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WATERPROOFING SYSTEMS

FOR

UNDERGROUND STRUCTURES

by

Thomas H. Boone, William C. Cullen, & William W. Walton

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Organic Building Materials Section
Building Research Division
Institute for Applied Technology

Sponsored by

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1. INTRODUCTION

Each waterproofing job presents its own combination of circumstances and conditions that require individual attention. This is especially true of underground areas because of the variety of soils, moisture and hydrostatic pressure problems. Therefore, from the initiation of the program it was realized that only basic guide lines regarding the selection of materials and methods of application could be developed which would pertain to all waterproofing installations.

In order to provide the Military Construction Agencies with performance data regarding waterproofing systems and criteria for the selection of adequate systems, a program was conducted under Project 10446, Waterproofing Membranes, Tri-Service Engineering Investigations of Building Construction and Equipment, NBS.

This report describes waterproofing systems which are intended for below-grade applications. This report also gives our observations of field investigations at 8 underground construction sites and the results of tests conducted at the National Bureau of Standards, including simulated backfill-water pressure tests, vapor permeance, impact resistance and strength. The results of other investigating laboratories were also considered.

2. WATERPROOFING SYSTEMS

Cost and a successful history are usually the important criteria for the selection of a waterproofing material. For this reason, the conventional hot-applied membranes, as shown in Figures 6, 7, 8, and 9, are the more commonly used types. However, other factors such as ease of application, good flow characteristics, space limitations, etc., have required that other systems be considered for waterproofing applications.

2.1 Materials

The materials have been grouped as follows: fluid-applied coatings; hot-applied bituminous membranes, cold-applied bituminous membranes, and sheet-applied systems.

2.1.1 Fluid-applied Coatings

The waterproof coating commonly used in the silo construction that we observed was a vinyl chloride dispersion applied by a hot-spray technique to an epoxy-primed surface. One-coat, epoxy-vinyl systems, high-solids epoxies, epoxy esters, and chlorinated rubber were also being considered for use. Materials used or observed in this study were:

a) Sprayed-on polyvinyl chloride membrane coating with a 30-mil dry film thickness over a 1-mil epoxy primer or bonding coat. After 24 hours, an additional 25-mil shell coat of a filled polyvinyl chloride was spray-applied. The panels were prepared by the Coloron Division of Kish Industries and were identified as "Vinylastic".

b) Similar system as (a) except the epoxy primer, PVC membrane coat and PVC shell coat were placed on by brush. The material was supplied by the Lion Oil Company.

c) Two brush coatings of neoprene with a total dry film thickness of 10 mils. Material supplied by the Tufcrete Co., Inc., and identified as "Black Elastomeric Coating".

d) Two brush coatings of "Hypalon" over 1 coat of neoprene. Total dry film thickness of 10 mils.

2.1.2 Hot-applied Bituminous Membranes

This waterproofing system usually consists of three or more alternate layers of hot, mopped-on asphalt or coal-tar pitch and plies of bituminous saturated felt or woven cotton fabric. The number of moppings exceeds the number of plies by one. Five plies is the maximum commonly used in building construction, but 10 or more plies have been recommended by some manufacturers for hydrostatic pressure heads of 35 feet or greater. The following materials of this type were studied:

a) Conventional 5-ply waterproofing consisting of alternate layers or plies of 15-lb. asphalt-saturated felt cemented together and covered with a hot-mopped waterproofing-grade asphalt.

b) Hot-mopped coating of asphalt known as "Gulf-Seal Waterproofing No. 626" over which was placed a 1/8-inch thick, 5-course preformed membrane. Material supplied by Gulf States Asphalt Co., Inc.

c) Conventional 5-ply waterproofing consisting of alternate layers or plies of 15-lb. coal-tar-saturated felt cemented together and covered with a hot-mopped coal-tar pitch.

2.1.3 Cold-applied Bituminous Membranes

This system of waterproofing may be similar to that of the hot-applied except that it is applied cold by trowel or spray. Other innovations are included in this group, such as glass fabric and epoxy/coal-tar. The systems that were studied are:

a) Coal-tar/epoxy system consisting of two coats with glass fabric embedded in the first coat. The system was identified as "Tarset (R) Standard" and was supplied by Pittsburgh Chemical Company.

b) Built-up 3-ply system of glass fabric and asphalt emulsion. The fabric was identified as "Yellow Jacket", the emulsion as "Asphalt Emulsion C-13-E" and were supplied by the Flintkote Company.

c) Built-up 3-ply system of glass fabric and cutback asphalt mastic. The system was identified as "Nokorode Seal Kote" and was supplied by the Lion Oil Company.

d) Asphalt emulsion and chopped glass fibers in the ratio of 3 gallons of emulsion to one pound of chopped glass applied in two coats over asphalt-primed concrete panels. The system identified as "Monoform" was applied to the test panels by the Flintkote Company with a spray gun that sprays the emulsion and glass fibers simultaneously.

2.1.4 Sheet-applied Systems

Plastics and rubber materials ranging from 8 to 100 mils thick are included in this category. The most commonly used plastic materials are polyvinyl chloride and polyethylene; the rubber is usually butyl. The following materials were investigated.

a) Polyvinyl chloride sheet which is applied to the forms before the concrete is cast. T-ribs formed on one side are encased in the concrete, mechanically locking the sheet in place. "T-Lock Amer-Plate" was supplied by the Amercoat Corporation.

b) Polyvinyl chloride sheeting supplied by three different companies in thicknesses of 8, 10, 15, 20, and 30 mils were also studied. The sheeting was applied to concrete and sealed at lapped joints with rubber or resin based adhesives.

c) Polyethylene sheeting, 6, 10, 15, and 20 mils thick were applied to concrete panels with a rubber-base adhesive.

d) Butyl rubber sheeting supplied by the Carlisle Corporation. Sheeting 30 and 60 mils thick were applied to concrete panels with butyl adhesive.

e) Neoprene sheeting laminated to an asbestos felt and applied to the concrete panels with a rubber-base adhesive.

2.2 Application

The materials used for underground waterproofing may be applied by a number of methods.

2.2.1 Spray, Trowel, and Brush Application

The vinyls, epoxies and some asphalts in suitable solvent or carrier systems may be sprayed on. Equipment is available to mix two component systems in the right proportions at the nozzle, to preheat the material, and to heat the material at the nozzle in order to facilitate faster cure or set. (See figures 2 and 3.) Trowel or brush is sometimes used for cold-applied asphalt systems.

2.2.2 Mopping

Asphalt, coal-tar pitch, and coal-tar enamels are generally applied hot with a mop. This type of application presents some hazard when working in confined areas. The heating equipment must be located fairly close to the area of application. If the material is at too low a temperature at the time of application, poor bond and inadequate penetration of the felt or cloth by the bitumen results.

2.2.3 Adhering

The flexible sheet systems are bonded and, in some cases, sealed at overlapping ends by thermoplastic adhesives (see Figure 11). A Thermoplastic adhesive is specified because such an adhesive can closely approximate the properties of the sheet and is likely to better withstand the stresses developed during the expansion and contraction that might occur. These adhesives dry by solvent evaporation, leaving the solid adhesive in place. The nature of

the adhesive required is determined by the temperature and other physical requirements of the application and the nature of the materials to be bonded. Besides involving fire and toxicity hazards, the use of adhesives in the field requires careful surface preparation and application.

3. FIELD OBSERVATIONS

Field observations were made at three Minuteman missile sites, two Titan II missile sites, one Titan I missile site, and two conventional building sites. The locations were as follows:

Larson AFB	Moses Lake, Washington	Titan I
Malstrom AFB	Great Falls, Montana	Minuteman
Little Rock AFB	Little Rock, Arkansas	Titan II
Ellsworth AFB	Rapid City, S. Dakota	Minuteman
Whiteman AFB	Knob Noster, Missouri	Minuteman
McConnell AFB	Wichita, Kansas	Titan II
Navy Facility	Washington, D. C.	Building
Pa. Agriculture Bldg.	Harrisburg, Pa.	Building

The Minuteman structures were identical, variation at each site being limited primarily to construction methods.

The Minuteman launch facility was a steel lined concrete tube approximately 80 feet deep with an inside diameter of 12 feet, together with a launcher support building, the top of which was flush with the ground. The upper 25 feet of the launcher was expanded to a diameter of 25 feet to provide an equipment and maintenance area surrounding the launch tube and was the area on the launcher specified for exterior wall waterproofing.

There was one launch control center for each ten launch facilities. They consisted of an above-ground building and an underground reinforced cylindrical concrete capsule. The underground control center capsule was over 40 feet long and approximately 20 feet in diameter. The capsule, a large access shaft and an equipment room, was waterproofed on the outside wall.

The launcher silo of the Titan II was a reinforced concrete cylinder with its top flush with the ground. The inside diameter was 55 feet and in depth the silo was around 150 feet from the top to the base slab. The wall was 4 feet thick to within 35 feet from the top, then it thickened to 8 feet. The launch control center for each silo was a dome roof over a cylindrical base structure. The inside diameter was around 40 feet and its height 50 feet. The foundation slab was

8 feet thick and the walls 3 feet thick. The launch control center was connected to the silo, the access portal, and the blast lock by tunnels. The control center, blast lock, and tunnels were waterproofed on the outside walls.

3.1 Larson Air Force Base

A visit was made to Titan I missile launching complex 1-C to observe systems of waterproofing on underground silos, tunnels, and adjoining structures. With the exception of a few structures near the surface, all work had been covered over.

The silo structures were waterproofed with a two-coat system. A hot-spray primer was applied at a rate of approximately 200 sq. ft. per gallon of a material identified as RC 900, after which a second coat of a material known as RC 920 was applied by a hot-spray technique to a thickness of about 30 mils. The coating system was reported to be a plastic membrane waterproofing of epoxy-polyvinyl chloride as manufactured by Ren Plastics, Inc., Lansing, Michigan.

The corrugated steel utility tunnels were coated with factory-applied asphalt-asbestos mastic.

The adjoining structures were waterproofed with a five-ply asphalt-felt system and protected with 1/2-inch fiberboard.

The site was surrounded by irrigated fields supplied by canals from the Columbia Basin Project and the complex was designed for a water table within a few feet of the surface.

At the time of the visit, the leakage of water into the structures and tunnels at this site was a serious problem. Water was being pumped from the site at a rate of 240,000 to 255,000 gallons per day during the period of 29 July to 9 August. There were numerous leaks around bolts in the tunnels. Leaks were also noted at tunnel junctions. Minor leaks were encountered in the concrete structures, generally at points where bolting into walls had taken place, or where steel members had been welded to ring beams set in the concrete structures.

3.2 Malstrom Air Force Base

A visit was made to six Minuteman launch silos and four control centers. The areas visited included all phases of construction.

The control center structures were being waterproofed with a two-coat system. First a hot-spray primer of a material known as "Gold Bond GP Vinyl-Epoxy Primer" was applied to a dry film thickness of 1 mil, and second a hot-spray finish coat called "Vinylelastic" was applied at a dry film thickness of 20 mils. The complete system was reported to be "Lifecoat Vinylelastic Waterproofing Membrane", as manufactured by Coloron Division of Kish Industries, Lansing, Michigan. The primer coat was, in some cases, used as or in place of the concrete curing compound. No protective board was used for back fill. Blisters were observed on some surfaces, but they were reported to disappear in time. Some small areas (1/4 to 1/2 inch) were torn on the membrane at one control center being back-filled.

3.3 Little Rock Air Force Base

Three Titan II Missile Sites (2, 15, and 4) were visited at Little Rock Air Force Base, Little Rock, Arkansas. The three sites were at various stages of construction, with site 4 most nearly completed.

The following observations were made during the visit:

Access Port. The access port was a reinforced concrete structure extending about 35 feet underground. The waterproofing system consisted of priming the relatively smooth concrete surface with an asphalt cut-back primer and applying a 5-ply asphalt built-up membrane horizontally. A fiberboard insulating material was used to protect the membrane from damage during the backfill operation.

The condition of the membrane waterproofing varied from site to site. On site 2, the application was excellent, while on site 4, it was poor. The poor condition was evidenced by a lack of adhesion between the plies of felt and severe slippage of the membrane at one area, and could be attributed to application difficulties.

Some difficulty was also experienced with the exposed fiberboard protection of the membrane. In many cases it was observed that the material had curled with a subsequent loss of adhesion to the membrane and hence gave little protection to it. It was suggested that this condition could be eliminated by coating the fiberboard with either hot asphalt or a cold asphalt coating to prevent moisture absorption and the resultant curling.

A point of weakness in the waterproofing system was observed at the junction of the access port and the electromagnetic shield on the blast lock. The original specification did not call for flashing at this point and leakage developed. Currently, a 12-inch strip of asphalt-saturated felt embedded in and coated with a fibrated asphalt emulsion is being successfully employed as a flashing. It was felt that this is a temporary measure and it was suggested that a more permanent type of flashing be designed.

Silos. The construction and waterproofing of silos were also observed at Sites Nos. 2, 4, and 15. The silos were constructed of heavily reinforced concrete and extend about 145 feet below the surface. No waterproofing, per se, was applied to the silo construction. However, a 1/4-inch welded steel plate which serves as an electromagnetic shield and completely encloses the silo, blast lock and control center also acts as the waterproofing member.

It was reported that water leakage had occurred both in the silos themselves and outside the silos in the vicinity of the intake and exhaust ports. There was no question that failures in the form of breaks in the EM shield had occurred. Since it was impossible to attack the problem from the outside of the silo, grouting from the inside was clearly indicated and successfully accomplished.

A chemical solution identified as Halliburton Pressure Grouting was used and reported successful on the silo at site No. 2.

The grouting process at Site No. 5 was observed during the inspections. The system consisted of drilling a 2-inch hole through the 4-foot thick concrete wall and injecting the chemical grout under pressure into the area between the EM shield and the concrete wall. The grout initially has a viscosity of water and thickens with time to seal openings in the concrete.

3.4 Ellsworth A.F.B., Rapid City, South Dakota - Minuteman Sites

Vinylelastic made by Coloron Division of Kish Industries, Inc., was being used to waterproof the support and equipment buildings of the launch facility. This material has also been used at Malstrom A.F.B., Great Falls, Montana.

There were some bubbles in isolated areas, but, in general, the coating looked very good. According to Kish Industires, the blisters are caused by too heavy an application in one pass of the spray gun. They recommend spraying on a webbing first and then building up the film gradually with several passes of the gun.

An earlier suggestion as to the cause of the blisters was that solvent collected in hollow spots in the concrete, and the vapor pressure of this collected solvent forced the membrane into a bubble. Examination of one of the blisters showed that the concrete surface under the blister was not hollow. The area around all of the blisters adhered tightly to the concrete and it seems that the only problem introduced by the blisters could be the increased danger of damage to the film during the back-fill operation.

In the present construction, there is no water stop where the base of the equipment room joins the launch tube, and this junction could develop water leaks. A water stop is required in the revised specifications.

There are no special problems with water at the present time, but the adequacy of the waterproofing can be determined only after back-filling has been completed and the water level reaches its normal table.

Observation of the back-fill operation confirmed the opinion that with the small working space and the large equipment involved, careful workmanship is required to prevent damage to the waterproofing (see figures 4 and 5).

3.5 Whiteman A.F.B., Knob Noster, Missouri - Minuteman Sites

Construction was at an earlier stage than at Ellsworth and no waterproofing had been started.

Some experiments with a waterproofing material had been conducted by a company from Kansas City, but the material bubbled badly and did not harden properly at high ambient temperatures and the tests were discontinued. The composition of the material was not known by the area engineer. The material exhibited a yellow color where it had dried on the side of the cut and it may have been some type of epoxy coating.

Very shallow open cuts were used at some of the sites at Whiteman and these could cause some difficulties in the waterproofing and back-fill operation.

3.6 McConnell A.F.B., Wichita, Kansas - Titan II Sites

Construction was well advanced at McConnell and the waterproofing had been completed and covered up.

Waterproofing generally consisted of a five-ply membrane built-up with hot-applied asphalt and protected with celotex board.

The cableways were slip-jointed and welded in contrast to the bolted joints used at Malstrom where serious water leaks occurred. At expansion joints in cableways, metal was welded around the outside of the joint and the space between grouted with portland cement.

As at Little Rock, there were some leaks at joints to the blast lock and this again suggests the possibility that flashing is needed at this point. The leaks at McConnell were stopped by the use of polyvinyl chloride.

Water leaks also occurred at some points where the walls were penetrated by conduits. These were stopped by pumping a solution of sodium silicate into the conduit under pressure and holding the pressure for several hours. It was found that the success of this technique depended upon having the conduit very clean.

3.7 Navy Facility, Washington, D. C.

A visit was made to observe the application of a membrane waterproofing system on a two-story buried concrete structure.

The concrete surface was coated with creosote primer and waterproofed with a four-ply, coal-tar-pitch membrane. The membrane consisted of three layers of felt and one ply of cotton fabric mopped to the primed concrete and to each other with hot pitch. A 1/2-inch fiber board was placed for back fill protection.

3.8 Pennsylvania Agriculture Building

A visit was made to Carlisle and Harrisburg to observe the manufacture and laboratory tests of butyl rubber and its installation as a waterproofing membrane.

<u>Material</u> - The "Sure-Seal" butyl rubber sheeting is manufactured by the Carlisle Tire and Rubber Co. in thicknesses of 1/32-, 1/16-, 3/16-, and 1/8-inches, in widths up to 20 feet. The butyl is supplied, at this time, by the Enjay Chemical Company. The compounding, mixing, calendering, extruding, and fabrication is done at the Carlisle plant. Butyl rubber, an isobutene polymer, is claimed to have good aging characteristics, and high resistance to alkalies, acids, ozone, mildew and moisture. Butyl rubber maintains its elastic properties at low temperatures.

<u>Installation</u> - An inspection was made of the installation of butyl sheeting as a foundation water barrier on a large office and laboratory building in Harrisburg, Pa. The building was being constructed for the Pennsylvania Department of Agriculture and was designed by Buchart Associates of York, Pa. Surburban Roofing Company of Mechanicsburg, Pa., was installing the waterproofing and roofing.

A 1/16-inch thick membrane was being placed under the foundation slab, under the footings, and up the vertical walls. Special corners and boots for outlets were fabricated at the factory for this waterproofing. The vertical sheets were held to the concrete walls by adhesive and/or clamps during the back-fill operation. A 2- by 4-inch stringer was placed along the top of the concrete wall to provide a place for the clamps (see figure 11). It was stated that the foundation will be subjected to a 20-foot water head. Field splicing was readily accomplished by a factory-made tongue and groove arrangement or by lap jointing. A butyl adhesive and an uncured butyl tape, sandwiched between the laps, was used for splicing. Damaged areas seemed to be readily repaired. Mr. Tom Detwiler of the Surburban Roofing Company expressed great satisfaction as to the handling and placing of the material. Mr. Detwiler's experience in waterproofing has been with built-up systems. Although the temperature at the time of inspection was 15°F., the membrane remained flexible and no difficulty was experienced in making joints.

The membrane was protected against damage by back-fill with an asphalt type of board. Mr. Detwiler thought that this was not needed with the back-fill material that was being used.

4. LABORATORY INSPECTION

4.1 Water Resistance

This is a fundamental property which was considered in the investigation. To have good water resistance a material selected for underground waterproofing must combine the following basic factors: 1) moderately low water-vapor permeability, 2) low water absorption, and 3) resistance to water under high pressure.

4.1.1 Water-vapor Permeance

This property was measured by the procedure described in ASTM designation E96, Method A and Method B.

The values in Table I, which were obtained with the water method, show that the specimens which were selected as being representative of most waterproofing systems are effective seals against vapor transmission.

Although the vapor permeance for some materials used for underground waterproofing are often reported to the third decimal place, it is believed that for the present use the digits beyond the first place are superfluous. Since the vapor permeability rates of the materials were extremely low, too much significance should not be placed on the differences.

4.1.2 Water Absorption

Absorption of water by some materials causes swelling and a reduction in strength. When the swollen material dries, shrinkage occurs. Alternate wetting and drying produces a swelling and shrinking cycle which constitutes a fatigue process that might readily occur with underground waterproofing materials. If the waterproofing of underground structures is below or near the water table, then the long-term water-absorption characteristics should also be known.

The properties of coatings and sheetings used in this study indicate low water absorption [1, 2, and 3].*

Pfeiffer [4] reported measurements of water absorption of test pieces of different types of bitumens upon being soaked in tap and sea water over a period of 10 years. From this data, the water absorption of a

*Numbers in brackets refer to literature references at the end of this report.

TABLE I.

SUMMARY OF RESULTS OF WATER-VAPOR PERMEANCE MEASUREMENTS

	Perms[1/]
Elastomeric coating, 30 mils	0.1
Epoxy-vinyl coating, 20 mils	0.0
Vinyl sheetings, 8 to 100 mils	0.0 to 0.8
Polyethylene sheetings, 6 to 20 mils	0.0 to 0.1
Butyl sheetings, 30 and 60 mils	0.0
3-ply glass fabric/asphalt emulsion, 3/16-in.	0.2
3-ply glass fabric/asphalt, cutback, 1/8-in.	0.0
1-ply glass fabric/coal-tar epoxy, 1/16-in.	0.0
1-ply glass fabric/hot coal-tar, 1/16-in.	0.0
1-ply glass fabric/hot asphalt, 1/16-in.	0.0
3-ply asphalt felt/hot asphalt, 1/4-in.	0.0
5-ply asphalt felt/hot asphalt, 1/2-in.	0.0
3-ply coal-tar felt/hot coal-tar, 1/4-in.	0.0
5-ply coal-tar felt/hot coal-tar, 1/2-in.	0.0

1/ Perms = grains/sq. ft./hr./in. of Hg

bitumen layer 5 mm. thick after 10 years contact with tap water was 3-4% for blown asphalt and less than 1% for a hard residual asphalt. The absorption from sea water was even less.

4.1.3 Water Under Pressure

A water and backfill pressure apparatus was designed and constructed to subject waterproofing materials in the laboratory to conditions simulating those encountered in the field (see figure 1). The apparatus permits the waterproofing, backed by concrete, to be exposed to water pressures of varying amounts. This treatment was designed to simulate the water head existing at various depths underground. The apparatus also permits exposure of the membrane to various sizes and types of gravel under varying pressures independent of the water pressure. Tables II and III show densities and pressures for various materials and depths.

The No. 4 gravel varied in size from 3/16-inch to 3/8-inch diameter. The 3/4-inch gravel varied in size from 3/4-inch to 1-inch diameter. The gravel was placed under a load of 600 pounds and allowed to slip along the concrete-backed waterproofing specimen a distance of about 1/4-inch. The load calculated to be 28 pounds per square inch on the specimen was held for 6 hours. The specimens were then exposed to a 60-pound water pressure for 2 hours while the load was on the gravel, and for one additional hour with the load released. Observations were made of the effectiveness of the waterproofing systems in preventing water leakage through the test specimens. The results are indicated in Table IV. The "X" indicates a failure or water leakage. On some of the softer bituminous materials, the gravel would seat itself into the coating and plug up the hole it had formed, thereby nullifying its own damage. In these cases, the specimen panels were removed from the box and retested, after removal of gravel, under the 60-pound water pressure.

Because of the varying shapes of fill material and the possibility that the concentration of load in some locations is likely to be severe and prolonged, the ability of the waterproofing systems to withstand such conditions was also studied. With the exception of the sprayed-on epoxy/vinyl with the 25-mil vinyl protective coat, all materials were tested without a protective board or system. Indenting tools, consisting of flat-ended cylindrical steel rods, 1/8-, 1/4-, 1/2-, and 1-1/8 inch in diameter, and under varying loads, were allowed to rest on the samples for a period of 6 hours. After removal of the rods, the samples were placed in the pressure box illustrated in figure 1 and exposed for two hours to 60 pounds water pressure. The results are indicated in Table IV. The "X" indicates a failure or water leakage.

TABLE II.

RANGE OF DENSITIES OF FILL MATERIALS

Soil Type	Bulk Density, p.c.f.
Dry sand	90 to 110
Clay	95 to 120
Soft flowing mud	105 to 120
Wet fine sand	110 to 120
Gravel	120 to 135

* * * * * *

TABLE III.

WATER AND EARTH-FILL PRESSURE AT UNDERGROUND DEPTHS

Depth	Water Pressure	Earth Pressure	
		with 100 p.c.f. fill	with 135 p.c.f. fill
ft.	p.s.i.	p.s.i.	p.s.i.
1 to 3	1.0	.5	.7
4 to 6	2.5	1.0	1.3
7 to 10	4.0	1.6	2.1
12	5.0	2.4	3.2
15	6.5	3.0	4.0
20	9.0	4.0	5.4
25	11.0	5.0	6.7
30	13.0	6.0	8.0
40	17.0	8.0	10.7
50	22.0	10.0	13.4
60	26.0	12.0	16.1
80	35.0	16.0	21.5
100	43.0	20.0	26.7
120	52.0	24.0	32.2
140	60.0	28.0	37.3

TABLE IV.

60-POUND WATER PRESSURE TESTS AFTER 6 HOURS
EXPOSURE TO THE STATED CONDITIONS

X = Leakage

	No. 4 Gravel at 20 psi	3/4" Gravel at 20 psi	1-1/8" rod at 100 psi	1/2" rod at 100 psi	1/2" rod at 400 psi	1/4" rod at 400 psi	1/4" rod at 1600 psi	1/8" rod at 1600 psi	1/8" rod at 5000 psi
Elastomer coating, 30 mils		X				X	X	X	X
Epoxy/vinyl, 20 mils	X	X			X	X	X	X	X
Epoxy/vinyl with protective coat, 45 mils									
Vinyl sheet, 8 mils	X	X							
Vinyl sheet, 10 mils	X	X							
Vinyl sheet, 15 mils	X	X							
Vinly sheet, 20 mils	X	X							
Vinyl sheet, 30 mils		X							
Vinyl sheet, 100 mils									
Polyethylene, 6 mils	X	X							
Polyethylene, 10 mils	X	X							
Polyethylene, 15 mils		X							
Polyethylene, 20 mils									
Butyl sheet, 30 mils									
Butyl sheet, 60 mils									
3-ply glass fabric/asphalt emulsion	X	X				X	X	X	X
3-ply glass fabric/asphalt cutback			X	X	X	X	X	X	X
1-ply glass fabric/coal-tar epoxy									
1-ply glass fabric/hot coal-tar									
1-ply glass fabric/hot asphalt									X
3-ply asphalt felt/hot asphalt									
5-ply asphalt felt/hot asphalt							X	X	X
3-ply coal-tar felt/hot coal-tar									
5-ply coal-tar felt/hot coal-tar									

4.2 Strength

A natural approach to comparing the laboratory performance of materials is to study the stress-strain properties. In this investigation, however, the following limiting factors must be considered:

a) The extreme differences in the types of materials.

b) The lack of information concerning the most favorable properties.

c) The method of preparing test specimens for such tests as tensile strength, elongation, and bursting strength was inherently different, in some cases, than the method used to install the material in the field.

d) The reproducibility of results with some specimens, such as a five-ply, hot asphalt membrane, was very poor because of difficulty in sample preparation.

Bursting strength was determined with the Mullen Bursting Strength Tester as described in ASTM Method D-774. In this test, the specimen was clamped over a circular orifice beneath which a steadily increasing hydraulic pressure is applied to the system. The pressure in the system at the instant of rupture is indicated by a maximum-reading dial gage; this pressure is taken as a measure of the bursting strength of the specimen and is reported as Mullen "points" rather than p.s.i., because the true bursting strength of the specimen involves other factors (for example, the distensibility of the specimen) in addition to the pressure in the system. As noted in Table V, some specimens withstood the maximum pressure of the tester (160 points) and are recorded as 160+. Other specimens stretched into what approached a hemispherical shape beyond the limits of the tester.

The measurement of the tensile strength of some of the waterproofing materials under study was made according to ASTM Method D-882, Method B, in which a constant rate jaw or grip separation is employed. The test specimen was a strip of uniform width and thickness and 4 inches or more in length. The width of the specimen was chosen to allow failure to occur well within the load capacity of the machine. A rate of cross-head motion of 20 inches per minute was used. Thickness and width were measured at several points and the maximum cross-section was recorded. Tensile strength is listed

in Table V. The average strengths in two directions are reported from specimens made at right angles to each other.

While the specimens were being tested for strength, the elongation was recorded to the moment of rupture. These results are also reported in Table V.

4.3 Toughness

The property of toughness, which is closely related to strength, implies, however, certain additional qualities. Tear resistance, puncture resistance, and tear-impact are of particular importance. Of these three properties the tear-impact could be tested on all samples and it was considered to be related to field conditions.

In this test, the concrete panels were set at 45 degrees from the horizontal with the membrane facing upward. A 220-gram steel dart (approximately 1/2-pound) with a 3/4-inch diameter rod, rounded at the edges, was dropped vertically on the surfaces of the specimens. The height of the drop, in feet, that the membrane would withstand without breaking or tearing as measured by its ability to withstand a 60 p.s.i. water pressure for two hours is recorded in Table VI.

4.4 Resistance to Soil Conditions

For good service underground, a waterproofing material must be able to withstand many corrosive and destructive conditions present in the soil environment.

In the presence of water, salts found in the earth's crust may create an acidic or basic environment almost as destructive as that produced by free acid or base. Polyvinyl chloride, polyethylene and butyl rubber have good acid and alkali resistance.

One of the early research activities of the Bituminous Laboratory of the Bureau of Reclamation was the development of the buried asphalt membrane lining [5]. The purpose of this program was to obtain information relative to the effects of field aging. An extensive testing program consisted of visual observations and physical testing of asphaltic membrane linings with service records up to 12 years. A summary of their laboratory test results and conclusions from 65 samples of buried asphalt membrane canal linings taken from 15 canals is as follows:

1) If hot-applied asphalt membrane is installed in accordance with the current Bureau of Reclamation specification, it should provide adequate seepage control for many years beyond the 12-year service test.

TABLE V.

STRENGTHS

	Thickness	Breaking Strength A dir.	Breaking Strength B dir.	Elongation A dir.	Elongation B dir.	Bursting Strength
	mils	lbs.	lbs.	%	%	pts.
Elastomer coating	30	1/	1/	1/	1/	15
Epoxy/vinyl	30	1430	1350	230	230	122
Vinyl Sheeting	8					25
Vinyl Sheeting	10	2000	1700	240	220	30
Vinyl Sheeting	15	to	to	to	to	56
Vinyl Sheeting	21					75
Vinyl Sheeting	30	3000	2200	300	300	102
Vinyl Sheeting	100	4100	3860	340	330	160+
Polyethylene	6	1800	1500	300	300	32
Polyethylene	10	to	to	to	to	55
Polyethylene	15					82
Polyethylene	20	2500	2000	500	500	94
Butyl Sheeting	30	2000	2000	500	500	2/
Butyl Sheeting	60					2/
3-ply glass fabric/asphalt emulsion						100
3-ply glass fabric/asphalt cutback						110
1-ply glass fabric/coal-tar, epoxy						160+
1-ply glass fabric/hot coal-tar		1/	1/	1/	1/	160+
1-ply glass fabric/hot asphalt						160+
3-ply asphalt felt/hot asphalt						160+
5-ply asphalt felt/hot asphalt						160+
3-ply coal-tar felt/hot coal-tar						160+
5-ply coal-tar felt/hot coal-tar						160+

1/ Adequate specimens could not be made
2/ Specimens stretched beyond the limits of tester

TABLE VI.

RESULTS OF TEAR-IMPACT TEST

	45° Tear-Impact Feet
Elastomer coating, 30 mils	4
Epoxy/vinyl, 20 mils	3
Epoxy/vinyl with protective coat, 45 mils	8+
Vinyl sheet, 8 mils	2
Vinyl sheet, 10 mils	2
Vinyl sheet, 15 mils	2
Vinyl sheet, 20 mils	2
Vinyl sheet, 30 mils	2
Vinyl sheet, 100 mils	8+
Polyethylene, 6 mils	1
Polyethylene, 10 mils	1
Polyethylene, 15 mils	3
Polyethylene, 20 mils	3
Butyl sheet, 30 mils	2
Butyl sheet, 60 mils	8+
3-ply glass fabric/asphalt emulsion	3
3-ply glass fabric/asphalt cutback	8+
1-ply glass fabric/coal-tar epoxy	8+
1-ply glass fabric/hot coal-tar	8+
1-ply glass fabric/hot asphalt	8+
3-ply asphalt felt/hot asphalt	8+
5-ply asphalt felt/hot asphalt	8+
3-ply coal-tar felt/hot coal-tar	8+
5-ply coal-tar felt/hot coat-tar	8+

2) As evidenced by service performance and visual examination, the slight change in the penetration, ductility, and softening point of the asphalt does not materially affect their ability to provide a flexible, watertight lining.

3) Based on change in physical properties as determined by softening point, penetration, and ductility testing, it is indicated that approximately 90 percent of the aging of the asphalt membranes studied occurred during the first 4 years of service. The change due to aging decreased sharply after about 8 years' service.

5. SUMMARY

The various materials that have been suggested for use in underground waterproofing of structures have certain advantages as well as some disadvantages.

Hot-applied, bituminous, built-up membranes have a long history of successful use under various conditions. These materials have adequate strength, flow slowly under stress (if temperature is not too low), bond well to the concrete and are low in cost. They can not be applied when temperatures are below 40°F and at high temperatures there is danger of slippage (see figure 7). The hot bitumen is hazardous to use in confined working areas, particularly where the wall slopes sharply outward and application is almost directly overhead of the worker. The bitumen must be heated to the proper temperature because too low a temperature results in poor spreading and too high a temperature damages the bitumen. If working space prevents the heating from being done near the area of application, there is the additional problem of keeping the material hot enough during transportation for good application. The network of penetrations that occur in some structures increases the difficulty of application.

Some problems of slippage have been caused by the low softening point of the asphalt. It is recommended that the asphalt should meet the requirements of ASTM Specification D449-49, Asphalt for Dampproofing and Waterproofing, Type C.

The cold-applied, solvent cutback, mineral-filled asphalt has many similarities to the hot-applied asphalt with respect to advantages and disadvantages.

An adequate specification must be used to obtain satisfactory material. A suitable specification developed under this project has been issued as MIL-C-82052 (DOCKS) 6 April 1964, Coating Compound; Mineral-Filled, Solvent-Type, Asphalt-Base.

Liquid-applied Systems

These materials are easily applied, even around complicated penetrations. They do require special equipment and experienced personnel to obtain a coating of uniform thickness without blisters (see figure 3). In confined areas precautions must be taken to avoid fire and health hazards. If a curing compound is to be used on the concrete it must be compatible with the coating to obtain proper bond.

Although these materials, if properly formulated, will remain intact if hairline cracks develop in the concrete it is unlikely that they would remain undamaged by large cracks. It seems possible that a product could be developed with a careful balance of bond strength, tensile strength and elongation to improve this characteristic. Some of these materials can be applied over a wide (0°-100°F) temperature range. Products intended for this use should be carefully tested including cut-out tests to insure proper application. A suggested specification for an epoxide-vinyl chloride material is given in Appendix A.

Sheet-applied Systems

Polyethylene sheets, 4- or 6-mils thick, have been used extensively in recent years as a waterproofing membrane. Their application has been limited generally to horizontal surfaces such as under concrete floor slabs because of difficulty in bonding to vertical surfaces and of sealing lapped joints. Polyvinyl chloride sheeting (see figure 10), which has also been used for waterproofing, presents similar bonding problems in some cases. Another difficulty arises in the use of PVC. It is very difficult to distinguish by short-term tests a PVC sheet with good aging characteristics from one with poor aging characteristics. Proper formulation and its control are very important.

A butyl rubber sheeting was developed by several concerns for waterproofing and roofing just before and during the early stages of this investigation. Butyl rubber sheeting had been used successfully as linings for irrigation canals, ditches, reservoirs, and ponds. When exposed to soils, water, and various climatic conditions for 10 years or more it did not show any appreciable loss in the original properties. A suggested specification for a butyl rubber membrane is given in Appendix B.

6. REFERENCES

[1] McKinley, R. B. and C. H. Seaberg, "Moisture vs. rubber insulation", Gen. Elec. Rev. 55 (4), 56 (1952).

[2] Modern Plastics Encyclopedia, Plastics Catalogue Corp., New York, N. Y. (1962).

[3] Roberts, A. G., "Properties of plastic films for use as waterproofing materials in underground heat distribution systems", National Bureau of Standards Report 5967 (July 1958).

[4] Pfeiffer, J. P., "The properties of asphaltic bitumen", pp. 107, 270-272, Elsevier Publishing Company, N. Y. (1950).

[5] Evaluation of field aging on the physical characteristics of buried hot-applied asphaltic membrane canal lining", Department of Interior Bureau of Reclamation Report B-34 (1964).

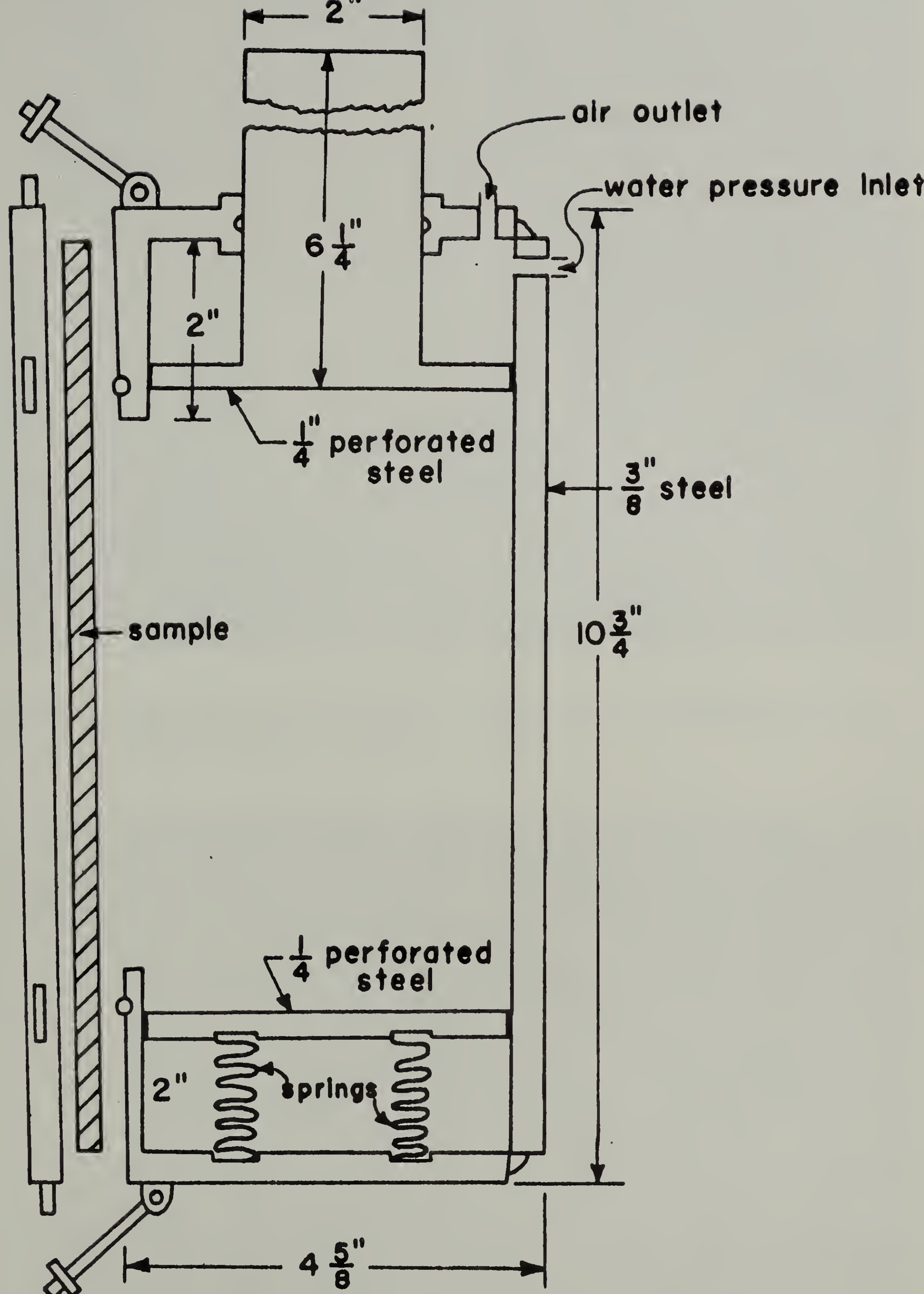

Figure 1. Simulated service test apparatus. The apparatus was designed to simulate conditions to which waterproofing systems are subjected.

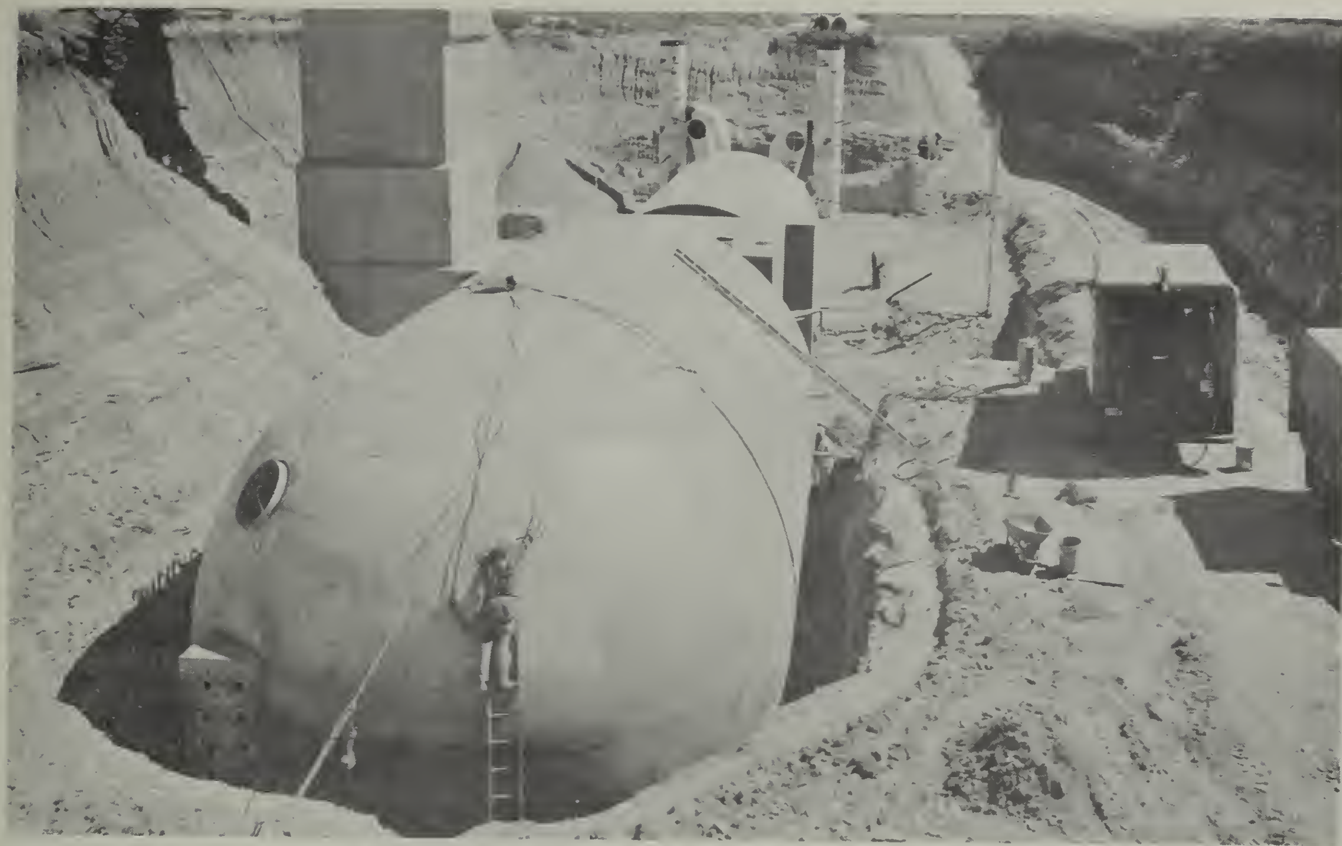

FIGURE 2. EPOXY - POLYVINYL CHLORIDE COATING; SPRAY APPLICATION OF EPOXY PRIMER COATING FORMULATED TO PRODUCE AN ADHESIVE BOND TO CONCRETE, FOUNDATION FOR APPLICATION OF VINYL OOATING AND AS A CURING COMPOUND FOR THE CONCRETE.

FIGURE 3. EPOXY - POLYVINYL CHLORIDE COATING; SPRAY APPLICATION OF 30 MIL THICK VINYL WATERPROOF COATING. CLOSE UP INSERT AT THE LOWER RIGHT OF PHOTOGRAPH SHOWS BLISTERS OBSERVED ON SOME VINYL SURFACES. LARGEST BLISTER ABOUT 2-INCHES IN DIAMETER.

FIGURE 4. BACKFILL OPERATIONS; TRACTOR AND VIBRATOR USED IN TAMPING FILL. THE 30 MIL VINYL WATERPROOF COATING HAS BEEN COVERED WITH A 25 MIL VINYL MINERAL FILLED COMPOUND FOR PROTECTION.

FIGURE 5. BACKFILL OPERATIONS; HAND TAMPING EQUIPMENT USED NEXT TO WALL. THE DARK SPOTS WERE DAMAGED AREAS IN THE VINYL WATERPROOF COATING WHICH HAVE BEEN REPAIRED.

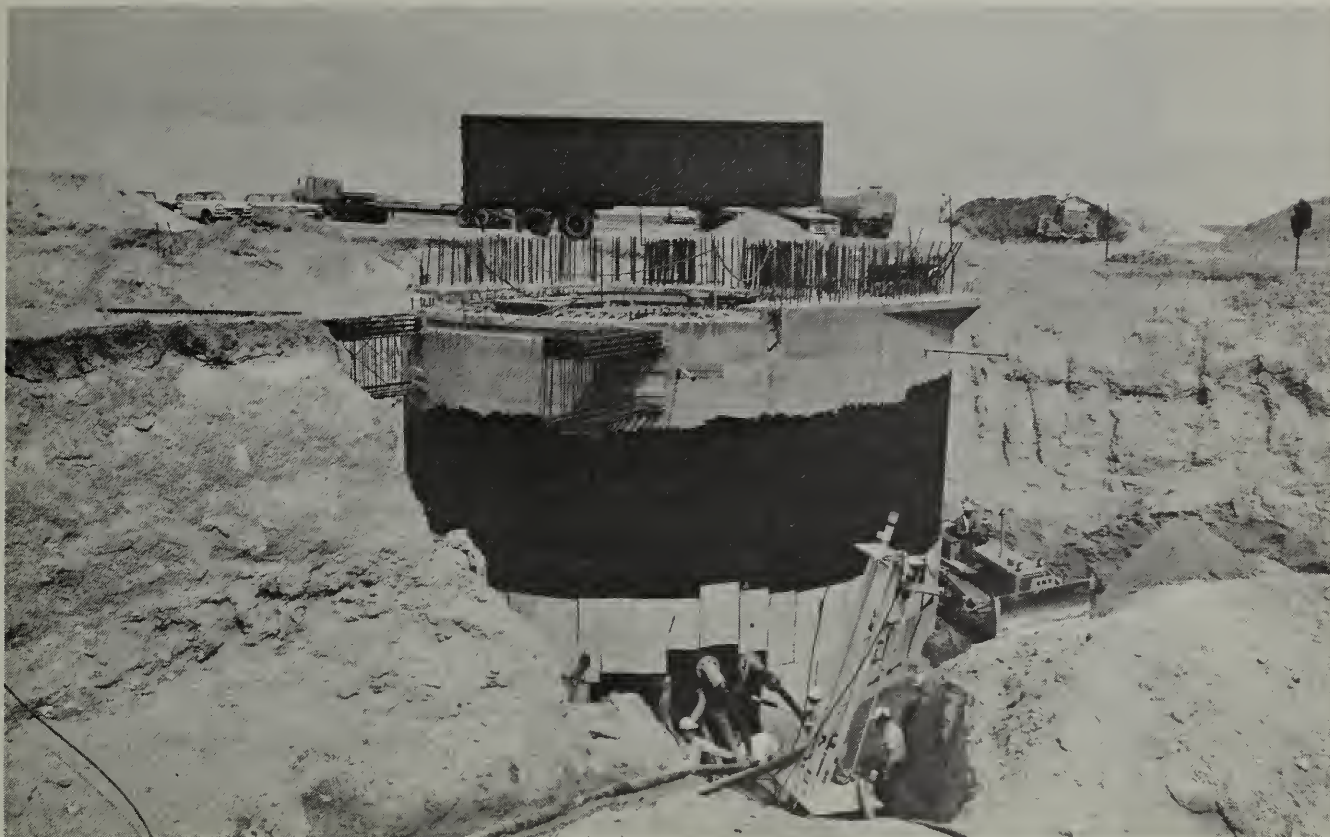

FIGURE 6. HOT-APPLIED BITUMINOUS MEMBRANE; WATERPROOFING OF THE FIVE-PLY ASPHALT TYPE, PLACED OVER ASPHALT PRIMED CONCRETE AND PROTECTED WITH INSULATING FIBERBOARD. THE FIBERBOARD WAS PRESSED INTO THE FINAL MOPPING WHILE THE ASPHALT WAS STILL HOT.

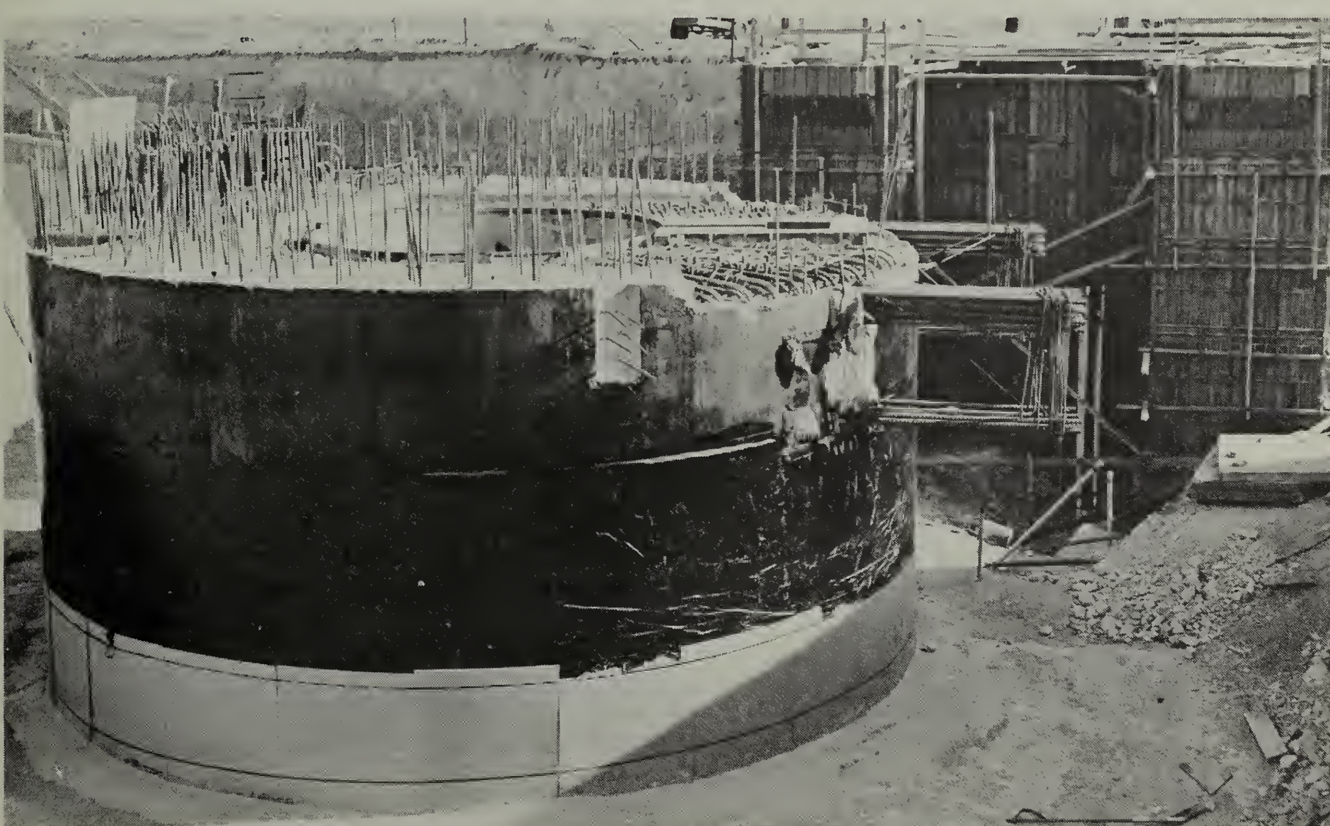

FIGURE 7. HOT-APPLIED BITUMINOUS MEMBRANE; VIEW OF SAME STRUCTURE AS ABOVE SHOWING METAL STRAPS USED TO HOLD THE PROTECTIVE BOARD IN PLACE. NOTE SLUMPING OF ASPHALT MEMBRANE ON THE RIGHT SIDE OF STRUCTURE.

FIGURE 8. HOT-APPLIED BITUMINOUS MEMBRANE; THE CONCRETE SURFACE WAS COATED WITH A CREASOTE PRIMER AND WATERPROOFED WITH FOUR-PLY, COAL-TAR-PITCH MEMBRANE. THE MEMBRANE CONSISTED OF THREE LAYERS OF FELT AND ONE LAYER OF COTTON FABRIC MOPPED TO THE PRIMED CONCRETE AND TO EACH OTHER WITH HOT PITCH.

FIGURE 9. HOT-APPLIED BITUMINOUS MEMBRANE; VIEW OF SAME STRUCTURE AS ABOVE SHOWING 1/2-INCH COATED FIBER BOARD PLACED FOR BACKFILL PROTECTION AND COARSE GRAVEL BACKFILL PLACED IN OPEN NET SACKS.

FIGURE 10. SHEET-APPLIED SYSTEM; POLYVINYL CHLORIDE, 30 MILS-THICK, APPLIED TO VERTICAL CONCRETE WALL WITH RUBBER BASE ADHESIVE. PROTECTIVE BOARD SHOWED IN LOWER RIGHT CORNER.

FIGURE 11. SHEET-APPLIED SYSTEM; A 1/16-INCH THICK BUTYL RUBBER SHEET BEING PLACED ON A VERTICAL WALL. CLAMP AND 2 BY 4 USED TO HOLD SHEETING BEFORE BACKFILLING. A BUTYL ADHESIVE AND AN UNCURED BUTYL TAPE, SANDWICHED BETWEEN THE LAPS, WAS USED FOR THE SPLICING SHOWN AT RIGHT CENTER OF PHOTOGRAPH.

APPENDIX A.

SUGGESTED SPECIFICATION FOR EPOXY POLYVINYL CHLORIDE WATERPROOFING

The epoxy polyvinyl chloride system shall consist of three separate coatings, primer, membrane, and shell coat, which shall be applied independently of each other. The materials shall be of a single manufacturer and comply with the following requirements:

a. Primer coating system shall be an epoxy coating formulated to produce an adhesive bond to concrete and provide a foundation for application of the membrane. The primer coating shall be supplied as a two-package system consisting of a pigmented polymer solution and a hardener. The primer shall be black in color. When combined and mixed in the ratio as recommended by the manufacturer thinning shall not be required.

b. Membrane shall consist of a polyvinyl-chloride compound of a light color contrasting with the color of the primer. The material shall be supplied ready for spray application. The membrane shall conform to the following:

PROPERTY	REQUIREMENT	TEST METHOD*
Water vapor transmission grams/H_2O/100 sq. in./ 24 hrs/30 mils	.178 max.	ASTM E 96-63 T
Water absorption 3" x 1" x 30-mil panel	Wt. increase 0.3% max.	ASTM D 570-63
Percent elongation at 77°F	170% min.	ASTM D 882-61 T Die "C" as per ASTM B 412-61 T Method B-882A
Ultimate tensile strength at 77°F	2000 psi min.	ASTM D 882-61 T Die "C" as per ASTM B 412-61 T Method B-882A
Chemical Resistance	No signs of swelling, pitting or dissolving	Immersed in 10% solution of H_2SO_4 at 70°F for 30 min. Also a 10% solution of sodium hydroxide at 70°F for 30 min.

c. Shell coat shall consist of a polyvinyl-mineral-filled compound. The shell coat shall be black in color and shall conform to the following:

PROPERTY	REQUIREMENT	TEST METHOD*
Chemical Resistance	No signs of swelling, pitting or dissolving	Immersed in 10% solution of H_2SO_4 at 70°F for 30 min. Also a 10% solution of sodium hydroxide at 70°F for 30 min.
Percent elongation at 77°F	80% min.	ASTM D 882 - Die "C" as per ASTM B 412-61 T Method B-882A
Impact resistance	No cracking or peel back	A 112-gram steel ball in dropped 30" on a 1/2"x3"x5" concrete panel coated with a complete epoxide polyvinyl chloride system consisting of a 4-mil primer, a 30-mil membrane, and a 25-mil shell coat. Panel is maintained at 32°F and both horizontal and 45° incline surface tests shall be made.

*American Society for Testing and Materials Standards:

D 570-63 Method of Test for Water Absorption of Plastics.

D 882-61 T Methods of Test for Tensile Properties of Thin Plastic Sheeting (Tentative)

E 96-63 T Methods of Test for Water Vapor Transmission of Materials in Sheet Form (Tentative). Procedure E.

APPLICATION OF WATERPROOFING:

a. Primer shall be applied at a rate of 200 square feet per gallon. Coverage shall be free of pinholes, holidays or other imperfections. Method of application and curing shall be in accordance with the manufacturers' written instructions.

b. Membrane shall be applied directly from the manufacturers' container. The prime coat surface must be dry to the touch and shall be clean and free of water, grease or other foreign matter. Temperature of the surface to which membrane is applied shall be no less than 0°F and no more than 120°F. Membrane shall be applied by spray application to a minimum thickness of 30 mils, in accordance with the manufacturers' written instructions. A minimum of four mils thickness membrane coat must be applied over prime coat as quickly as prime coat becomes dry to touch. Successive coats of membrane material as required to attain the full thickness may be applied at any time thereafter. Special attention shall be given to corners and edges to insure the minimum thickness is obtained.

c. Shell coat shall be applied directly from the manufacturer's container. The membrane surface must be dry to the touch and shall be clean and free of water, grease or other foreign matter. Shell coat shall be applied by spray application to a minimum thickness of 25 mils in accordance with the manufacturers' written instructions. Special attention shall be given to corners and edges to insure the minimum thickness is obtained.

APPENDIX B.

SUGGESTED SPECIFICATION FOR BUTYL RUBBER MEMBRANE WATERPROOFING

The butyl rubber membrane system shall consist of butyl rubber sheeting, bonding adhesive, cement and tape for splicing, and protective board. The materials shall comply with the following requirements:

a. Membrane shall consist of an unreinforced butyl rubber sheeting, 1/16-inch in thickness, with a uniform color and surface texture and conforming to the following:

PROPERTY	REQUIREMENT	TEST METHOD*
Tensile Strength	1200 psi (min)	ASTM D412-61T
Modulus at 300% elongation	650 psi (min)	ASTM D 412-61T
Ultimate Elongation	300% (min)	ASTM D 412-61T
Shore "A" hardness	55 ±5	ASTM D 676-59T
Tear resistance, die B	150 psi (min)	ASTM D 624-54
Ozone resistance: 50 PPHM of ozone at 38°C for 7 days while extended 20%	No cracks	ASTM D 1149-60T
Heat Aging: 7 days at 120°C		ASTM D 573-53
Tensile strength	At least 75% of original	
Ultimate elongation	At least 75% of original	
Low temperature impact at -40°C	No failures	ASTM D 746-57T (Procedure B)
Water Vapor Transmission at 27°C, perm-mils	0.15 (max)	ASTM C 355-59T (water method at 80°F)

b. Adhesive shall be compatible with the membrane waterproofing and with the materials to which it is bonded. Adhesive shall remain elastic at minus 20 degrees F and shall be as recommended by the manufacturer.

c. Cement for splicing shall be a self-vulcanizing butyl rubber compound with a minimum of 30 percent solids, workable at minus 20 degrees F, and as recommended by the manufacturer.

d. Butyl Gum Tape for splices shall be unvulcanized butyl rubber .022 inches thick with a strippable backing.

e. Insulation Board shall conform to Federal Specification LLL-I-535, Class C, 1/2 inch thick.

*American Society for Testing and Materials Standards:

C 355-59T	Methods of Test for Water Vapor Transmission of Materials Used in Building Construction (Tentative).
D 412-61T	Method of Tension Testing of Vulcanized Rubber (Tentative)
D 573-53	Method of Test for Accelerated Aging of Vulcanized Rubber by the Oven Method
D676-59T	Methods of Test for Tear Resistance of Vulcanized Rubber
D 746-57T	Method of Test for Brittleness Temperature of Plastics and Elastomers by Impact (Tentative)
D1149-60T	Method of Test for Accelerated Ozone Cracking of Vulcanized Rubber (Tentative)

Federal Specifications:

LLL-I-535 & Am.-1	Insulation Board, Thermal and Insulation Block, Thermal

APPLICATION OF WATERPROOFING:

a. Adhesive shall be applied to surfaces that will receive membrane waterproofing using either strip mopping or solid mopping as recommended by the manufacturer. Adhesive shall be applied with a stiff bristle brush having bristles not longer than 2-1/2 inches.

b. Clean all seams and splice areas with heptane, hexane, toluene, trichlorethylene, or white gasoline using a clean cloth or mop.

c. Spread cement continuously on seam and splice areas of membrane. Apply cement with a brush at a uniform rate of 50 square feet per gallon.

d. Apply butyl gum tape to cemented areas of membrane. Extend tape at least 1/8 inch beyond edges and splice areas. Roll or press the tape firmly into place. Avoid bridging and wrinkling. Obtain full contact for all tape areas. Splices shall be made with a 6-inch minimum lap and shall be of the type recommended by the manufacturer. Reinforce corner splices with two layers of membrane over one layer of butyl tape.

e. Membrane shall be applied by pressing firmly and uniformly in place against the previously applied adhesive in accordance with the manufacturer's written instructions. Avoid wrinkles and buckles.

f. Flash all projections, pipes, conduits, sleeves, etc., passing through membrane, providing watertight construction. Use prefabricated or field-fabricated boots, fitted coverings, etc., as necessary. Use butyl gum tape between layers of membrane.

g. Prior to backfill, the entire membrane shall be inspected and approved and any defects shall be satisfactorily patched.

h. Membrane terminations shall be mechanically fastened as recommended by the manufacturer.

i. Waterproofing against which backfill other than sand is to be placed shall be protected by a single thickness of insulation board. The insulation board shall be applied with the butyl adhesive or other adhesive compatible with the membrane providing adherence until the backfill is placed.

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