; therefore, the contractor used the fasteners' "self-tapping" capabilities to anchor the strip ends. At the parabolic arch and flat roof transition area, a special 6-in. (150-mm)-wide piece of PVC-coated metal was installed with screws at 24 in. (610 mm) on-center.

Before installation of the PVC membrane, the PVC sheets were unrolled laterally across the parabolic area. Typically, several rolls were unrolled at once to allow an even relaxation time (Figure 29). The rolls were allowed to relax a minimum of 1 hr; however, in some extreme cases, the sheets were allowed to relax as long as 24 to 30 hr. After relaxation, the sheets were placed to provide a 2- to 4-in. (50- to 100-mm) overhang along all outside perimeters. This procedure, which required the membrane to be nailed off against the perimeter blocking, was used because the contractor rarely was able to complete installation of the perimeter sheet-metal components during the same day. After the sheets were placed along the premarked 2-in. (50-mm) lap line, the contractor provided temporary ballast (typically 2 x 6 in. [50 x 150 mm] plank sections) to prevent the sheets from moving or being blown off.

After all the sheets were aligned, solvent welding of the sheet laps was started, generally at the top and progressing downward toward the flat areas. Upon completion of the solvent lap welds, the entire "finished" membrane section was folded back to the first row of batten strips. The folded membrane was then welded to the batten strips in essentially the same way as the lap welds (Figure 30), although the sand bag ballast was allowed to remain at the lap area slightly longer to enable membrane conformation with the batten strip. This was because minor deflections occurred within the immediate 3-in. (75-mm) diameter of the fastener heads and at the batten strip ends where self-tapping screws were used. As each lateral run of strips was welded, the membrane was folded progressively across adjacent rows of batten strips, up to the seal-off area. After the batten strips were welded, the previous lap welds were checked for adhesion using a small screwdriver

or screw point, and the deficient areas were marked in ink. A hand-held heat gun was used to "spot" heat weld the marked areas (Figure 31).

A continuous bead of seam sealer was applied to the completed lap welds with a small squeeze bottle (Figure 32). The seam sealer was furnished in 1-2 gal (3.8-L) cans and had a "jelly" consistency. To achieve a viscosity that would flow out of the squeeze bottle, the sealer was diluted with the welding solution until the desired consistency was achieved.

The completed membrane was solvent welded to the perimeter fascia metal by the same process used for lap welding. However, the membrane-to-perimeter welds were not completed on a daily basis; perimeter welds were completed 6 to 7 weeks after the initial system construction. As a result of this delay, the membrane shrank extensively at all batten strip ends (Figure 33), adjacent to the perimeter metal, and wrinkling of the membrane was prevalent along the entire perimeter. Additionally, due to the delay in completing the perimeter welds, dirt and bitumen flakes accumulated at the membrane and perimeters. The contractor attempted to clean these areas with the recommended cleaning solution; however, this appeared to dissolve the membrane. The contractor then used another manufacturer's cleaner which cleaned the material rather easily and had no visible deteriorating effects. The fully adhered system was installed over the south half of the parabolic roof area, which contained no penetrations.

After the insulation was installed, the wood fiber insulation cover was lightly swept to remove excess debris before priming. When the insulation had been thoroughly cleaned, the membrane adhesive was applied over the wood fiber cover. This priming was accomplished with 12-in. (305-mm) standard lambs' wool paint rollers to spread the adhesive (Figure 34). The membrane was unrolled laterally over the primed insulation across the parabolic arch, after which one-half of the sheet was turned back to expose the black underside. Adhesive was applied to the turned-back membrane with the roller, and 5- to 6-ft (1500- to 1800-mm) sections were completed at a time (Figure 35). Once the immediate area had been coated with the adhesive, it was quickly turned back over the primed surface and pressed down solidly. After that half had adhered, the same procedure was used on the opposite side. When several sheets had been initially adhered, a neoprene-padded

roller was used over all the sheets to insure full contact with the insulation (Figure 36). All of the end laps were staggered and lapped a minimum of 4 in. (100 mm). Additionally, where an end lap did occur, the corners of the top sheet were rounded (Figure 37), and the underlying sheet was tapered slightly to accommodate the automatic heat welding machine (Figure 38).

The finished membrane was terminated approximately 1-in. (25 mm) over the gutter edge before the perimeter PVC metal was installed. As a horizontal keeper strip was used, this required a 1/2-in. (13-mm) double face foam tape "sealing strip" to be installed under the overlapped membrane (Figure 39), over which the keeper was installed (Figure 40). The "sealing strip" was designed to prevent water entry in case of gutter back-up.

The other mechanically fastened system was installed over the lower canopy roofs, racquetball court roofs, boiler room and storage roof, and the hallway transition roof areas. These areas have penetrations of exhaust units, vent stacks, and hot pipe vent stacks.

Before installation of the membrane and slip sheet, all required PVC-coated sheet metal components were installed. All vent stacks, both septic and hot pipes, also received the required sleeves. Before placement of the membrane sheets, a fiberglass slip sheet was rolled over the foil-faced insulation and was lapped a minimum of 4 in. (100 mm) on all sides. After placement of the fiberglass slip sheet, the 3-ft- (915-mm-) wide rolls of membrane were unrolled, starting at the perimeter and progressing inward, in an uphill direction (Figure 41). To prevent the fiberglass slip sheet from being blown off, several rolls of the membrane were rolled out at once and temporarily ballasted. By using this procedure, the membrane sheets could usually relax 20 to 45 min. The sheets were lapped at the factory-marked 4-in. (100-mm) lap lines. The fasteners were placed through the metal plates along the lap area and pounded through the bottom sheet (Figure 42). These fasteners were placed 1 in. (25 mm) from the edge of the sheet. Within the immediate 7-ft- (2100-mm) square perimeter of all outside corners, the fasteners were placed at 10 in. (250 mm) on-center. Along all other immediate 7-ft (2100-mm) perimeters, the fasteners were placed at 24 in. (610 mm) on-center. Additional fasteners were placed at the sheet end-lap locations. Where "T-joints" occurred

along these sheet end laps, a heat gun was used to chamfer the lap edge of the membrane to provide a smooth transition for the top lap. In addition, the sheets were rounded slightly at these end laps to ease the solvent welding process.

The membrane laps and perimeter were secured by solvent welding. The automatic solvent seam welder was difficult to control, and excessive solvent ran freely out of the lap area (Figure 43). The drag of the weight brushes caused excessive wrinkling of the membrane (Figure 44), so this machine was used very little.

After all solvent laps had been completed, a "spot check" was conducted using a screw point. Deficient areas were marked in ink and were heat-welded with a heat gun. Most welds to the PVC-coated metal were completed with the solvent welding process, although the hand-held heat guns had to be used more extensively at these areas due to the limited accessibility to the immediate weld.

Base flashings of PVC-coated sheet metal were originally made with 90 degree bends (Figure 45). This made it difficult to insert the solvent brush to achieve a 2-in. (51-mm) seam (Figure 46), so subsequent base flashings were made with a small 45 degree cant (Figure 47), and it was easier to insert the brush to complete the joints.

Dugway Proving Ground

Two buildings were provided for application of the experimental roofing systems: 5132 and 5140. These are two L-shaped dormitory buildings next to each other, built as mirror images. The long leg of each building is divided into two equal lengths by a transverse expansion joint. The short leg is separated from the long leg by a similar expansion joint. Figure 48 shows the arrangement of the buildings; they are two stories high, of concrete block construction, with poured-in-place concrete roof decks. The roofing consisted of a gravel-surfaced BUR above 1 in. (25 mm) of mineral-fiber insulation, much of which had been torn off by high winds. A single ply of felt had been placed as a temporary roof (Figure 49).

Materials and Method

The installation method at Dugway was unbalanced because of the high winds in this area. Membranes selected were Plymouth Rubber Company's Plyroof PVC 45 FR White, USM Weather-Shield's Flexhide LR-50, and Sarnafil's G21 410. The Flex-

hide is reinforced with a polyester fabric; the Sarnafil is reinforced with a glass fiber scrim. The Plyroof is unreinforced. The Sarnafil membrane was installed fully adhered; the Flexhide and Plyroof were fastened mechanically.

The contract for reroofing Buildings 5132 and 5140 specified removal of the existing BUR system down to the deck, as well as all existing sheet metal work. The deck was cleaned off, but no vapor retarder was required. Two layers of urethane foam board insulation complying with Federal Specification HH-I-530 A and Interim Amendment 4 were installed. The board was classified as Type I, Grade 2, Class 2, Style B, which indicates 1.5 to 2.3 lb/cu ft (24 to 37 kg/m³) density, self-extinguishing type, faced surface, with aluminum facings on both sides. Each layer was specified as 1-1/2 in. thick (38 mm), to provide a value of at least R20. Because of the aluminum facing, a slip sheet was not required by USM Weather-Shield for the Flexhide membrane, but Plymouth Rubber Company required it for the Plyroof.

Discussion

The expansion joints were used to separate the three membranes from each other so that no physical contact occurred between them. These joints were covered with specially formed galvanized steel sheet. Although the original roof expansion joints were flush with the surface, raised ones were installed to provide complete isolation between systems.

Construction began on 6 June 1983 with removal of the existing BUR on the part of the Building 5132 roof designated Area C. In order to work with only one membrane material at a time, Area C of Building 5140 was also started. Area A, the final one on each building, was completed on 16 August 1983.

The two layers of insulation were applied with all joints staggered, and were fastened to the deck mechanically as specified. Fasteners for Areas B and C were similar, but not identical. Each was a nylon plastic expansion type inserted into a hole drilled through the insulation into the concrete deck. A pin in the center of each fastener was hammered home, expanding the fastener to grip the concrete. The manufacturers of the membranes for Areas A and C required a threaded fastener for the membrane attachment to be screwed directly into a predrilled hole in the concrete. Instead of washers for Area A,

a batten strip was used, spaced 24 in. (610 mm) on-center (Figure 50). The threaded fasteners, however, did not hold satisfactorily. They penetrated into the concrete only 1 in. (25 mm) and caused it to spall as they were tightened. Longer fasteners were tried, but they kept breaking instead of penetrating. Expansion fasteners were then substituted, and they functioned satisfactorily. The manufacturer of the Area C roofing approved the substitution. The Area A manufacturer gave preliminary verbal approval, but later withdrew it after installation had been completed.

The membrane on Area C was also fastened mechanically. Each fastener, in addition to anchoring the insulation, was centered on a 7-in. (178-mm) disc of reinforced membrane material. They were spaced at 22 in. (559 mm) on-center, 7 ft. (2100 mm) from each corner; for the rest of the area, spacing was 30 in. (762 mm) (Figure 51).

Existing nailers around the perimeters were reused. To make them flush with the insulation surface, it was necessary to fasten another length of treated wood on top. The second layer was fastened with galvanized nails spaced 4 in. (100 mm) on-center and staggered. End joints were cut at a 45-degree angle. Metal fascia consisted of PVC-coated steel, fastened to a galvanized steel continuous cleat.

Installation of the batten system was similar to that at Fort Polk. Joints between the membrane and battens were welded by hand, as shown in Figure 52. A sand bag was used as a weight to force the seam area into intimate contact. Since this operation was performed by hand, the worker did not always resume his solvent application at the exact point he had stopped. The manufacturer's representative instructed him to mark the location with a lateral swipe of the brush, which would leave a shiny mark on the slip-sheet surface.

The disc-attached system was installed by using an adhesive to bind the membrane to each disc. This adhesive consists of two components, one of which is a small bottle of hardener, added for each gallon (3.78 L) of adhesive. Since only a small amount of adhesive was used at once, the hardening agent was gauged by eye to the quantity of adhesive being mixed. The possible effect of nonuniform proportions of the two components on long-term performance of the adhesive is not known, and will bear watching. Figure 53 shows application of the adhe-

sive to a disc, and Figure 54 shows the membrane being adhered. After adhering the membrane to the discs, the seams were welded by a hand-held hot-air gun, probed and corrected as on the batten system, and sealed with the sealant as at Chanute and Fort Polk.

Since all seams of the two mechanically fastened systems were welded by hand, the wrinkling caused by the machine at Chanute and Fort Polk was absent. However, the time consumed in forming seams by hand is longer than when using a machine, and the operation is more prone to error. Figure 55 shows a typical seaming operation.

Dust from other operations settled on the battens or discs during their attachment to the membrane. Therefore, it was necessary to clean these surfaces just before applying the adhesive or solvent. Neither manufacturer's instructions addressed this situation, so the contractor had to decide which cleaning method to use. Xylene was used to clean the discs and toluene was used to clean the battens. The battens were supposed to be installed with a 1/2-in. (13-mm) gap between ends, but this left each end free to rise when fasteners were installed. Approval was received from the manufacturer to slip one batten end into the other since there is a turned-under hem on each side, and a fastener was then inserted through both battens. Sharp edges at the end were taped before membrane installation. Also, high winds created problems in attaching the membrane to the battens. There were numerous waves and unbonded locations, which necessitated much cutting and patching.

Since urethane insulation was used at Dugway, a fiber board layer was not required for the fully adhered system on Area B; the system could be cemented directly to the foil facing. Installation was similar to that at Fort Polk, except that seams were welded by hand instead of with a self-propelled hot-air gun (Figure 56). As with the solvent welding, this is more time-consuming. The seams of this system do not require calking after completion.

General Comments

Several problems were experienced at the three test sites, the most important of which was poor housekeeping. Much dust and debris resulted from demolition operations, and clean-up was not performed as regularly or as carefully as was required. Dust containing asphalt was blown onto installed membranes; when heated by the sun, the asphalt

became bonded to the membrane surface and required hand scrubbing to remove.

Rolls of membrane material were not wrapped before shipment and were dirty when received, both on the exposed surface of the rolls and at the ends of the rolls along the edges of the sheets. Construction dirt tended to accumulate on the surfaces of the mechanical fastening devices, necessitating clean-up before membrane attachment. Manufacturers did not address these situations in their installation instructions.

Contractors sometimes began demolition and thus reroofing in the same area as workers and materials gained access to the roof. This necessitated continuous traffic over newly completed work, causing both contamination and damage. It was necessary to have the contractor at one site relocate his point of access because he did not do this on his own initiative.

The nonreinforced membranes were observed to shrink considerably during the relaxation period after unrolling, whereas the reinforced membranes were dimensionally stable. One of the nonreinforced membranes did not shrink uniformly, and much wrinkling was observed as the sheets relaxed. The manufacturers' instructions state that relaxation time should be adjusted according to temperature, but do not provide a specific relationship between relaxation time and temperature.

The method of attachment seems to affect seam quality, especially when seams are formed with the self-propelled machines. These machines tend to pull the membrane along with them as they travel. The loose-laid and mechanically fastened systems do not resist this action, and can be severely wrinkled as a result. The fully adhered system, on the other hand, resists wrinkling and remains flat.

High winds interfere with membrane attachment as well as with insulation board position. With loose-laid systems, even using what appears to be adequate temporary ballast, wind intruding under the membrane tends to shift the insulation boards out of position. Since foam boards such as urethane or polystyrene are usually used with single-ply membranes, chances of wind interference are very good. High winds can also interfere with handling lightweight boards for adhered or mechanically fastened systems, especially if large boards such as 4 x 8 ft

(1220 x 2440 mm) are used. Smaller boards are easier to handle and can be installed with less chance of breaking and flying away during installation. If ballasted systems are installed, mechanically fastened insulation will not be apt to become displaced by wind intruding under the membrane before permanent ballast is spread.

4 CONCLUSIONS AND RECOMMENDATIONS

Polyvinyl chloride (PVC) single-ply roofing appears to be a viable substitute to the built-up roof for Army use. Application techniques are acquired easily, but are exacting in their demands. Much care on the part of the installing work force is necessary to insure freedom from contamination and workmanship deficiencies.

Manufacture of the membrane has a great effect on the quality of installation. Nonreinforced membranes tend to shrink to an alarming extent. Manufacturers' instructions specify a relaxation time, but state that this time should be adjusted, depending on the ambient temperature. They do not specify a quantitative relationship between time and temperature.

An unreinforced membrane may not shrink uniformly when allowed to relax. Scattered areas may shrink less, resulting in wrinkles. If this wrinkling extends into the seam area, the seams may not be watertight after welding.

Loose application of insulation under loose-laid membranes can result in severe displacement of the insulation during high winds. Even what appears to be adequate temporary ballast may not be enough to prevent this.

Mechanically attached systems and loose-laid systems can be pulled and wrinkled by automatic self-propelled welding equipment, whether the welding is performed by hot-air fusion or by solvent action. This tendency is greatly lessened if the membrane is fully adhered before seaming.

Threaded mechanical fasteners can be unsatisfactory for use with concrete roof decks, even if they are designed by the manufacturer for that purpose.

Insertion can cause the concrete to spall, and if longer screws are used, they can break from torsion before they are fully inserted.

PVC membrane roofing should be given tentative approval for Army use, pending results of field testing. However, not all materials or techniques should be allowed.

Material should be restricted to the reinforced type of membrane. The advantage of this material is its dimensional stability, as it has little or no shrinkage compared with large shrinkages with unrein-

forced membranes. Chances for distortion of the membrane during seaming with self-propelled equipment are greatly reduced over those of the unreinforced membrane. Installation technique should be restricted to the fully adhered or ballasted systems.

Insulation should be fastened at all times, whether the fully adhered or ballasted system is used. Insulation should be fastened to concrete decks with expansion-type fasteners only to prevent spalling of the concrete surface or breaking of threaded fasteners that are too long.

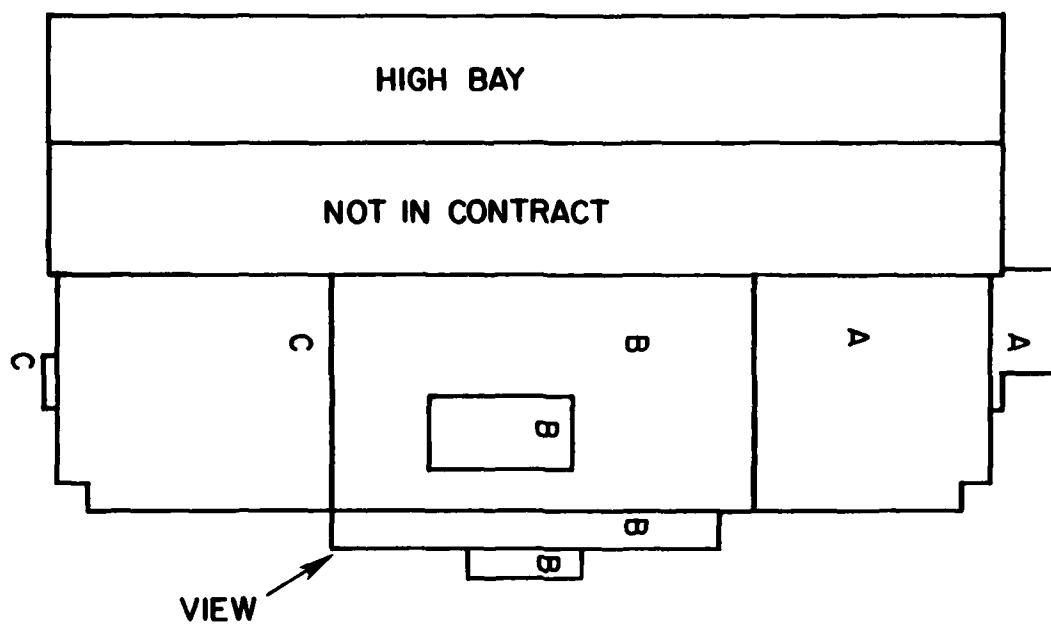


Figure 1. Building 96 at Chanute Technical Training Center.

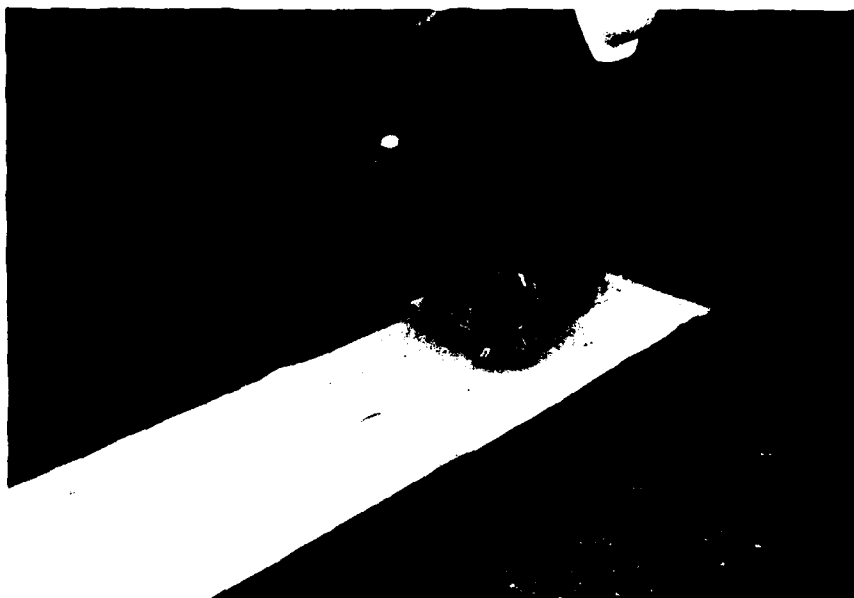


Figure 2. Demonstration of seaming technique.



Figure 3. Wrinkles in seam caused by hot-air gun.



Figure 4. Wrinkles caused by too slow speed of hot air gun.



Figure 5. Evidence of improper heat settings for seam welder.



Figure 6. Effect of wind on unballasted membrane.



Figure 7. Membrane shrinkage after cutting loose from sheet metal.



Figure 8. Factory wrinkles in membrane sheets—View 1.



Figure 9. Factory wrinkles in membrane sheets—View 2.



Figure 10. Factory wrinkles in membrane sheets—View 3.



Figure 11. Original lightning rod installation.



Figure 12. Flashing for lightning rod cable.



Figure 13. Shop vacuum unit used for smoke test.

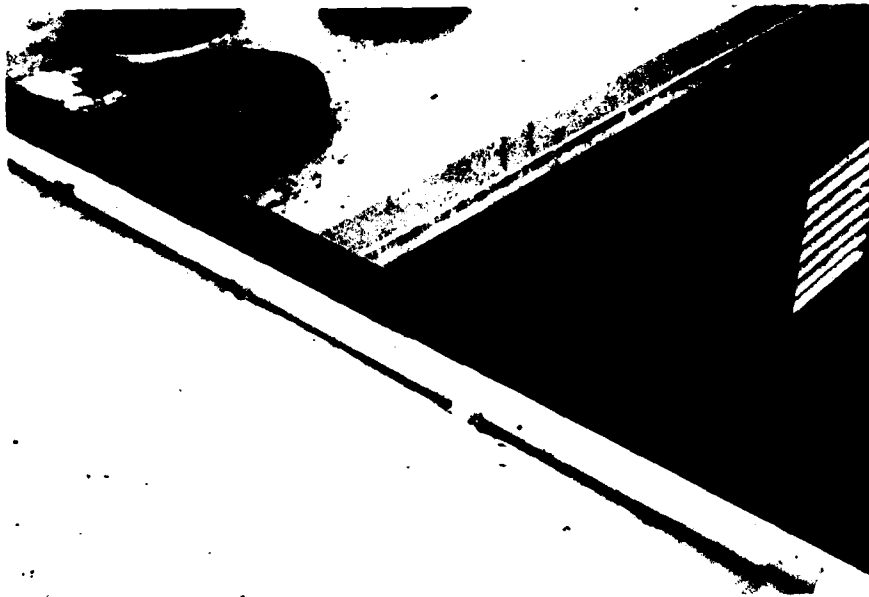


Figure 14. Smoke visible at edge of roof.

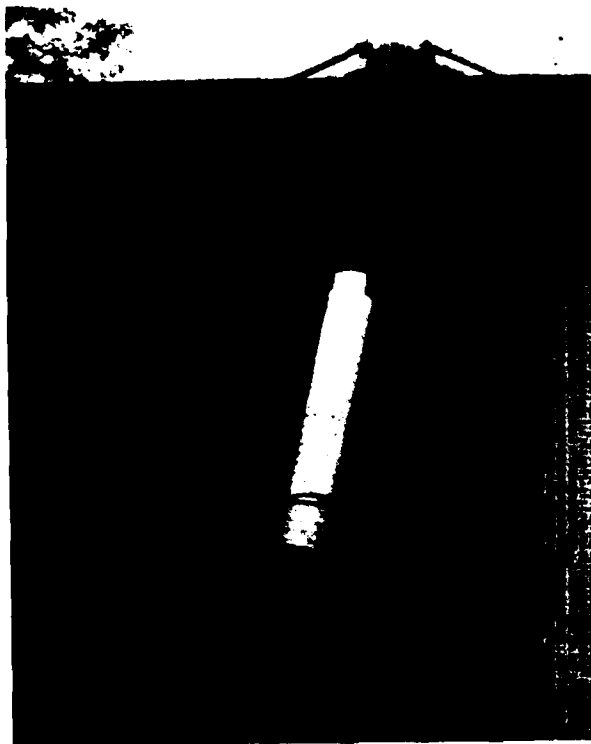


Figure 15. Chute for dumping debris into truck.



Figure 16. Throwing debris off the roof into truck.

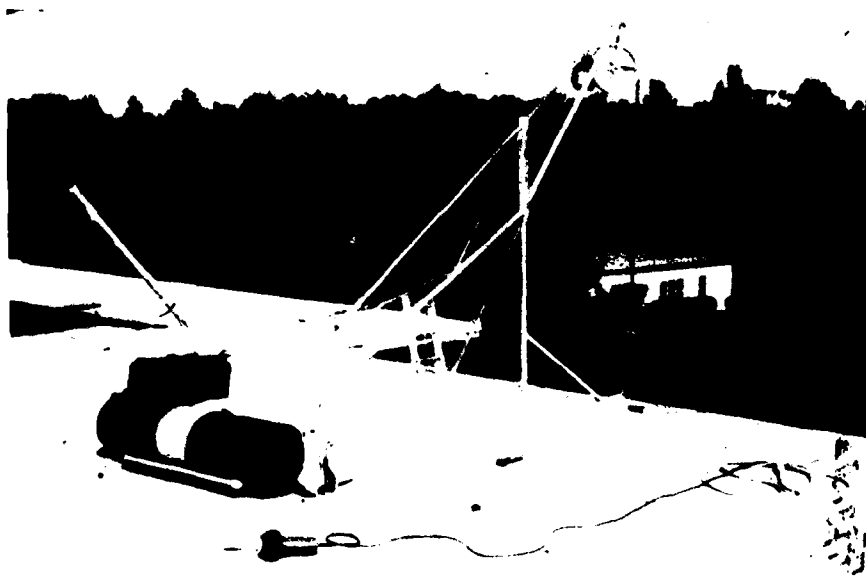


Figure 17. Hoist for lifting materials to the roof.

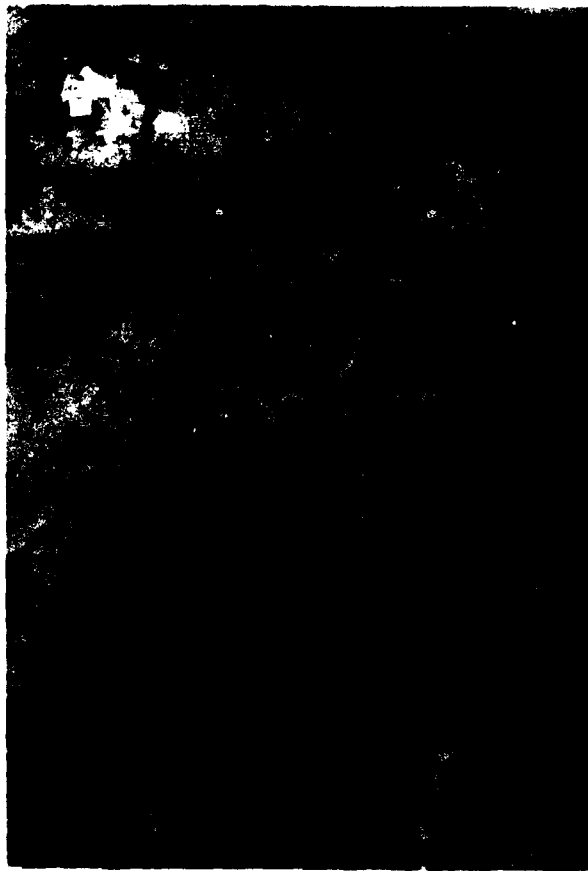


Figure 18. Contamination of newly installed membrane.



Figure 19. Ladder to low roof without foot protection.

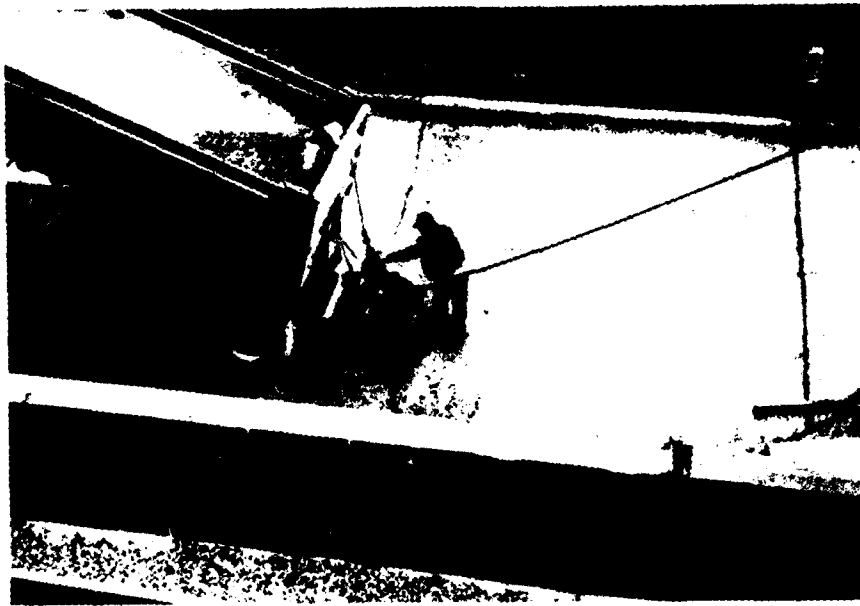


Figure 20. Dumping gravel from truck into bucket.

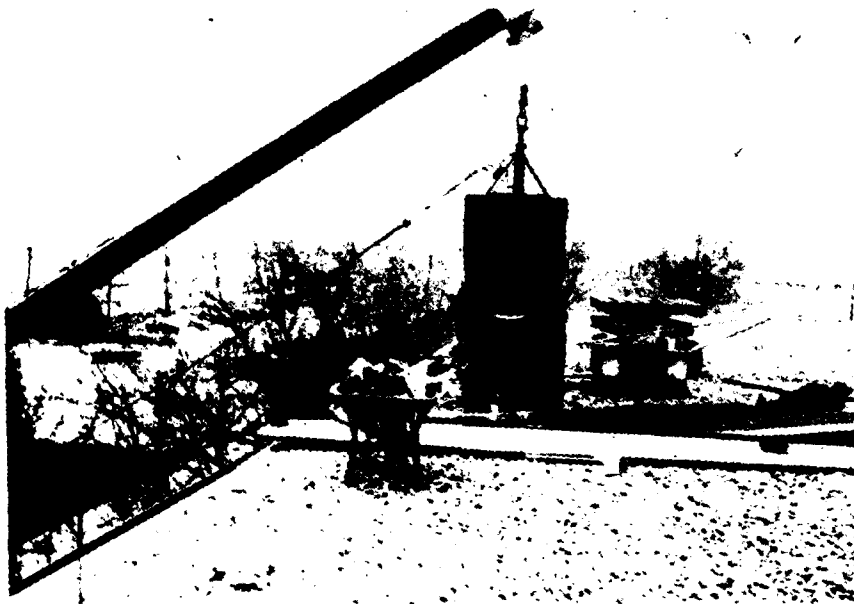


Figure 21. Dumping gravel from bucket into buggy.



Figure 22. Spreading gravel on roof.

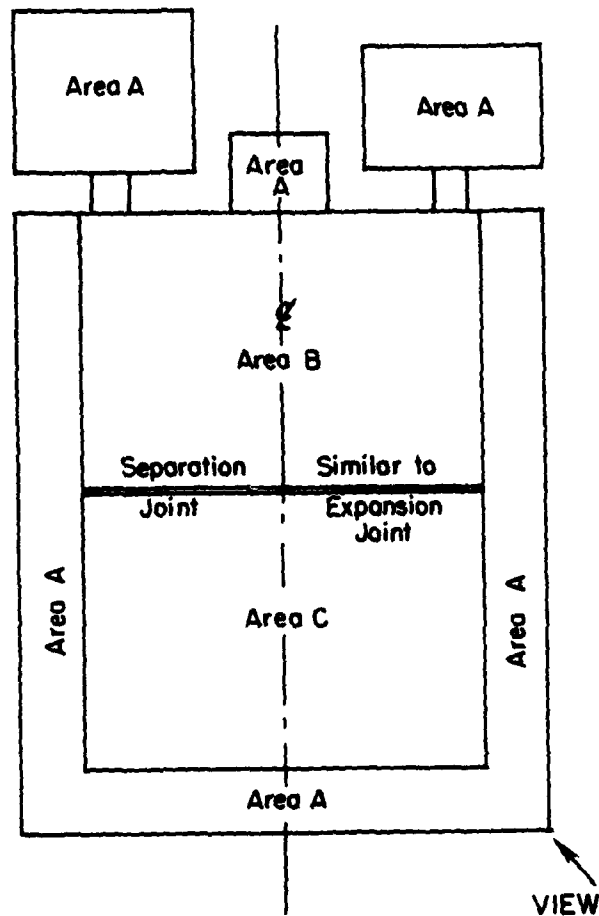


Figure 23. Building 1411 at Fort Polk.

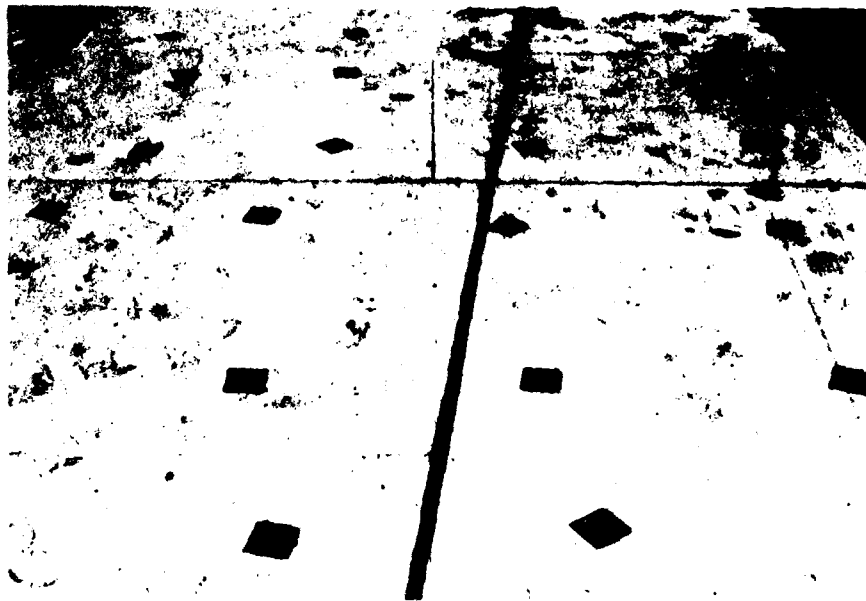


Figure 24. Fastening pattern for first insulation layer.



Figure 25. Fastening pattern for second insulation layer.

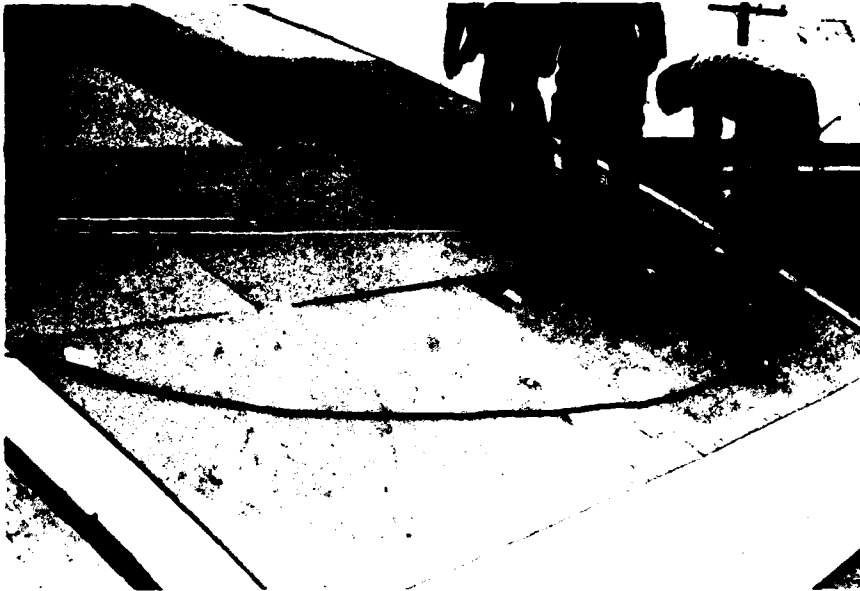


Figure 26. Fastening pattern for insulation under Sarnafil.

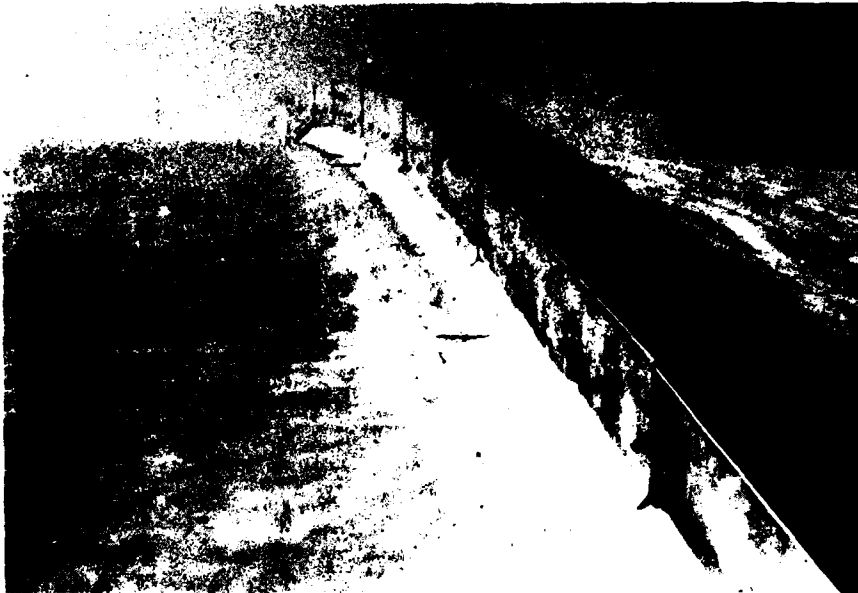


Figure 27. Divider across arched roof between two PVCs.



Figure 28. Batten strips installed above slip sheet.

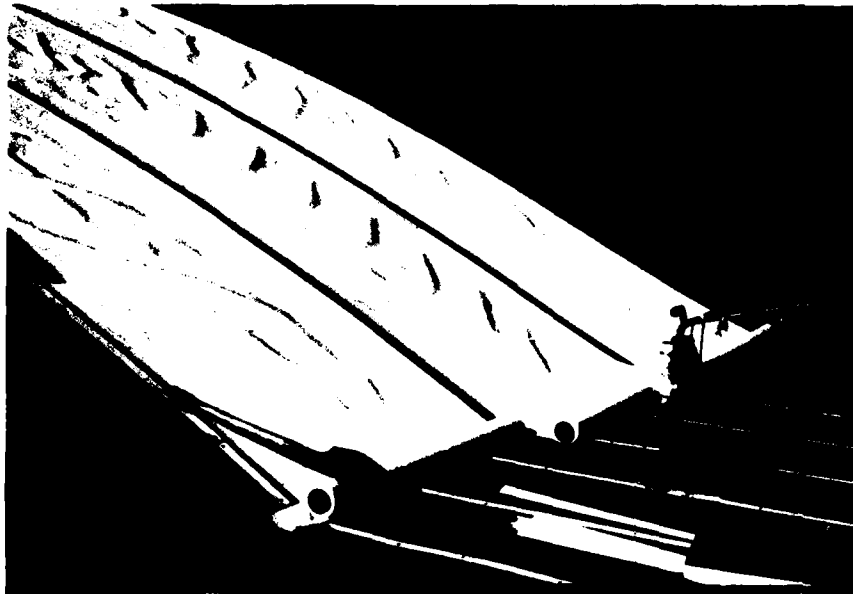


Figure 29. Rolls of membrane relaxing.



Figure 30. Welding membrane to batten strip.



Figure 31. Spot welding to batten strip with hot-air gun.



Figure 32. Applying seam sealant.



Figure 33. Wrinkling of membrane at end of batten.



Figure 34. Applying adhesive to insulation.



Figure 35. Applying adhesive to back of membrane.

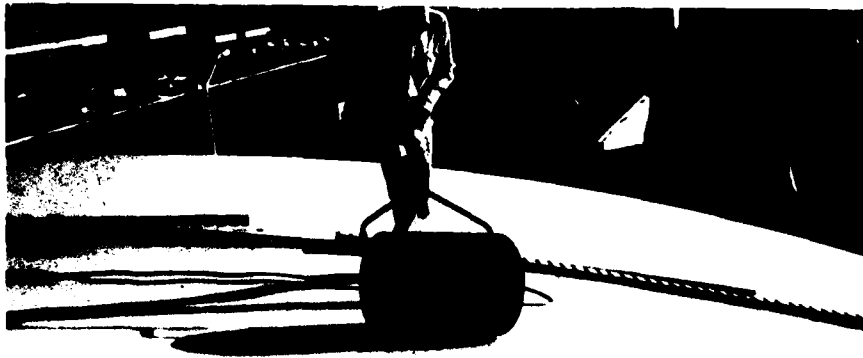


Figure 36. Rolling membrane to insure full contact.



Figure 37. Rounded corner at end lap.

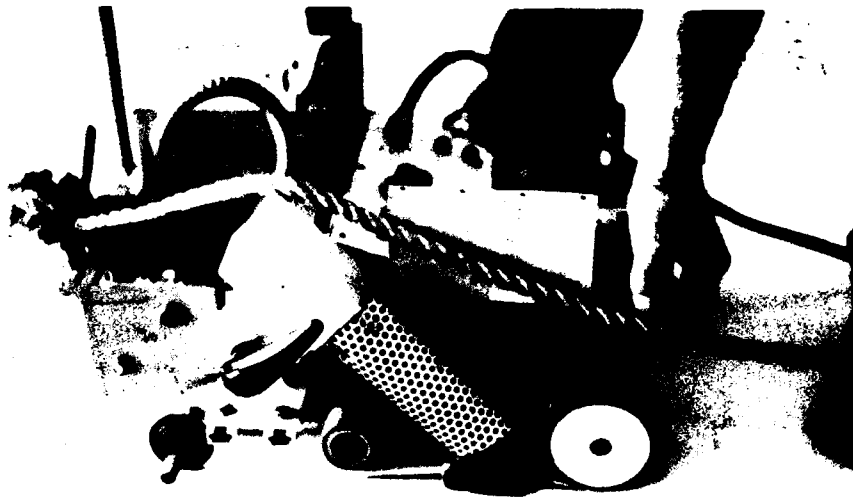


Figure 38. Automatic hot-air seam welder.



Figure 39. Installing sealing strip at edge of roof.

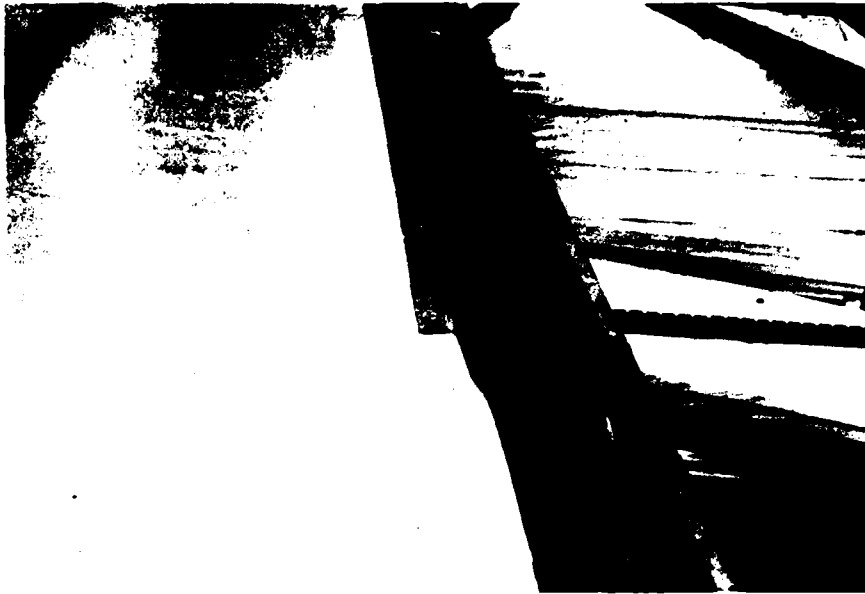


Figure 40. Keeper strip at edge of roof.

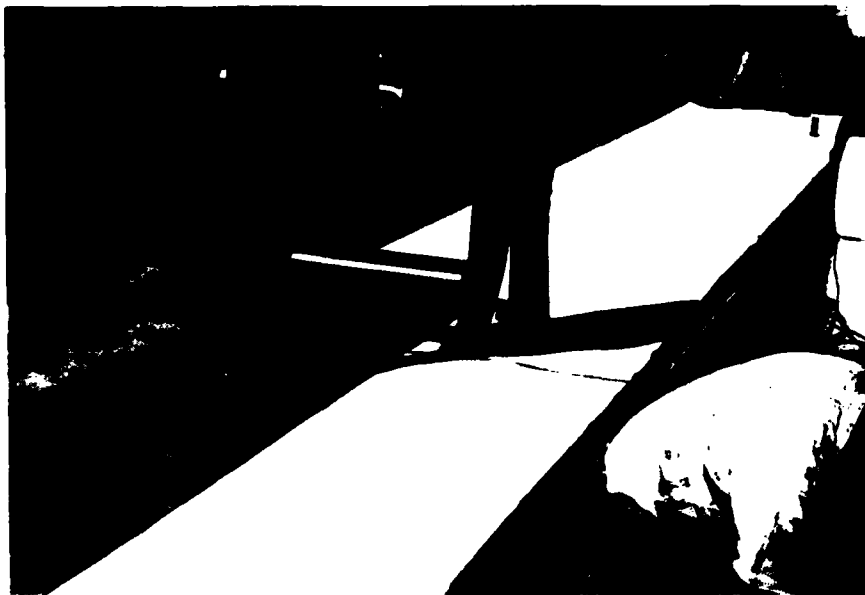


Figure 41. Fiberglass slip sheet and first roll of membrane.



Figure 42. Fasteners along edge of sheet

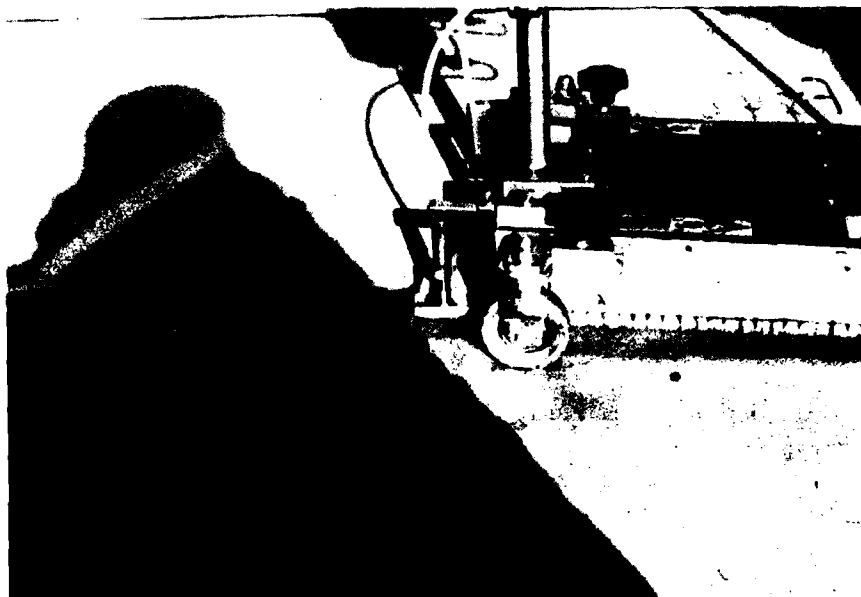


Figure 43. Automatic solvent welder.



Figure 44. Wrinkling caused by automatic solvent welder.



Figure 45. Base flashing with 90 degree bend.



Figure 46. Solvent welding sheet to 90 degree bend.



Figure 47. Base flashing with 45 degree cant.

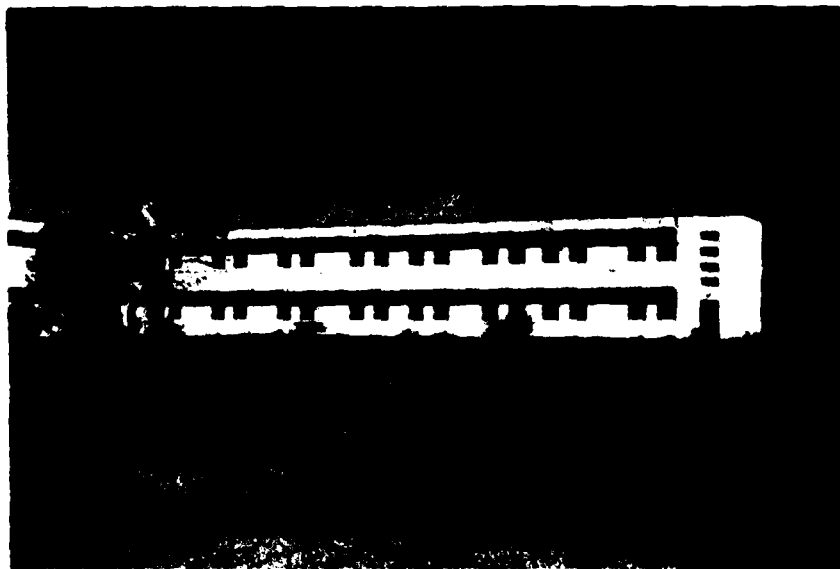
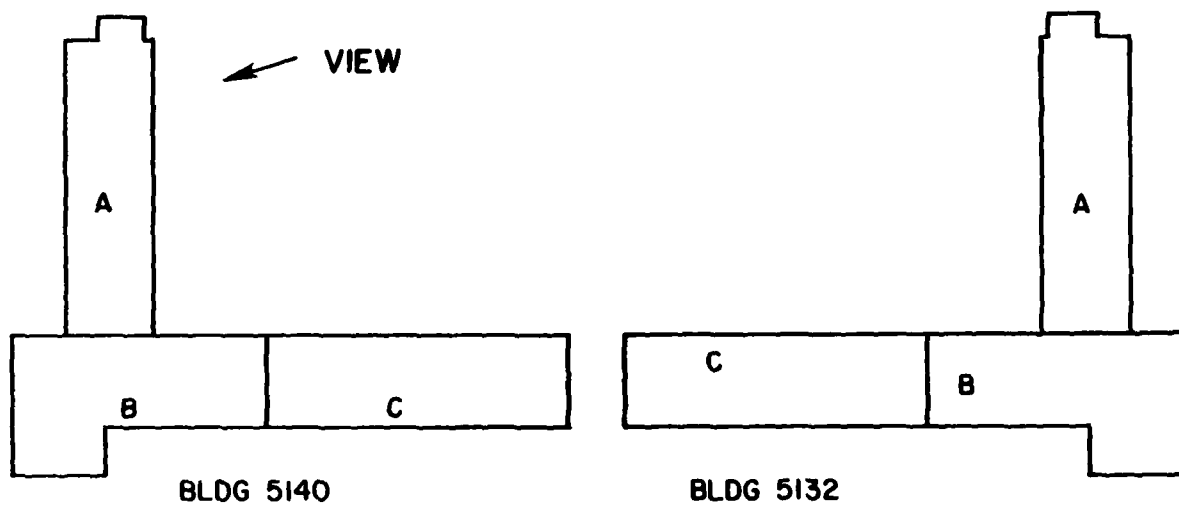


Figure 48. Buildings 5132 and 5140 at Dugway.



Figure 49. Temporary roof on building 5132.



Figure 50. Batten strips installed above slip sheet.



Figure 51. Discs for attaching membrane.



Figure 52. Welding membrane to battens.



Figure 53. Applying adhesive to PVC disc.



Figure 54. Adhering membrane to PVC disc.

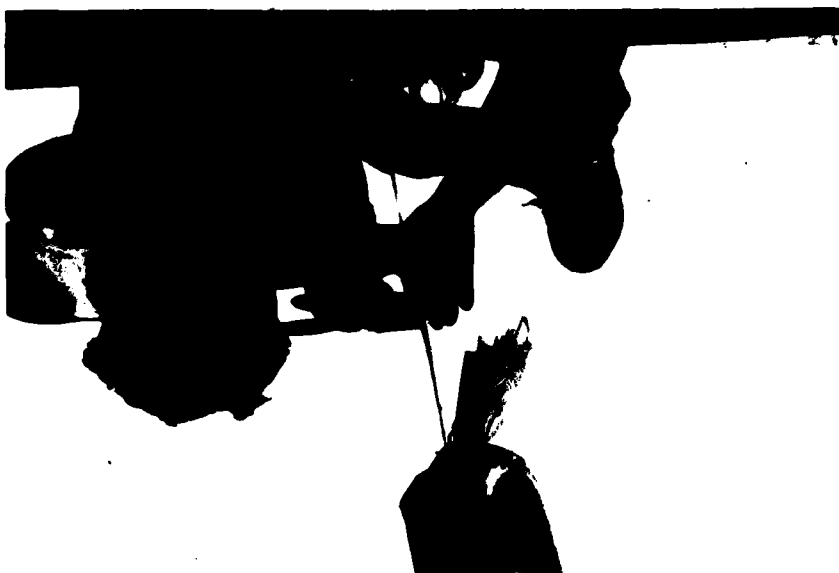


Figure 55. Hand welding seam with solvent.

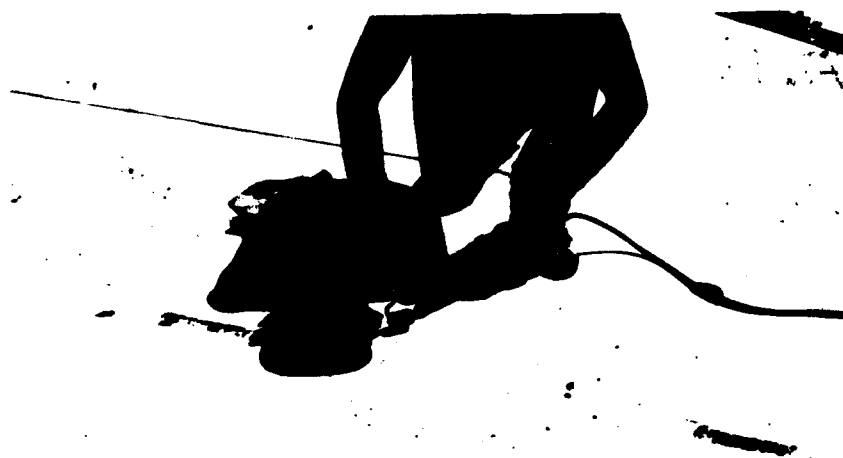


Figure 56. Heat welding of adhered system.

APPENDIX:
ROOFING TEST GUIDE SPECIFICATION
SECTION _____
SINGLE-PLY POLYVINYL CHLORIDE
(PVC) ROOFING

ROOFING TEST GUIDE SPECIFICATION

SECTION _____

(A)

SINGLE-PLY POLYVINYL CHLORIDE (PVC) ROOFING

(B)

(C)

1. **APPLICABLE PUBLICATIONS:** The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.

1.1 American Society for Testing and Materials (ASTM) Publications:

D 448-80	Standard Sizes of Coarse Aggregate for Highway Construction
D 2240-81	Standard Test Method for Rubber Property - Durometer Hardness
D 3083-76 (R 1980)	Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal and Reservoir Lining
E 96-80	Water Vapor Transmission of Materials

1.2 Factory Mutual Engineering Corporation (FM) Publications:

Approval Guide 1984	Equipment, Materials, Services for Conservation of Property
Data Sheet 1-29	Single Ply Membrane Roof Systems

1.3 Underwriter's Laboratories (UL) Publications:

790	Tests for Fire Resistance of Roof Covering Materials
-----	---

1.4 American Wood Preservers Bureau (AWPB) Publications:

LP2-80	Standard for Softwood Lumber, Timber and Plywood Pressure Treated With Water-Borne Preservatives for Above Ground Use
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2. **GENERAL REQUIREMENTS:** [Loose-laid with ballast] [partially bonded] [bonded] [unreinforced] [reinforced] polyvinyl chloride (PVC) single-ply membrane roofing shall be applied to the roof surfaces indicated. Roofing membrane shall be furnished in rolls of the manufacturer's standard width. Membrane shall be free of any pinholes, lumps and foreign material.

(D)

2.1 Standard Product: The PVC roofing system, including flashing, shall be the standard product of a single manufacturer who has been regularly engaged in the production of this type of product for at least three consecutive years.

(E)

2.2 Delivery and Storage: Materials shall be delivered to the job site in the manufacturer's original, unopened packages, clearly marked with the manufacturer's name, brand name, and description of contents. [Materials shall be labeled for compliance with UL requirements.] Materials shall be stored in clean, dry areas at a temperature between 60 degrees F and 80 degrees F. [Aggregate for ballast shall be stored either in the delivery trucks or in piles on tarpaulins, and covered with tarpaulins. Aggregate shall not be stored on the roof.] Plastic sheets shall not be used instead of tarpaulins for covering any materials stored out-of-doors.

2.3 Coordination: Roofing operations shall be coordinated so that flashings are installed to permit continuous roof surfacing operations. Roofing operations shall also be coordinated with roof insulation work so that all insulation applied each day is weatherproofed the same day with the completed roofing system. [Ballast shall not be applied until the membrane has been smoke tested for leaks.]

2.4 Fire and Wind Uplift Requirements: The completed roof shall be rated Class A as determined by UL790. Roofing systems to be installed over steel decks shall be rated Class I as specified in FM Approval Guide. Wind uplift resistance shall be based on FM Data Sheet 1-29.

2.5 Performance Tests: The proposed procedure for forming seams shall be demonstrated on two pieces of membrane at least 20 feet long and 12 inches wide. Width may be increased if necessary to meet manufacturer's requirements. Demonstration shall include lapping and sealing the two pieces of membrane together along the long dimension, inspecting the completed seam, correcting identified faults, and sealing the seam edge if part of the recommended procedure. Upon completion, the Contracting Officer will inspect the seam using cut samples, and approve the procedure before work is initiated on the roofing. If the procedure is found unacceptable, the Contracting Officer may require a second test or changes in the procedures or both. One of these seams may be submitted as the sample required below.

3. SUBMITTALS: Contractor shall submit the following in accordance with SPECIAL PROVISIONS.

3.1 Certificates of Compliance attesting that the materials meet specification requirements.

(F)

3.2 Manufacturers' Instructions for [mechanical fastening of insulation and] installation of the membrane, including procedures for installing the membrane, flashing, splicing [and bonding of the membrane], [use of prefabricated pipe sleeves for smoke testing, methods for performing the smoke test],

and installation of walkways in accordance with these specifications shall be submitted for approval.

3.3 Samples: The following samples shall be submitted for Government testing:

Membrane	18 in wide, full width sample from end of each roll of membrane used, plus 200 sq ft in one piece from one roll
[Slip Sheet	[10 ft from end of one roll]
Seam	20 ft of seam 1 ft wide in one piece
Bonding Solvent	1 quart
Seam Sealant	1 cartridge
PVC Coated Sheet Metal	8 ft section of formed flashing
[Ballast]	[100 pounds]
Fasteners and Washers	1 pound of each type

(D)

3.4 Qualifications of Installer: Certificate from membrane manufacturer identifying the installer, certifying that the installer is qualified to install the roofing system, that the installer has been certified by the manufacturer for the previous three consecutive years, and that the installer has had documented installation experience for the previous three consecutive years.

(G)

3.5 Shop Drawings, showing arrangement of sheets, location of splices, and all flashing details including waterproofing of joints where sheet metal flashings change direction. Typical details as shown in catalogs shall not be submitted in lieu of shop drawings.

4. MATERIALS:

(H)

4.1 Membrane shall be ___ mils thick and shall comply with ASTM D 3083 except as follows:

Reinforcement	[None] [glass fiber] [polyester] [nylon]
Tensile Strength (minimum)	[Non-Reinforced 2000 psi] [Glass Fiber Reinforced 1400 psi] [Polyester Reinforced 1500 psi] [Nylon Reinforced 5000 psi]
Tear Resistance (minimum)	[Non Reinforced 250 lbs/in] [Reinforced 300 lbs/in]
Shrinkage (maximum)	[Non Reinforced 1%] [Reinforced 0.5%]
Elongation (minimum)	[Non Reinforced 250%] [Reinforced 25%]

Volatile Loss 1%
(maximum)

Soil Burial Not Required

Shore A Hardness: Between 70 and 85-Durometer, as determined
by ASTM D 2240

Water Vapor Permeance: Minimum 0.14 perms as determined by
ASTM E 96, Procedure A

4.2 Adhesives, splicing cements, sealants, mastics, and building adhesives shall be as furnished by the roofing membrane manufacturer.

4.3 Nailers shall be number 2 or better grade lumber and shall be water-borne preservative treated in compliance with AWPB LP-2, except that acid copper chromate shall not be used.

4.4 Insulation shall be as specified in SECTION: INSULATION FOR BUILT-UP ROOFING, and shall be certified as compatible with the roofing system by the membrane manufacturer.

4.5 Fasteners for sheet metal flashing shall be corrosion-resisting steel annular-ring type nails or screws of the size appropriate for use. Fasteners for anchoring insulation and anchoring the roofing membrane shall be as furnished or approved by the roofing manufacturer.

4.6 Flashings shall be UV-resistant materials furnished as standard by the membrane manufacturer, including heavy-gage elastomeric material and PVC coated or covered sheet metal, and certified by him as compatible with the membrane. Shaped flashing components shall be pre-fabricated. Sheared edges of metal flashings that will contact the membrane shall be turned under for at least 1/2 inch.

4.7 Prefabricated Accessories such as pipe seals, expansion joint covers and walkway materials shall be of the types and sizes as furnished by the roofing manufacturer.

(I)
[4.8 Ballast shall be smooth water-washed round stone approximately 3/4 to 1 1/2 inch diameter with gradation complying with ASTM D 448, size 4, except that pieces passing the 1/2-inch sieve shall not exceed 2 percent. Ballast shall be dry and dust free when installed.]

[4.9 Slip sheet between insulation and membrane shall be as furnished or approved by the roofing manufacturer.]

5. PREPARATION: [Existing roof surface shall be cleared of all loose stone, debris, oil, grease, and all other objects that may damage the new roofing membrane.] [Existing roof deck shall be stripped of roofing system, insulation and cants. Surface shall be swept clean and shall be free of rough edges or items that may penetrate the new roofing membrane. All debris shall

be removed from the roof using a covered chute or other device to minimize the spread of dust and debris. Existing surfaces shall be protected from damage; repairs shall be made to renew such surfaces at the Contractor's expense. Ground area around the chute shall be cleaned immediately after completion of stripping activities. Stripping shall be limited to area to be re-roofed during the same day.] Roofing shall not be applied in the rain or under excessive wind.

6. INSTALLATION: Installation shall comply with the manufacturer's approved instructions except as otherwise specified.

(J)

6.1 Nailers shall be installed on the perimeter of roof surfaces, curb flashing, skylights, expansion joints and similar penetrations. Surface of all nailers shall be flush with surface of insulation. Ends of nailers cut in the field shall be treated with a brush coat of copper naphthenate solution. Nailers shall be installed to resist a force of [75][175] lbs per foot in any direction.

(K)

6.2 Insulation shall be placed completely covering the area prepared for roofing. Insulation shall be [installed loose] [mechanically fastened] as specified in the roofing manufacturer's approved instructions. [Fasteners shall have a metal washer and disc of suitable material for anchoring the roofing membrane. Mechanically fastened insulation shall be approved by the Contracting Officer prior to placing membrane. Improperly placed fasteners shall be replaced.] [Insulation around drains shall be tapered to provide a smooth transition between roof and drain clamping ring.]

(L)

[6.3 Separation: Roof deck or insulation surface shall be covered with slip sheet material installed in compliance with manufacturer's approved instructions.]

6.4 Membrane: One end of the membrane shall be fastened to the perimeter anchorage. The membrane shall be rolled out on the deck and allowed to relax for at least one-half hour prior to other installation activities. Time allowed for relaxation shall depend on the ambient temperature. Membrane shall be sealed to the adjoining sheets using minimum 3-inch wide laps. End laps shall be 6 inches. Transverse seams at ends of sheets shall be staggered. Direction of laps shall be such that water flows over the lap. Membrane shall be sealed to perimeter and horizontal flashing the same day it is installed. Membrane joints shall be free of wrinkles (fishmouths). Seams shall be probe-tested and approved during the day of installation; all defective areas shall be resealed. An 18-inch long by 12-inch wide sample taken from the first 100 feet of seam constructed shall be furnished for evaluation and the hole recovered with an unseamed piece using a 3-inch lap on all sides. An additional sample the same size shall be cut from each additional 300 feet of seam constructed. [Membrane shall be tested with smoke forced into the cavity between the roof and membrane. Membrane areas containing faults shall be removed and recovered using 3-inch wide laps on all sides. Repaired membranes shall be retested for approval.]

6.5 Perimeter Nailing: Sheet metal shall be fastened to nailers [in accordance with the roofing manufacturer's approved instructions] [with corrosion resistant annular ring type nails or screws as recommended by the roofing manufacturer. Nails shall be installed on 4-inch centers, staggered. Screws shall be installed on 8-inch centers, staggered. Rows of fasteners shall be at least one-half inch from edges of sheet metal.]

6.6 Flashing: All projections and changes in roof planes shall be flashed. The splice between the flashing and the main roof sheet shall be completed [after] [before] bonding flashing to vertical surfaces. The splice shall be sealed a minimum of 3 inches beyond the fasteners which attach the membrane to the horizontal nailers. The installed flashing shall be nailed at the top of the flashing a maximum of 12 inches on centers under the counterflashing or cap. Spacing of nails shall be closer if so specified by the manufacturer. Factory prefabricated pipe seals shall be used where possible.

6.7 Cut-Offs: If work is terminated prior to weatherproofing the entire roof, the insulation line shall be straightened using loose-laid cut sheets as required, and the membrane shall be sealed to the roof deck. [Flutes in metal decking shall be sealed off along the cut-off edge.] The membrane shall be pulled free or cut to expose the insulation when resuming work and cut insulation sheets used for fill-in shall be removed. Asphalt or coal tar products shall not be used for sealing.

6.8 Ballast shall be applied in a minimum 10 pounds per square foot layer uniformly distributed over the completed membrane, after testing. Membrane shall be protected from mechanical damage during ballast application. Ballast shall not be stockpiled on the roof deck. Ballast showing evidence of dust and dirt shall be removed from the site and washed before installation. Membrane shall be weighted temporarily with old rubber tires or other method that will not damage the membrane [nor interfere with free passage of the smoke beneath the membrane.]

6.9 Walkways shall consist of concrete pavers and shall be installed as recommended by the manufacturer before ballast is installed. Ballast shall not cover the walkways.

7.0 CERTIFICATION: Manufacturer shall certify that the completed roof has been installed in compliance with his approved instructions and these specifications, and that it meets the requirements of UL 790 Class A [and FM Class I].

GENERAL NOTES

1. This guide specification is to be used in the preparation of contract specifications in accordance with ER 1110-345-720. It will not be made a part of a contract merely by reference; pertinent portions will be copied verbatim into the contract documents.
2. The capital letters in the right-hand margins indicate that there is a technical note pertaining to that portion of the guide specification. It is intended that the letters in the margins be deleted before typing the contract specifications.
3. Where numbers, symbols, words, phrases, clauses, or sentences in this specification are enclosed in brackets [], a choice or modification must be made; delete inapplicable portion(s) carefully. Where blank spaces occur in sentences, insert the appropriate data. Where entire paragraphs are not applicable, they should be deleted completely.

TECHNICAL NOTES

- A. The section number should be inserted in the specification heading and prefixed to each page number in project specifications. This section is intended for use in contracts integral with a test and evaluation project and requires revision before use in a construction contract.
- B. This specification is intended to cover reinforced and nonreinforced polyvinyl chloride (PVC) sheet roofing in either a loose-laid or adhered system over various types of decks. While this type of roofing system can be used on new construction, this specification is limited only to reroofing projects. PVC systems should not be used in direct physical contact with asphalt, coal tar pitches, or petroleum products, nor where coal tar fumes are present. Separation layers and barriers should be designed and installed in accordance with the manufacturer's recommendations. All roofs must be constructed to drain. The loose-laid system can be applied to roofs having slopes from 1/4 inch to 2 inches per foot. Do not specify PVC membrane systems for buildings 300 ft high or higher, nor for use in hurricane zones and other unusual exposure, nor for roofs that collect drinking water, unless manufacturer can certify use of his materials under these conditions and assist in the design.
- C. Paragraph 1: The listed designations for publications are those that were in effect when this guide specification was being prepared. To minimize the possibility of error, the letter suffixes, amendments, and dates indicating specific issues should be retained in paragraph 1 and omitted elsewhere in the project specifications.
- D. Paragraphs 2.1 and 3.4: Experience of both manufacturer and installer are essential to provide proper installation of roof membrane with careful attention to all details, and to ensure that materials are satisfactory and will perform well for many years. Certification of an installer by a

manufacturer, without sufficient previously documented installation experience, is insufficient for the purposes of this test program.

- E. Paragraph 2.2: Compliance of the finished roof with UL standards requires that each component be labelled to indicate that it complies also, or that certification be provided by the manufacturer if labels are not provided.
- F. Paragraph 3.2: Paragraph includes the requirement for the Contractor to develop a smoke test plan for determining the integrity of the installed membrane. This test can only be used on cast-in-place roof decks and the requirement should be deleted in all other cases.
- G. Paragraph 3.5: The Contractor will have to prepare detailed installation drawings for each specific item of construction. Catalog drawings are general in nature and do not normally reflect actual conditions.
- H. Paragraph 4.1: It is intended that several specific brands of PVC roofing be installed, one or more each at various locations in the continental United States. This paragraph should contain the values for the specific membrane selected.
- I. Paragraph 4.8: The type of ballast available in the area must be considered when the system is being designed. If the available aggregate is crushed rock with angular faces and sharp edges, a fully or partially adhered system must be selected. Only round, water-washed aggregate must be allowed on the membrane surface.
- J. Paragraph 6.1: All non-reinforced membranes and reinforced membranes having a thermal shrinkage of more than 0.1% shall be required to use nailers. Nailers used for loosely laid systems shall be anchored to resist a minimum of 175 lbs. per foot for the anticipated life of the roof. Nailers for fully adhered systems shall be anchored to resist a minimum of 75 lbs. per foot for the anticipated life of the roof. In no event shall the fastening rate be less than that specified by the manufacturer.
- K. Paragraph 6.2: Insulation applied over existing roofing systems shall form a smooth surface for the new roofing system. If there is no requirement for the additional insulation, other types of leveling course materials may be furnished by the roofing manufacturer. However, a leveling layer shall always be used to protect the membrane when covering existing roofing systems.
- L. Paragraph 6.3: An impervious slip sheet may be required by the manufacturer if the new system is installed over an existing built-up roof or for other conditions.
- M. General: Manufacturer's published installation procedures may omit details required under these specifications. Check with manufacturer during specification preparation to be sure that nothing is omitted.

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