NATIONAL BUREAU OF STANDARDS REPORT

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PROGRESS REPORT ON NEW ROOF SYSTEMS

by

William C. Cullen

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Sponsored by

Office of the Chief of Engineers
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NBS

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NATIONAL BUREAU OF STANDARDS

PROGRESS REPORT ON NEW ROOF SYSTEMS

1. INTRODUCTION

In the field of building design and construction, the subject of roof systems has become one of paramount importance to the designer, specification writer, contractor, inspector, and to those charged with maintenance responsibility. In future construction there will, no doubt, be a continued need for the conventional roofing to protect both flat and sloping decks. However, in this day of the exotic type roof decks, as the hyperbolic parabola, the dome, the barrel or arch, the conventional and conical folded plate, and the numerous combinations of these styles, it is readily evident that roofing materials and systems other than the conventional are indicated. Although it is not anticipated that the roofs of unusual contour will become commonplace in military construction, it is believed that the use of new roof systems can fulfill secondary functions which the conventional systems may not be able to perform. There has been increasing interest in roofing systems which would have one or more of the following characteristics and still perform their primary function of protecting the interior of a structure from the weather:

a. Light in weight
b. High elasticity
c. High reflectivity
d. Easy removal of atomic fall-out
e. Resistance to traffic.

Heretofore little unbiased information regarding the application, performance and limitations of the new roofing materials has been available to assist those charged with design, construction and maintenance responsibilities. Therefore, in response to a request of the Bureau of Yards and Docks, U. S. Navy; the Office of the Chief of Engineers, U. S. Army; and the Directorate of Civil Engineering, U. S. Air Force, a program was conducted to investigate the performance of new roofing systems as a task under Project No. 1004-12-10447, Performance of Roofings, of the Tri-Service Engineering Investigations of Building Construction and Equipment, NBS.

This report gives in detail the results of the performance of a number of new roof systems as they were observed in field inspections during 1961 and 1962. In addition, it gives information regarding the manufacture, application, and limitations of these materials.

In an investigation of this type, it is desirable to obtain lists of roofs for inspection from an unbiased source. However, this was obviously impossible in this study, since the investigation dealt with proprietary materials. Therefore, we have attempted to interpret our observations accordingly.

We have used proprietary names throughout the report to accurately describe the materials under investigation. However, no attempt was made to compare properties or performance of one system with another or with conventional roofing systems. We believe that experience based on a few year's service cannot be projected into the future performance life of any roof system.

2. CONVENTIONAL ROOF SYSTEMS

2.1 Flat Roofs (Slopes of 0-2 in. per ft.)

The flat or slightly sloping roof decks are generally protected with a built-up bituminous membrane which consists of alternate layers or plies of a bituminous-saturated felt, cemented together with a bituminous material. The bitumen used to impregnate the felt and to cement the plies may be either asphalt or coal-tar pitch.

Coal-tar pitch roofs are always surfaced and are always hot-applied, while asphalt-built-up roofs may be either hot- or cold-applied and may be surfaced or left smooth. Cold-applied roofs (cold process) are made up of alternate plies of saturated and coated felts, cemented to each other with "cutback" cements. They are generally surfaced with an asphalt roof coating or an asphalt emulsion.

Economics, size of the roof, slope of the deck, climate to which exposed, etc., are factors which influence the type of built-up roof selected for a specific job.

2.2 Steep Roofing (Slopes in excess of 2 in. per ft.)

The conventional materials for protecting steep roof decks are many. The type of structure, the climate, economics, aesthetics, etc., dictate the particular roofing required. The following roofing systems are commonly used on sloping decks:

a. Asphalt Shingles
b. Asphalt-Prepared
c. Cold-Process, Built-Up

In addition, other roofings, as asphalt built-up, wood shakes or shingles, slate, tile, and metal are frequently used in specific areas.

2.3 Traffic Decks

Traffic or promenade roof decks generally consist of a structural deck over which a multiple-ply, bituminous membrane is applied. A wearing surface, such as promenade tile of vitrified clay, concrete, or macadam, is in turn applied over the waterproof membrane.

This type of construction currently represents the best experience of the roofing industry for traffic. Obviously, the success or failure of such a system depends to a large extent on the skill and experience of the roofing contractor and the surface finisher.

Generally the built-up, bituminous membrane under a traffic bearing surface should be considered as waterproofing and not as roofing.

3. NEW ROOF SYSTEMS

A number of new roofing materials and roof systems have appeared on the market during the past 3 or more years. Some of these systems have been introduced as substitutes for current types of roofing for both flat and steep roofs, while others have been promoted to serve a particular function which conventional roofings can accomplish only with difficulty; for example, the protection of roofs of unusual contours as the curved shells, the dome, the folded plate, or the hyperbolic parabola. In some cases, the new systems were designed to fulfill both needs.

Under the category of new roof systems we have included traffic or promenade decks other than the conventional type waterproofed with a built-up, bituminous membrane. One of the two systems described has been in use for over 9 years.

3.1 New Roof Systems Other Than Traffic Decks

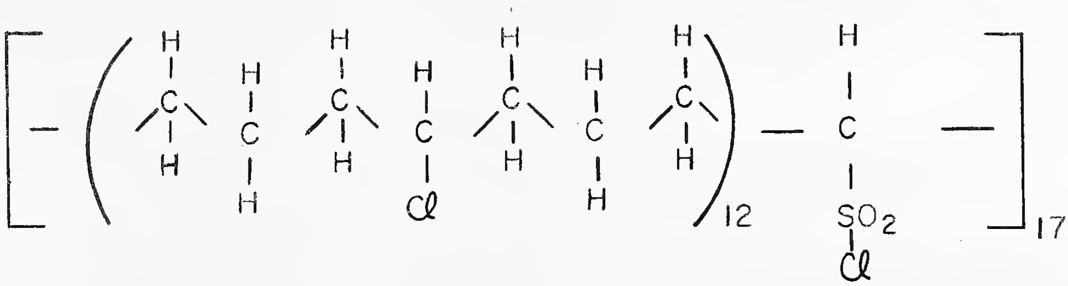
3.1.1 Neoprene - Chlorosulfonated Polyethylene

The most common of the elastomeric materials which have been used as roof systems are based on systhetic rubbers identified as neoprene and Hypalon.[1/]

1/ Registered Trade Mark of E. I. duPont de Nemours & Company, Inc.

Neoprene, one of the first synthetic rubbers to be produced on a commercial scale, was introduced in 1932. It is reported to have a history of good resistance to sunlight, temperature extremes, weather, ozone, and to oil and grease.

Hypalon was introduced to the rubber industry in 1952 and has the chemical name of Chlorosulfonated Polyethylene. It is prepared by treating a solution of polyethylene with gaseous chlorine and sulfur dioxide to yield a product containing one chlorine for each seven carbon atoms and one solfonyl chloride group for each 90 carbon atoms. The idealized structural formula is illustrated as follows:



The neoprene and Hypalon are used either singly or in combination to form a roofing membrane.

The neoprene may be applied in either a sheet form or as a liquid roofing solution. The cured sheet, about 1/16-inch in thickness, is applied as a one-ply membrane with a minimum of 2-inch lap joints at all seams. A neoprene cement is generally employed as the adhesive.

By far the most common technique is to apply the neoprene in solution form using the conventional methods of brushing, rolling, or spraying. Of course, each of these methods has its advantages and limitations. However, it has been reported that the pressure roller method has proven most satisfactory and economical.

The chlorosulfonated polyethylene roofing solution, although used alone in some cases, finds most use as a protective, reflective, and decorative coating on the neoprene base, whether it is applied in sheet or solution form.

It is important in the fluid-applied systems that the total dry film thickness should not be less than 20 mils (.020 in.).

3.1.2 Asphalt Emulsion-Chopped Glass Fiber Combination

The roof system employing asphalt emulsion and glass fiber combination is identified as the "Monoform"2/ system. The roof system essentially consists of a base sheet applied over the prepared roof deck with either hot or cold asphlat cement. In some instances, the base sheet may be eliminated. The Monoform system, which consists of the asphalt emulsion and the chopped glass fibers in the ratio of 3 gallons of emulsion to one pound of chopped glass, is applied over the base sheet or prepared deck by means of a special three-nozzle spray gun identified as the "Sealzit Gun" which sprays the emulsion and glass simultaneously. This provides a relatively smooth surface which can be further coated with selected light colored, light-reflective coatings.

The main components of the "Monoform" roof are:

a. Base Sheet - A special asphalt-coated and asphalt-saturated felt which weighs about 55 pounds per square.

b. Asphalt Emulsion - A clay type emulsion which meets Military Specification MIL-R-3472 and contains asphalt, clay (emulsifier), chemical stabilizers and film-tightening agents.

c. Glass Fiber - Type L or electrical glass treated to insure uniform and complete bonding with asphalt emulsion and especially designed for use in the "Sealzit Gun" and as a reinforcement for asphalt roofing.

3.1.3 Cold-Applied, Coal-tar Roof Membrane

A coal-tar roofing product identified as "Bitumagic"3/ cold-applied roofing recently appeared on the market. This product consists of a coal-tar-pitch impregnated asbestos or glass felt to which coal-tar base adhesive is applied. A rather unique feature of this system is that a 35-mil (.035 in.) thick, pressure sensitive adhesive is factory-applied, which eliminates the need for either hot or cold cements during application. The surface of the adhesive is covered with a disposable release paper which prevents the material from adhering to itself during storage or shipping.

2/ A trademark of The Flintkote Company.
3/ Koppers Company Tradename.

For application, the release paper is stripped off and the roofing is applied to the surface, face down. Each sheet is lapped from 2 in. to 19 in. depending on the number of plies required.

A top coating of a coal-tar emulsion is then applied to serve as the weather coating and to complete the roof system. This in turn may be coated with a decorative or reflective coating if desired.

3.1.4 Polyvinyl Fluoride-Asbestos Felt Roofing Membrane

This new roofing material, which is identified as T/NA 200 [4/], consists of a laminate of a polyvinyl fluoride plastic film (Tedlar) [5/] and an asbestos felt. The asbestos fibers are formed into the felt using an elastomeric (neoprene) binder. The Tedlar film, about 2 mils (.002 in.) thick, is laminated to the asbestos felt with an adhesive and the product is then wound in rolls for shipment.

In practice, the T/NA 200 roofing is applied in a roof system using conventional hot or cold methods. Generally a one-ply system is employed. However, a base sheet is often necessary for application over certain decks. The roofing sheet has a 2-inch selvage edge to allow for side lapping. Caution is required on the part of the roof applicator to avoid the contamination of the adjoining sheets with the adhesive. The side laps are secured with a pressure-sensitive tape of the Teddar film about 4-inches in width. This practice makes it unnecessary to bring the mopping adhesive to the edge of the lap.

It is claimed that this roofing may be applied over roof decks from level to vertical. The high coefficient of solar reflectivity of the white plastic film reduces surface temperatures to such an extent that the possibility of slippages is greatly reduced.

4/ The Ruberoid Company Trade Mark
5/ duPont Company Trade Mark

3.1.5 Miscellaneous New Systems

From time to time during this investigation, other roofing systems have been brought to our attention. Many of the systems are unique in either composition or method of application and, no doubt, will find a place in the roofing industry, especially in the future era of new and radical designs in building construction.

Since most of these materials are only in experimental stages and little information is available regarding their performance as or in a roof system, we have not included them in this report. However, a simple listing of them appears warranted.

a. Polyvinyl chlorides
b. Epoxies
c. Butyl Rubbers and Butyl latexes
d. Polyisobutylenes
e. Combinations of Epoxies and Elastomers

3.2 Traffic Decks

3.2.1 Dexotex Weatherwear[6/]

The Dexotex roof system provides a seamless roof surface suitable for use as a traffic deck. This system is recommended by the manufacturer for application over new roof decks as well as over existing built-up roofs, quarry tile roofs, etc. The roof system is custom made on the job site and is applied essentially as follows:

> The roof surface is prepared and pitched to the drains with a trowelled-on coating of a mixture of asphalt emulsion, portland cement and sand. One ply of asphalt-saturated asbestos felt is placed on the deck, but is not adhered to the roof surface. This is called the "slip-sheet". The flashings are formed with burlap fabric embedded in a rubber-like mastic. The membrane, consisting of a burlap fabric and a rubber-base mastic, is applied over the asbestos felt. A traffic surface, consisting of two trowel coats of a neoprene-aggregate mixture, is then applied, followed by two trowelled-on grout coats. The cured surface is then sanded smooth and two coats of a penetrating sealer are applied.

6/ Crossfield Products Corporation Trade Mark.

The maintenance of the roof surface generally requires the application of additional coats of the sealer every 3 to 5 years.

3.2.2. Neoprene-Crushed Walnut Shells Traffic Deck

The neoprene-walnut shell deck has been used in the Western United States. It provides a deck for either automotive or pedestrian traffic and is generally applied over either a concrete or plywood substiate to form a non-skid, continuous membrane. The surface usually is a dark color. However, it may be coated with a chlorosulfonated roofing solution to obtain various colors.

In practice, the roofing system is applied as follows:

> The roof deck is first primed with a coating made up of 1 part of a neoprene roofing solution diluted with 1 1/2 parts of solvent. The joints or cracks in the plywood or concrete deck, as the case may be, are treated by stripping with a reinforcing tape. Nylon and glass tapes have been used successfully for this purpose. The prepared deck is then coated with the neat neoprene roofing solution at a spreading rate of 2 gallons per square and allowed to dry. A trowel coating of a mixture consisting of 3 to 5 gallons of neoprene and 1 1/2 gallons of crushed walnut shells is then applied uniformly to each square of roof area.

4. FIELD OBSERVATIONS

In this investigation we have relied primarily on field observations to ascertain both the functional and performance aspects of the new roof systems. We have observed these materials and systems in the various stages, ranging from the actual manufacturing processes through their application to their performance on the roof deck. We have talked with people interested in the various phases of each system, such as the research personnel in the laboratory, the manufacturer, the supplier, the applicator, and the consumer. The opinions contained in this report and the conclusions drawn are based on this information.

4.1 New Roof Systems Other Than Traffic Decks

4.1.1 Neoprene Roof Systems

The neoprene roof systems can be separated into two separate and distinct classes as: (1) the fluid-applied coatings and (2) the sheet-applied materials.

(1) Fluid-applied Neoprene-Hypalon Systems.

We have had these roofing systems under observation for about 5 years and the oldest application that was observed was applied in 1952. The neoprene and chlorosulfonated polyethylene roofing solutions have been used alone and in combination to serve as roofing systems.

The techniques which have been employed during the application of these materials are many including spray, roller, and brushing where small areas are involved. It was the consensus of opinion that the pressure-fed roller technique was the most satisfactory and economical. The materials were applied in a number of coats to build up a dry film thickness of approximately 20 mils (.020 in.). Our observations indicated that the best results were obtained where membranes of at least 20 mils in thickness were used. In cases where the chlorosulfonated polyethylene roofing solution was used alone over concrete, it did not appear to be sufficiently thick to act as a waterproof membrane, although it provided an attractive, decorative finish.

Generally the materials which were properly applied in sufficient quantities over a suitable deck indicated good results. Certainly the weathering characteristics of this system were very good. However, certain defects were observed on a number of jobs, which are worthy of note:

(a) Blistering.

Our observations have indicated that the most common problem associated with the application of the liquid systems has been blistering. This deficiency was observed only on concrete decks. Although the mechanism of this blistering has not been sufficiently established to eliminate blisters in 100% of the cases, methods of application based on the results of research carried out by the manufacturers has greatly reduced the incidence of this failure.

It has been postulated that two conditions are largely responsible for the blistering: 1) the entrappment of solvent in the deck and 2) solar heating. Many masonry slabs contain sub-surface cavities which may be vented to the surface via a small pinhole. The volatile solvent of the roofing solution penetrates into the cavity and condenses on the cool surface during the application of the coating. The coating in turn forms a soft impermeable film over the opening as it dries, entrapping the solvent in the cavity. An increase in the deck temperature due to solar heating will increase the vapor pressure of the trapped solvent to such an extent that blisters are formed in the film over the pinholes.

This theory appears to be valid since many manufacturers have reported means and methods of application which reduce the frequency of blistering. One manufacturer reported that sealing the surface of the concrete with a chlorinated rubber sealer prior to the application of the roof system has proven effective. Another reported that the blistering was completely eliminated when the masonry surface was trowel-coated with a mixture of sand and neoprene. Still another has reduced the problem by employing a light-tan color neoprene to reduce surface temperatures and applying the first two coats only at selected times during the day. Of course, all manufacturers require the deck to be dry before the coatings are applied. One manufacturer describes a dry deck as one that does not contain more than 16% moisture by weight.

(b) Bridging Characteristics.

Our observations indicated that the fluid-applied systems will not, in most cases, bridge structural cracks or joints in a roof deck unless the joint or crack is covered with a reinforcing tape prior to the coating application. Fiberglas, nylon, and cotton tapes have been used successfully in these applications.

We also found in a few instances that serious cracking which developed in the substrates subsequent to the coating application caused a failure in the roof membrane. It may be of interest that one applier remedied this condition and rendered a failed roof watertight by applying a trowel-coating of a compound consisting of medium-length asbestos fibers and the neoprene roofing solution.

(c) Other Deficiencies.

Curing compounds are often used on poured concrete decks to retain moisture in the slab which in turn assists in curing the concrete. It was reported that a problem of loss of adhesion to the concrete may occur due to the incompatability of the curing compound and the roofing solution. In fact, one case was observed where the use of such a material was suspect where a failure occurred. As a precautionary measure, some manufacturers recommend that only water-cured concrete be used as substrates for the Neoprene-Hypalon systems.

(2) Sheet-Applied Systems.

We have had the neoprene sheet materials under observation since 1958. The high initial cost of this material precludes its use except in extreme cases. Probably the most publicized application of this material is the roofing on the Terminal Building at Dulles International Airport which covers an area in excess of two acres. In addition, we have followed two other installations of this material which protect the roofs of transformer buildings at the Navy Annex, Arlington, Virginia, and were applied in 1958 and 1961, respectively. In all three installations, the sheet was applied directly to concrete decks and in two cases, the sheets were coated with a chlorosulfonated polyethylene roofing solution.

Without exception, the performance of these materials has been excellent. The weathering characteristics have been good and no defects were observed in the adhesive systems which secure the sheets to the roof deck. Evidence of slight deterioration was observed on the uncoated neoprene roof. This deterioration appeared as slight hairline cracking which occurred in areas of stress where the sheet was permanently bent over a 90° bend.

From a practical point of view, the use of this material as roofing in specialized areas appears quite promising. However, from a standpoint of economics, it is much too expensive to compete with the more conventional materials in conventional applications.

4.1.2 Asphalt Emulsion-Chlopped Glass Fiber Combination

A number of roofs protected with the Monoform roof system were observed on the East and West Coasts during the survey. The roofs varied in size from a few squares up to 37 acres in area and varied in age from new to about 2-1/2 years. The Monoform roofs which were observed, were applied over various substrates including weathered asphalt planks, insulations, various old roofings, and concrete decks. A base sheet

was employed in a number of cases to receive the sprayed-on coating, while in other cases the emulsion-glass combination was sprayed directly on the roof deck. Generally, a light-colored, reflective coating was applied to the roofs in the Western United States, while the natural black surface of the Monoform roof acted as the weather surface in the Eastern states.

Our observations indicated that the performance of the Monoform system was generally good. The system is easy to apply and is readily adaptable to both flat and vertical surfaces. In addition, it appeared that it is particularly suitable for use over existing roof flashings and for roofs of unusual contours. A number of roofs of this type were observed in the Los Angeles, California, area and have given excellent service.

It is our opinion that the performance of the system applied over a base sheet appeared superior to that applied directly to a roof deck.

The use of a reflective coating with the Monoform system, has proven very successful on the West Coast from both a practical and aesthetic standpoint. No doubt the application of a reflective coating reduces both surface temperatures and thermal movements, prolonging the life of the roofing material. The white and pastel shades have proven better than the aluminum pigmented coatings. A decorative coating must be renewed periodically, about every five years.

In the course of the field survey we observed a number of defects in these systems which are worthy of mention and are discussed below. However, as with any roof system, the proper preparation of the roof surface and careful workmanship during application are primary requisites for a satisfactory roof. In our opinion, many of the deficiencies observed could be eliminated if the cardinal principles of roofing were observed.

Cracking.

We have observed two types of cracking which have occurred in the Monoform systems. Surface or mud cracks were observed in the coating applied over slag (loose slag removed). This deficiency apparently resulted from the use of an insufficient amount of the reinforcing glass fiber in the emulsion. The applier elected to reduce the amount of glass fiber to eliminate the bridging effect over the particles of slag with the specified mixture. This defect probably could have been eliminated by building up the coating gradually with the neat emulsion and then applying the reinforced emulsion. This, of course, is a time consuming procedure. In our opinion, if this system is selected for application over an existing mineral surfaced roof, it is better practice to remove the mineral surfacing completely prior to the application of the Monoform.

Cracking in the film which results from structural cracks in the substrate is obviously much more serious. The asphalt emulsion-glass fiber system is not capable of resisting extended elongation without rupture and, therefore, structural cracks which develop in the substrate are readily transferred to the coating. This failure was observed on some jobs in the Los Angeles area where a base sheet was not specified or used. Obviously the use of a base sheet in situations where cracking in the substrate is likely to occur will eliminate this defect.

4.1.3 Cold Process Coal-Tar-Pitch Roofings.

We have had these roofs, identified as "Bitumagic" roofings under observation for about one and one-half years, although the system was announced publicly in June 1962. We have observed the performance of this material on both flat and sloping decks in the Pittsburgh, Pennsylvania, area as well as in a number of Southeastern States. These materials have been applied to new decks as well as over existing roofs and insulation.

Although the "Bitumagic" is available prepared on a glass tape as well as on an asbestos tape, we observed no particular difference in their actual performance other than the glossy appearance of the coal-tar emulsion applied over the glass tape. The use of a factory-applied adhesive as the plying cement is a definite advantage, since it eliminates the use of either hot or cold cements on the job. In addition, it reduces the chances of voids and holidays between components during haphazard application practices.

Our observations indicated that little difficulty was experienced in applying these pressure-sensitive roofings. They were generally applied in either one or two plies. However, the one-ply system is generally recommended based on economics. In the one-ply system, the sheets are lapped about 6-inches at the end joints and 3-inches at the side laps and consequently watertight joints are essential. In this connection, a special water-filled roller has been developed and is used to secure good adhesion between sheets at the lap areas. Some difficulty was experienced in stripping the release paper from the adhesive during hot weather. However, this difficulty was overcome by a slight wetting of the paper which facilitated its release from the adhesive.

This roofing material, surfaced with a coal-tar emulsion, appeared to have good weather resistance on all slopes. There were no slippages noted even when applied to a vertical surface. On areas where the material was obviously submerged under water for long periods, there was no evidence of deterioration of either the tape or the protective coating.

On a few roofs, wrinkling, buckling, and blistering were observed. These apparent deficiencies resulted from a disbonding of the adhesive at the substrate and may have been caused by poor initial contact between components during installation.

Blisters were observed in the roofing protecting two structures. On one, the Bitumagic tape was applied over precast concrete planks which presented a very uneven surface and prevented proper contact between the deck and the roofing. In the other case, the roofing was applied to a concrete deck that was subject to unusually high temperature and moisture conditions.

4.1.4 Polyvinyl Fluoride on Asbestos Felt.

The roofing system identified as Ruberoid's T/NA 200 has recently been announced publicly and has been in use as a roofing material for just over one year. However, according to the reports of the duPont Company, the polyvinyl fluoride (Tedlar) film has had approximately 7 years of exposure to Florida weather with no apparent defects. In the roof survey we observed the performance of a number of these roofs in the Wilmington, Delaware, area. The observations indicated the performance of these materials was very good and no defects were apparent. There was some indication of a slight shrinkage in the vicinity of the laps which were sealed with the pressure-sensitive tape. There was no indication of blisters, delaminations, cracking, checking or chalking. Although the results of a few years exposure indicate excellent weather resistance, it is obviously impossible to predict the future performance and life of these materials.

In July 1961, we observed the application of T/NA 200 on an experimental roof at the duPont Company plant, Waynesboro, Virginia. The material was applied in one ply over a weathered, smooth-surfaced, asphalt, built-up roof, using hot asphalt as the adhesive. The application techniques appeared to be no more difficult than in the application of conventional roofings. However, extreme care must be taken to keep the surface in the vicinity of the side laps clean to receive the pressure-sensitive tape.

The high reflectivity of the white surface was particularly notable. Even on hot summer days, the roof surface was cool to the touch. This feature will not only reduce interior temperatures during hot weather, but will also permit these materials to be used on steep slopes without danger of slippage. These roofing materials appeared to be adaptable to roofs of unusual contour, providing careful and skillful roofing practices are observed.

4.2 Traffic Decks.

In the course of the roof survey we observed the performance of two types of decks used for traffic decks. Although the "Dexotex" roofing system has a history of about 10 years, we have included it in this report because we have had many inquiries concerning this system. The other system, consisting of a neoprene-walnut shell combination, has been recently used in the Western United States.

4.2.1 Dexotex Weatherwear System.

We have observed the performance of a number of decks protected with this system in the New York City and New Jersey areas. The roofs varied in age from new to about 9 years old and were applied to various substrates including new concrete, old built-up roof, and even a quarry tile promenade deck.

In general, the performance of the "Dexotex" roof system appeared to be satisfactory. There were few serious deficiencies observed and there were no cases where the owner or building manager reported leakage, failures, or serious difficulties. On the contrary, many of the people interviewed expressed complete satisfaction with this roofing system, especially where used on hospital deck areas and school play areas.

Cracking of the weather surfaces was quite prevalent on the older installations. The cracking generally occurred at areas of stress, such as at the junction of the roof deck with the vertical surfaces. In two instances, cracking was observed in the field of the roof area and this was attributed to a "heaving" of the substrate. It was not established whether the membrane itself was damaged at these areas of failure. The employment of the "slip-sheet" no doubt prevented cracking due to lateral movements in the roof deck. It is felt that the use of a cant strip at all 90° angles would eliminate or lessen the chances of cracking at these areas.

The other deficiencies observed, such as peeling, pitting, and indentation were considered minor. No blistering was observed on any installation, regardless of the base to which the system was applied.

The maintenance of this type of roofing generally requires that additional coats of sealer be applied every 3 to 5 years.

The "Dexotex Weatherwear" roof deck is custom-made on the site and its success or failure depends largely on the skill and workmanship of the roofing applicator.

4.2.2 Neoprene-Crushed Walnut Shell System.

Three traffic decks protected with this system were observed in the San Francisco, California, area although it was reported that its use is quite common. In two of the three jobs observed, the surface was used for automotive traffic over a concrete deck, while the other served as a walkway surface over a plywood base. The performance of the material over the concrete decks was exceptionally good with respect to its weathering and wear characteristics. However, a failure occurred on one structure when cracks in the substrate transferred through the protective surface causing leakage into the building. The supplier expressed the opinion that the ratio of neoprene binder to the crushed walnut shells which was used (2:1 by volume) was insufficient to provide adequate elastic properties. He further indicated that a ratio of 4:1 or even 3:1 would eliminate this failure.

The condition of the other traffic surface over concrete was good after about 2-years exposure.

The appearance of the materials over the plywood walkway surface was very good after over 2-years exposure in the Berkley, California, area. The surface indicated excellent wear and weather resistance despite the fact that it was subjected to heavy foot traffic daily.

It was reported that these surfaces can be repaired or maintained by the application of liquid neoprene solutions, the quantity being determined by the condition of the deck. In addition, a decorative surface can be obtained by the application of a chlorosulfonated polyethylene (Hypalon) roofing solution.

5. SUMMARY

5.1 Performance

In our opinion, the performance of the roofing systems described in this report has been satisfactory. This conclusion was based primarily on the field observations made during the past two years. However, it was apparent that, like most other roofing systems, each has its own limitations in various respects. For example, many crack failures were observed when a liquid system was applied without a membrane to a deck in which joints were present or where structural cracking had taken place. These failures were prevented in many cases by the intelligent use of a reinforcing fabric or mesh in these areas of stress prior to the application of the liquid-applied materials. In regard to the roofings applied in sheet form, the application of proper roofing techniques and skilled workmanship were the prime requisites for a satisfactory job as with the conventional built-up roofings.

The better performances were obtained with the new systems when they were applied over new roof decks in contrast with those applied as repair membranes over existing roofs. This observation was not surprising, since experience has shown that the condition of the substrate to which the roofing is applied influences its performance to a great extent.

The property of durability is probably the most important single characteristic of a roofing product, since its primary function is to protect a structure against all types of climatic conditons. In this connection, we are somewhat reluctant to predict the long range performance of any of these systems under the many weather conditions to which they will be exposed based on their relative short-time exposures. On the other hand, we see no reason for concern in this area, since the basic materials used in these systems, such as the neoprene and Hypalon rubbers, the polyvinyl fluoride films, the bituminous emulsions, the coal-tar and asphaltic base materials, the glass and asbestos reinforcing products have certainly indicated excellent weather resistance both in laboratory tests and in outdoor exposures.

5.2 Application.

Our observations indicated that the roofing procedures and application techniques have been developed to such a degree by the respective manufacturers that little difficulty can be anticipated in applying these systems to most decks. This assumption is made, of course, on the premise that roofing crews have received a period of indoctrination as to the correct procedures and are supplied with the proper specialized equipment as necessary.

5.3 Utilization.

In our opinion, the new roof systems are not developed to such a degree that they can be utilized to replace the conventional roofings for flat or sloping decks. However, when a special condition dictates the requirement for a particular roofing, more than likely one or more of the new systems will fulfill the need. In recent years, many conditions have been brought to our attention where conventional roofs would not perform adequately without considerable alteration. For example, in the case of the roofing at Dulles Airport, Washington, D. C. the architect selected a sheet neoprene roof to take advantage of its high elasticity. Although many questioned the wisdom of the decision to use this material, it was apparently justified on the basis that it was the only material currently available which had the required properties.

In some cases, a highly reflective surface was required in order to obtain desirable thermal characteristics, while in others the employment of either hot or solvent type adhesives in the roofing application would present hazards. In each case, one or more of the systems described in this report would suffice. Situations have also arisen where for many reasons the use of a membrane roofing was either impracticable or impossible and the fluid-applied or spray-applied systems have performed adequately. In these days of strained international relations, numerous inquiries have been received about a roofing system which will facilitate the removal of atomic fallout in the event of a nuclear explosion. Each of the systems described in this report could be decontaminated by flushing with water.

In connection with the protection of some of the exotic roof decks now being designed and used, the new roof systems have been employed to solve many of the problems which heretofore went unsolved with conventional roofings.

5.4 Traffic Decks.

In regard to the promenade or traffic decks, the two systems described in this report performed satisfactorily with some exceptions. We believe that these systems, although probably more economical, present problems similar to those which have plagued their more conventional counterparts for many years. It is the same old story that the performance of the system is largely determined by the condition of the substrate and the caliber of the workmanship during application.

6. CONCLUSION

In conclusion, we believe that the performance of the roofing systems described herein was satisfactory and that these systems may be suitable for special roof applications in military construction when the more conventional roof systems for either flat or sloping decks are not practicable for one reason or another.

7. SPECIFICATIONS AND COST

It was obviously impossible to include in this report the various specifications issued by the respective manufacturers for the many types of roofing systems for new roofs and reroofing over existing roofs. However, in order to give some idea of the basic systems involved, the weight and the cost of each system, the following information was compiled from various sources. The cost data are approximate and may vary even from the ranges stated especially since the costs of material, labor, and transportaion vary greatly from area to area.

7.1 Sheet Neoprene.

One-ply, cured neoprene sheet, 1/16-inch thick.
Applied in sheet form using a neoprene adhesive.
Coated with Chlorosulfonated Polyethylene roofing solution.
Weight per square - 55 pounds.
Cost per square - $100-$150.

7.2 Fluid-Applied Neoprene Roofing Solution.

Prime coat - neoprene roofing solution cut with solvent.
Neoprene Roofing Solution, one or two coats at 1-3/4 gallon per coat.
Hypalon Roofing Solution, two coats at 3/4 gallon per coat.
Applied by spray or pressure roller.
Weight per square - 20 pounds.
Cost per square - $25-$35.

7.3 Monoform System.

Base sheet, one or two plies.
Monoform compound, 6, 8, 10 gallon per square (depending on Spec.)
Glass Reinforcement, 2, 2-2/3, 3-1/3 pounds per square (depending on Spec.)
Decorative top coating may be specified.
Applied by spray (Sealizit Gun).
Weight per square - 100-200 pounds.
Cost per square - $15-$25.

7.4 Bitumagic System.

Bitumagic cold applied sheet, one or two plies.
Top coating of a coal-tar emulsion at 2-1/2 gallon per square.
Aluminum coal-tar emulsion may be specified.
Applied sheet form, no adhesive necessary.
Weight per square - 70 pounds for one ply.
Cost per square - $20-$30.

7.5 T/NA 200

Base sheet.
T/NA 200 sheet, one ply.
Pressure sensitive tape at laps.
Applied in sheet form with hot or cold asphalt adhesive.
Weight per square - 65-105 pounds.
Cost per square - $35-$50.

7.6 Dexotex Weatherwear.

Asbestos felt laid dry.
Burlap membrane applied with rubber-base mastic adhesive.
Two trowel coats and two grout coats of neoprene-aggregate surfacing.
Two coats of penetrating sealer.
System constructed on job-site.
Weight per square - 250 pounds.
Cost per square - $125-$150.

7.7 Neoprene-Crushed Walnut Shells.

Prime coat - neoprene solution cut back with solvent.
Neoprene roofing solution at 2 gallon per square.
Trowel coat - neoprene-crushed walnut shell combination.
Hypalon roofing solution may be specified.
Applied by trowel and roller.
Weight per square - Not known.
Cost per square - Not known.

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The Ruberoid Company

9. NOTE

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