NATIONAL BUREAU OF STANDARDS REPORT

7489

PERFORMANCE OF ROOFING IN PUERTO RICO

by

William C. Cullen

and

William W. Walton

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Organic Building Materials Section
Building Research Division

Sponsored by

Office of the Chief of Engineers
Department of the Air Force
Bureau of Yards and Docks

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U. S. DEPARTMENT OF COMMERCE

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PERFORMANCE OF ROOFING IN PUERTO RICO

1. INTRODUCTION

The many problems involved with roofing materials and systems exposed to tropical conditions has long been recognized by the construction agencies of the Defense Department. Heretofore, little information has been available regarding the performance of roof systems in the tropics to assist those charged with design and maintenance responsibilities. Therefore, in response to request of the Bureau of Yards and Docks, U. S. Navy; Directorate of Civil Engineering, U. S. Air Force; and the Office of the Chief of Engineers, U. S. Army, a study of roofing was conducted on the island of Puerto Rico as a task under Project No. 10447, "Performance of Roofings" of the Tri-Service Engineering Investigations of Building Construction and Equipment, NBS.

This report gives the results of the performance of the various roof systems which are employed on both military and civilian structures. In addition, it identifies the failures which are common to roofs in the area and describes the maintenance and repair methods employed to keep the roofs in a serviceable condition.

The survey of roofing was conducted on March 20 through March 24, 1962, primarily in the vicinity of the cities of San Juan and Ponce, Puerto Rico. The following Military Installations were included in the survey:

Fort Buchanan, San Juan, P. R.
U. S. Naval Station, San Juan, P.R.
Naval Communications Station, Sabana Seca, P.R.
Fort Brooke, San Juan, P.R.
U. S. Naval Station, Roosevelt Roads, P.R.
Fort Allen, Ponce, P.R.

Personal contacts were made with contractors, military and civilian engineers, and with maintenance personnel experienced in the performance, construction and maintenance of roofing systems in the Puerto Rico Area.

2. CLIMATE[1/]

The climate of Puerto Rico is tropical marine, slightly modified by insular influences when land breezes blow. Radiational cooling frequently causes land breezes at night; consequently, somewhat lower night-time temperatures

[1/] Source: Weather Bureau, U. S. Dept. of Commerce Local Climatological Data, San Juan, Puerto Rico, 1961.

occur than would normally be experienced with sea breezes. The air drainage from the higher altitudes (peak elevation 4,000 ft.) gives relatively cool night breezes during December, January, and February.

Characteristic of all tropical marine climates, the coastal areas of Puerto Rico have a small annual range of temperature. The difference between the average temperature of the warmest and coolest months is only about 5.6°F. This is also true concerning the absolute range of temperature. The highest temperature of record is 96°F. and the lowest 62°F.

The coastal areas of Puerto Rico have an average rain fall of 60 inches per year with a fairly even distribution throughout the year. Rainfall is generally the showery type, except for continuous rains which occur in connection with the passage of tropical storms.

Puerto Rico is in the tropical hurricane region of the eastern Caribbean where the season for these storms begins June 1st and ends November 30th. Several hurricanes affect this area every season, but weather records show that only five of these storms have caused winds of hurricane intensity in the San Juan area during the past 50 years.

The normals, means, and extremes for temperature, precipitation, wind, and humidity in San Juan, Puerto Rico, are as follows:

Temperature: Normal for year, Daily - max. 82.8°F.
Daily - min. 73.2°F.

Precipitation: Normal Total for year - 60 inches.

Wind: Mean hourly speed for year - 8.4

Relative Humidity: Mean for year at 2:00 A.M. - 87%
at 8:00 A.M. - 84%
at 2:00 P.M. - 66%
at 8:00 P.M. - 79%.

3. ROOFING SYSTEMS

A number of roofing materials and roof systems were observed during the survey and it is believed that the following types are typical of a large percentage of the roofs used on structures in Puerto Rico.

3.1 Exposed Concrete Slabs

The predominate type of roofs employed on both civilian and military residential structures in Puerto Rico was reinforced concrete slab. The thickness of the roofing slabs varied from 3 to 6 inches with the 4-inch slab being the most common. Figures 1 through 4 illustrate typical residential structures which were protected with exposed concrete roofs. In addition, exposed slabs were often employed on relatively large roof sections, such as the family housing structure illustrated in Figure 5. Generally, the slope of the roof decks varied from level to about one inch fall per foot run. In some cases, exposed slabs were used on structures of modern architecture with almost vertical slopes, as on the cathedral illustrated in Figure 6. The exposed slabs were either broom- or steel-trowel finished depending on the surface desired. In many cases, the surface was coated with various materials to provide solar reflectivity and/or for aesthetic reasons.

3.2 Built-Up Roofs

Conventional 4- or 5-ply, surfaced, built-up roofs were used to protect both military and civilian structures where it was not practicable to utilize the monolithic concrete deck. This was generally true of industrial installations, shopping centers, and on large military structures where precast concrete slabs or wood planking were employed for the roof deck.

The built-up roof was also used to repair exposed concrete when it became uneconomical to isolate and repair cracks in the deck. A typical structure employing such a roof is shown in Figure 7.

3.3 Metal Roofs

Corrugated metal roofings were quite often observed on relatively steep roofs (slopes in excess of 3 in. per foot), on temporary military structures, on warehouses and factories, and on extremely low cost housing.

3.4 Asphalt Prepared Roofings

The use of "wide selvage", mineral-surfaced, prepared roofings was observed on some military structures at Fort Buchanan, Fort Allen, and the Naval Station, Roosevelt Roads. Prepared roofings were generally restricted to use on temporary buildings having wood decks with a slope of approximately 5 inches per foot.

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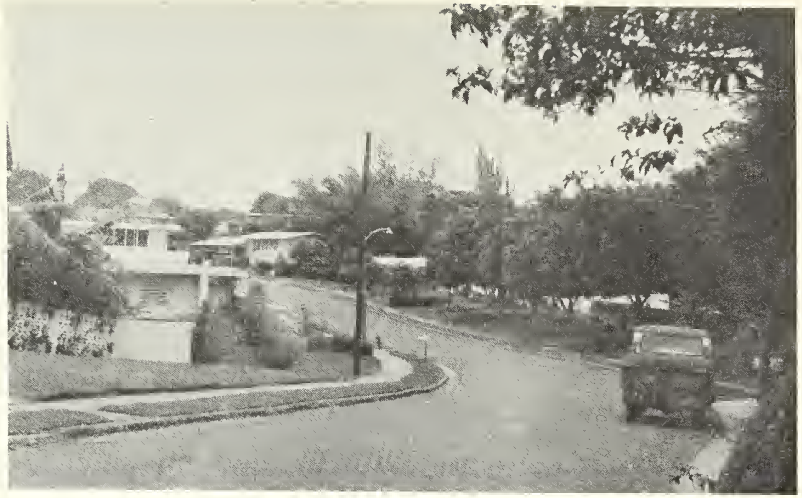

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3.5 Miscellaneous Roofings

Roofing systems other than those described above, which were observed with a passing interest, included:

a. Thatched roofs
b. Asbestos-cement roofs
c. Mission tile
d. Bituminous protected metal

4. OBSERVATIONS

4.1 Exposed Concrete Slabs

4.1.1 Performance

Exposed reinforced concrete slabs were used for roofs in many areas of Puerto Rico and had apparently performed very satisfactorily. It was reported and confirmed by observation that no leakage or seepage occurred in the slabs unless some defect such as a crack was present. However, the inspections revealed evidence that few exposed concrete slabs on military structures escaped cracking to some extent. One of the common difficulties which was encountered in the construction of the concrete buildings was the attainment of a sufficiently stable foundation to prevent cracks in the roof slab due to the unequal settlement of load-bearing walls. Typical cracks which were observed on Officers' Housing, Fort Buchanan, and attributed to the unequal settlement of foundations are illustrated in Figures 8 and 9. It was reported that cracking also resulted from shock due to blasting in the vicinity, shrinkage, and from thermal stresses and movements due to temperature changes.

The exposed slab of one relatively large structure (EM Barracks, NCS, Sabana Seca, P.R.), illustrated in Figure 10, was relatively free of cracking and the occupants reported it to be watertight. This two-story structure was of reinforced concrete construction and was built in 1952. The roof slab had a broom finish. A biological growth, common to the exposed roofs in Puerto Rico, contributed to the dark roof surface, as shown in the photograph.

In cases where multiple roof levels were employed, some trouble was encountered at the junction of the deck with the vertical surface. A grout coating of concrete was unsuccessfully employed to remedy this condition. Cracking, as illustrated in Figures 11 and 12, soon developed and, in addition, the adhesion between the grout and the dense concrete was poor and water was invariably found in that area. Interior examinations generally revealed leakage in these areas.

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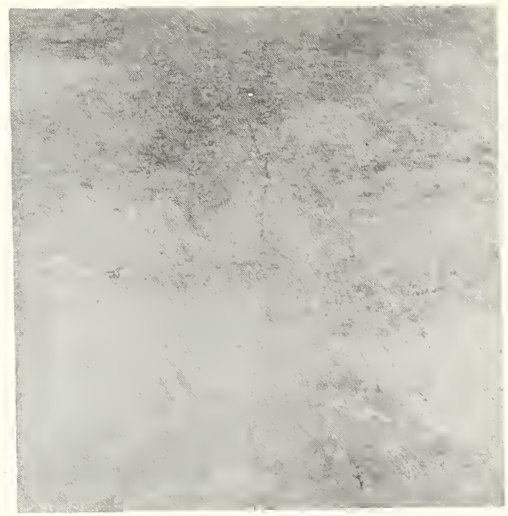

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Obviously, the most serious problem involved in keeping the exposed slabs watertight is the development of cracks. Therefore, the methods and remedies set forth for the repair of cracks have been many. For example, it was reported that a method effectively employed by the natives to render a cracked slab waterproof was the application of a boiled G.I. soap solution. We were unable to confirm the effectiveness of this procedure. Among the more conventional methods used to repair cracks were the following:

A. Grouting with Concrete.

This method consisted of applying a cement grout directly over the crack, as illustrated in Figure 13. Our observations indicated that this method was not effective due to the poor adhesion to the dense concrete deck. On the other hand, if proper adhesion was obtained it is predicted that the crack in the substrate would soon be transferred to the patching compound due to its relatively poor elasticity.

B. Plastic Cements and Other Mastics.

This method consisted of applying a bituminous plastic cement, caulking compound, or other mastic directly over the crack. These methods appeared to be adequate for temporary repair only (less than one year). It was apparent that these materials oxidized, cracked, and lost their adhesion to the substrate. These defects were observed in such systems after less than 6 months exposure.

The patching of cracks with an elastomeric type of material was observed at the Naval Station, Roosevelt Roads. This system was performing quite well after three months exposure which, obviously, was too short a period for evaluation.

C. Bituminous Material and Reinforcing Medium.

The repair method consisted of applying a mastic (bituminous emulsion, asphalt plastic cement, or proprietary materials of similar viscosity) over the crack and extending 4 to 6 inches on both sides of the crack. A reinforcing strip (generally woven glass fabric or glass mat) was embedded in the mastic and coated with a similar material. A typical roof employing such a system is illustrated in Figure 14.

This method of crack repair has proven the most successful of the many methods tried. However, it has many limitations. Our observations indicated that movements in the deck at the crack due to expansion and contraction sometimes resulted in a break in the system over the crack. In addition, poor adhesion between the fabric and the deck was observed, indicating poor preparation of the surface.

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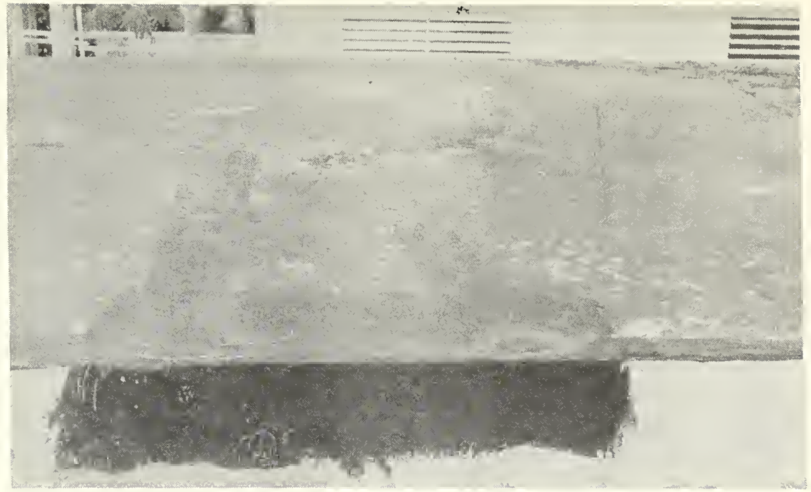

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D. Repair Membrane Over the Entire Roof.

The application of a waterproof membrane over the entire deck was deemed necessary in cases where the cracks became so numerous that the isolation and the repair of each individual crack became uneconomical. A case in point was the Lanham Act Housing at Fort Buchanan. This development was constructed in 1940 and consisted of 200 units in 25 two-story buildings, one of which is shown in Figure 5. The exposed concrete slabs performed adequately until 1957, when due to the high maintenance cost of crack repair and the relative ineffectiveness of the repair, a complete roof system was applied. The roof system consisted of asphalt emulsion (5 gal. per square) - glass mat combination, followed by a reflective aluminum coating. It was reported that leakage has almost been eliminated with this repair system.

Our observations indicated the condition of the membrane was good after five years exposure, as shown in the general view in Figure 15. Two deficiencies were noted in the system. Ruptures of the membrane, as illustrated in Figure 16, were observed in two areas. However, these cracks were not typical of the irregular cracks generally found in the exposed decks. Therefore, they were attributed to other causes. In addition, many blisters were observed which ranged from a few inches in diameter up to 15 inches or more, as shown in Figure 17. The blisters apparently occurred between the deck and the membrane and were possibly caused by poor preparation of the surface prior to the application of the membrane. The blisters have caused no particular problems and, therefore, no action to eliminate them is indicated at this time.

The aluminum coating had weathered to a dull finish exposing the bituminous material in some areas and its condition after 5 years exposure indicated that additional coatings are warranted.

4.1.2 Coatings for Exposed Slabs

Protective coatings of various types were observed on many of the exposed slabs. These materials were, in many cases, employed for aesthetic reasons, but were primarily used to reduce temperatures by reflecting solar energy and, therefore, were pigmented white, alumimum, or other pastel shades. The use of these coatings apparently had little effect on the waterproofness of the slab. However, it was obvious that the light-colored coatings exerted a dominate influence on the temperatures attained by the slab. There is a tendency to think of unpainted concrete slabs as white in color, but this is not true in Puerto Rico where exposed slabs are quite dark due to biological growths, as illustrated in Figure 8.

As would be expected from a wide variety of coatings, the performance varied from poor to good and it is felt that the type of material, the quality and quantity used, and the proper preparation of the substrate are of great importance. Experience should be used to dictate whether a particular material will perform adequately.

The performance of an elastomeric type of coating identified as "Hypalon" (a chlorosulfonated polyethylene roofing solution) was observed on the parabolic roof of the Santa Maria Reina Cathedral in Ponce, P.R., shown in Figure 6. The roof consisted of a 3-inch reinforced concrete shell supported by a series of 54-foot span cantenary arches and had an area of about 240 squares. It was reported that two coats of "Hypalon" were applied by conventional pressure pot-spray equipment in January 1957. Our observations indicated the material had weathered quite well and no obvious defects were observed after 5 years exposure. A general view showed a somewhat mottled appearance indicating either unequal coverage or unequal weathering. It was felt that an additional application of the material should be applied in the near future.

4.2 Built-Up Roofs

Although it was reported that both asphalt and coal-tar-pitch built-up roofs have been employed in Puerto Rico, only surfaced asphalt roofs were observed. As previously indicated, this type of roofing was used where it was impracticable for one reason or another to leave the slab exposed.

It was interesting to note that roof insulation was seldom used in the Puerto Rico area.

The built-up roof protecting the Public Works Shop Building, Roosevelt Roads, was the oldest built-up roof observed. It was a 5-ply, surfaced, asphalt built-up roof applied in 1941 over a 2-inch T & G wood deck on a low slope (approximately 1/4 inch per foot).

The appearance of this roof was good after about 20 years exposure, as shown in Figure 18. An examination of the asphalt showed it to be very hard and brittle even at the high temperature of the roof. However, there were no other signs of deterioration and it was apparently performing its basic function. The only defects observed were a number of bare areas where the felts were exposed. Some 41 leaks were reported in this roof. However, our observations indicated that most, if not all, of the leaks resulted from defective flashings, as shown in Figure 19. Obviously such deficiencies could be prevented by adequate and timely maintenance.

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In our opinion, this roof could be expected to perform for another 10 years with adequate repair and maintenance procedures. The performance of this roof compares favorably to the performance of similar roofs in the continental United States.

Built-up roofs used to render cracked slabs waterproof were also observed on residential buildings at the N.C.S., Sabana Seca, P.R., illustrated in Figure 7. The membranes were applied in 1961 to the main roof sections, as shown in Figure 20. The roofs were in excellent condition and were watertight. However, some leakage was still apparent in the interior. It, no doubt, resulted from cracks observed at the angles formed by the intersection of the roof slab with vertical surfaces.

An examination of the asphalt revealed it to be very soft (135°F Softening Point or less) at roof temperatures. The use of this soft material between the deck and the first ply of felt resulted in an asphalt drippage through a crack in the slab. This, of course, was a matter of some concern to the building occupants.

4.3 Metal Roofing

Corrugated, galvanized steel roofing was observed on many temporary structures and low-cost housing (slum areas). This material had apparently given good service on sloping roofs with little maintenance. It was reported that wind damage was common to this material during the heavy winds in connection with the passage of tropical storms.

4.4 Prepared Roofings

In the course of the survey, a few "wide selvage" asphalt-prepared roofs were observed on sloping roofs (5/12 slope) on one-story temporary structures at both Fort Buchanan and at Roosevelt Roads. Our observations indicated that this type of roofing gave adequate service for approximately 10 years in the Puerto Rico area.

Asphalt shingles were not observed, but it is predicted that they would perform at least as well as the "wide selvage" roofing on relatively steep slopes, if they were adequately protected from wind damage.

4.5 Miscellaneous

Various roofing materials other than described above were observed with only a passing interest. No attempt is made here to describe their advantages and limitations.

5. DISCUSSION

The majority of roofs used by the military on Puerto Rico consisted of either the exposed concrete slab or the mineral-surfaced, built-up roof. Therefore, this discussion will be limited to the two systems.

The exposed concrete slabs have performed very satisfactorily on roofs of low slope (0-2 inches per foot) in the Puerto Rico area. However, our observations indicated that cracks resulting in leakage occurred in the slabs and can be attributed to one or more of the following events:

a. Foundation settlement
b. Shrinkage
c. Thermal movements and stresses
d. Effects of blasting
e. Substandard concrete.

Some of the factors can be controlled to some extent, while others cannot. For example, defects due to shrinkage and substandard materials may be reduced somewhat by proper design and construction practices combined with adequate inspection during construction. Further, the initiation and propagation of cracks due to thermal movements and stresses may be reduced by the proper selection and application of a heat-reflective coating. It is our opinion that the thermal movements are quite large on exposed slabs in Puerto Rico due to the dark color resulting from the biological growth and therefore, the application of a reflective coating would prove effective.

Some methods have been discussed by which cracking may be reduced, but it is extremely doubtful if cracking can be entirely eliminated. Therefore, methods of repair to render the cracks leakproof are considered essential. The repair of cracks may be accomplished as follows:

a. Isolate and repair each individual crack.
b. Application of a waterproof membrane to the entire roof.

It is felt that the former method should be employed as long as it is economical. Now the question arises, when does it become uneconomical to isolate and repair the existing cracks? This point we cannot define. It is suggested that an analysis of repair and maintenance costs to keep the slab leakproof together with the opinion of competent engineers at the camp, post or station involved should largely govern.

In regard to crack repair, it is our opinion that the one-component systems, such as cement grouts, various bituminous mastics, and cauling compounds, generally have not been satisfactory except as temporary expedients. It is felt that a reinforcing medium in conjunction with a suitable mastic, emulsion, or plastic cement offers the best possibility of permanent repair. The selection of both the reinforcing medium and waterproofing agent should be based on past experience or research, where experience is lacking.

In connection with crack repair, we are of the opinion that the placement of a 2- to 3-inch wide paper or plastic strip over the crack prior to the installation of the repair system will permit the stresses set up by movement in the slab to be distributed over 2 or 3 inches of the repair membrane instead of in the very small area above the crack. This system should prevent premature cracks in the repair system.

The installation of a waterproof membrane over the entire exposed slab is indicated when the isolation and repair of cracks becomes uneconomical. The selection of the type of membrane will be influenced by the type of structure, and its predicted future life and use. In the case of permanent structures, the 4- or 5-ply, mineral surfaced, built-up roof appears to be the logical selection and, based on past experience, should provide 20 or more years of service. The type of bitumen selected for these roofs should be commensurate with the slope of the roof and precautions should be taken to prevent drippage through existing cracks to the interior.

A more economical repair system may be indicated depending on the type and future use of the structure. In this case, the membrane, consisting of the glass mat or woven glass fabric-asphalt emulsion combination, has given adequate service. This membrane should be further protected with a reflective coating compatible with the asphalt emulsion. Best results are usually obtained by allowing the emulsion to weather 3 to 6 months prior to the application of the reflective coating.

No doubt, there are other systems which may prove satisfactory in this capacity.

The conventional 4- or 5-ply, bituminous, built-up roof, surfaced with gravel, has performed very well over wood decks, precast concrete slab decks, and other decks having many joints, and the continued use of these roofs in these situations appears warranted.

6. CONCLUSIONS AND RECOMMENDATIONS

(1) Exposed reinforced concrete slabs have provided excellent service on both military and civilian structures in Puerto Rico.

(2) Built-up roofs should be employed only where the use of the exposed concrete slab is impracticable.

(3) The conventional surfaced, built-up roofs have provided excellent service both as new roofs and as repair membranes for defective exposed slabs.

(4) Mineral-surfaced prepared roofings will provide approximately 10 years of adequate service on sloping roofs.

(5) In the warm, humid climate of Puerto Rico, concrete slabs become quite dark due to biological growths on the surface and, therefore, reflective coatings should be employed to reduce thermal movements in the slab.

(6) Methods for the repair of cracks in exposed slabs should be investigated, since experience has indicated cracking will occur in such slabs. A system for providing the distribution of stresses over larger areas of the repair membrane should be investigated.

(7) Repair methods employing a mastic and reinforcing medium have proven most successful.

(8) A membrane type roof should be employed when it becomes uneconomical to repair cracks. The type of roof should be determined by the type and future use of the structure.

7. ACKNOWLEDGMENT

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