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Waterproof Membranes for Protection of Concrete Bridge Decks

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 12-11, "Waterproof Membranes for Protection of Concrete Bridge Decks - Laboratory Phase," by C. J. VanTil, B. J. Carr, and B. A. Vallerga, Materials Research and Development, Oakland, California

THE PROBLEM AND ITS SOLUTION

During the past several years, the problem of premature deterioration of reinforced concrete bridge decks has appeared prominently in almost every listing of major problems facing highway transportation agencies. Although the problem has been the subject of numerous researches, and much has been learned, no universally acceptable solution has been found. Therefore, the search for systems that offer more positive protection continues.

NCHRP Synthesis 4, "Concrete Bridge Deck Durability," issued in 1970, places first awareness of the severity of the problem in the late 1950's. Surveys of the extent and severity of the problem subsequent to that period identified cracking, scaling, and spalling as the most common deck defects. Spalling was found to be the most serious defect, and experience has shown it to be the least susceptible to control. Spalling is now generally agreed to be caused mainly by corrosion of the reinforcement steel in the presence of moisture and a chloride salt.

Although high-quality concrete, air entrainment, and a good thickness of concrete cover over the steel reinforcement have been found to improve the resistance of bridge decks to deterioration, it is generally agreed that additional control measures are required. Waterproofing barriers have become the most favored means for providing the added control. However, experience shows that most of those used to date probably are not providing the desired degree of protection. The project with which this report is concerned was undertaken to discover improved waterproof membrane protective systems. Concurrently, alternative approaches to

protection, including reinforcement steel coating, cathodic corrosion protection, and polymer impregnation to waterproof concrete, are being investigated elsewhere. Recognition that even the best of waterproof membrane systems can be effective only where decks are relatively free from chloride contamination adds impetus to the search for alternative systems.

FINDINGS

In the research with which this report is concerned, 147 known (in 1970-71) membrane systems were subjected to preliminary examination. The examination included an inspection of the performance of 25 systems in place on existing bridge decks. Seventy-eight of the initial 147 systems showed sufficient promise to be selected for more detailed study. A comprehensive series of laboratory characterization and performance tests, many of which were devised in the project effort, produced nine candidates for a field application test. Permeability, crack-bridging capability, durability, resistance to impact damage, and structural serviceability were among the principal characteristics examined in the laboratory. Ease of application was tested in the field. As a result of the testing, five systems, all of which include preformed sheeting, were selected as the most promising for further evaluation in the in-service environment. The surviving membranes consist of vulcanized, cured, or cross-linked elastomers, all of which appear to provide good dimensional stability on exposure to asphaltic concrete at application temperature, to water, to solar heat, and to freeze-thaw conditions. All of the survivors require a protective coat of asphaltic concrete to serve adequately, and all but one appear to require application of an intermediate protective layer to avoid damage during construction operations following membrane installation.

The in-service evaluation of the five survivor systems is being conducted by Materials Research and Development as a follow-on to the present study. Until the results of this work become available, some discretionary judgment must be applied in the adoption of any one of the systems in general practice. However, the chance seems good that any of these systems will serve better than applications represented by the 25 systems examined in the field survey of existing installations conducted as part of the study. Electrical resistance measurements on these in most instances showed them not to be impermeable.

APPLICATION

Tentative specifications have been developed for the five most promising waterproof membrane systems based on the findings of this study. Use of the information for immediate trial installations seems appropriate. Test procedures also have been developed for monitoring the behavior of the selected systems in the field. Following the field-evaluation project now in progress, it is anticipated that the tentative specifications will be found to be acceptable, or can be modified as indicated by the field trials, to serve as guide specifications for membrane waterproofing systems.

SPECIFICATION
FOR
MEMBRANE WATERPROOFING SYSTEM 10a

1. SCOPE. This specification covers materials and construction for a waterproofing membrane system for portland cement concrete bridge decks to provide an impervious barrier to water and deicing salts.

2. DESCRIPTION. The waterproofing membrane system shall consist of a primer

applied to the prepared deck surface; an adhesive; and a preformed sheet of waterproofing membrane. Under conditions where blistering is anticipated, a ventilating layer, consisting of a perforated, preformed sheet shall be placed on the primer before application of the adhesive. A tack coat of emulsified asphalt and an asphaltic concrete wearing course shall be placed on the membrane system.

3. MATERIALS

3.1. PRIMER. The primer shall be an asphalt meeting the requirements of ASTM D41.

3.2. ADHESIVE. The adhesive shall be an asphalt meeting the requirements of ASTM D312, Type III or Type IV. (Type IV shall be used unless Type III is designated by the Engineer.)

3.3. WATERPROOFING MEMBRANE

3.3.1. *Description.* The waterproofing membrane shall be a preformed sheet, 0.125 ± 0.010 inch in thickness and weighing 6.7 to 7.1 lb/yd^2, of a polyvinyl chloride polymer extended with selected coal tar pitch and reinforced with nonwoven natural and synthetic fibers randomly and uniformly distributed throughout the thickness of the sheet. The sheet shall be impermeable, black in color, flexible, nontacky, and packaged in rolls without release paper.

3.3.2. *Tensile Strength and Elongation.* When tested in accordance with ASTM D412 (specimens cut from longitudinal direction of the roll, using Die C) the ultimate tensile strength shall be 1,000 to 1,500 psi at 77 ± 3°F and 600 to 900 psi at 140 ± 3°F, and the elongation at break shall be 130 to 180% at 77 ± 3°F and 200 to 250% at 140 ± 3°F.

3.3.3. *Deflection Temperature.* When tested in accordance with ASTM D648 (specimen prepared by laminating with adhesive, oil bath replaced by isopropanol/dry ice, and using 264 psi load) the deflection temperature shall be -5 to -15°F.

3.3.4 *Water Absorption.* When tested in accordance with ASTM D570, using 1x3-in. specimens, the absorption after 7 days in distilled water at 77 ± 3°F shall be not more than 2.2%.

3.3.5. *Dimensional Stability.* When a 9x9-in. specimen is exposed in air at 140 ± 3°F for one hour, it shall not change in dimension in either direction by more than ± 0.25%.

3.4. VENTILATING SHEET. The ventilating sheet shall be a preformed sheet, 0.0500 to 0.0625 in. in thickness, meeting the requirements of ASTM D250, with 0.875- to 1.000-in. diameter holes evenly spaced center-to-center 3.00 to 3.25 in. in the transverse roll direction and 6.25 to 6.50 in. in the longitudinal roll direction. The surface shall be dusted with a fine sand (approximating 100% passing the No. 60 sieve), or other suitable mineral material, to prevent adhesion to the dry primed surface of the concrete; and shall bond to, and be compatible with, the asphalt adhesive.

4. CONSTRUCTION

4.1 PREPARATION OF THE SURFACE. The surface of the deck shall have a smooth, fine-textured finish similar to that obtained by machine troweling. All honeycombed areas and surface cavities shall be cleaned and filled with approved patching materials. All sharp protrusions which, in the opinion of the Engineer, would puncture the membrane shall be removed. The surface shall be clean, dry, and free of laitance, oil, or other contaminants. Residual curing compound need not be removed if, in the opinion of the Engineer, it will not interfere with adhesion of the primer or adhesive. Immediately prior to application of the primer, the deck shall be cleaned by brooming and blowing with a compressed-air jet.

4.2. APPLICATION OF PRIME COAT. The primer shall be thoroughly mixed prior to application. Primer shall not be applied when the air or deck temperature is less than 50°F, or during rain or fog. The primer shall be applied at the rate of 90

to 150 sq ft/gal to the entire area to which the membrane is to be applied. The primer shall be completely dry and all solvent evaporated prior to application of the membrane. (Note: This may require up to 24 hr, depending on temperature, humidity, and wind conditions.)

4.3. APPLICATION OF ADHESIVE AND MEMBRANE. The adhesive shall not be applied when the air or deck temperature is less than 50°F, or during rain or fog. The adhesive shall be preheated in a thermostatically controlled roofing kettle to a temperature no higher than required for application by the method used. The adhesive shall be applied to the primed surface by pouring and distributing by a roofer's mop to the width of the membrane sheet. The membrane shall be immediately rolled and pressed into the adhesive in one continuous operation. (An alternative method of application is by means of a roofing machine which mechanically applies the adhesive and membrane in one continuous operation.) The adhesive and membrane shall overlap previously applied membrane by at least 4 in. at the sides and 6 in. at ends. Membrane shall be applied with the longitudinal roll direction parallel to the direction of traffic on the bridge. Application shall begin at the lower points of the deck, in order that the direction of water flow will be over, rather than against, lapped edges and ends.

4.4 APPLICATION OF VENTILATING SHEET. If a ventilating sheet is specified, it shall be placed by unrolling directly onto the cured primer, in the same direction as specified for the membrane. Edges and ends of sheets shall be loosely butt-jointed, without overlap. The adhesive and membrane shall then be applied to the surface of the ventilating sheet in the same manner as specified for application to the primed surface.

4.5. APPLICATION OF WEARING COURSE. A tack coat of emulsified asphalt and a wearing course of asphaltic concrete shall be applied to the surface of the membrane. No unnecessary traffic shall be permitted on the surface of the membrane, and trucks and paving equipment shall be operated in such a manner as to minimize the possibility of damage to the membrane. Any damage to the membrane shall be repaired before paving will be permitted to proceed.

SPECIFICATION FOR MEMBRANE WATERPROOFING SYSTEM 20

1. SCOPE. This specification covers materials and construction for a waterproofing membrane system for portland cement concrete bridge decks to provide an impervious barrier to water and deicing salts.

2.DESCRIPTION. The waterproofing membrane system shall consist of two coats of adhesive; a preformed sheet of waterproofing membrane; an asphalt emulsion bond coat; and a layer of protective board. A tack coat of emulsified asphalt and an asphaltic concrete wearing course shall be placed on the membrane system.

3. MATERIALS

3.1. ADHESIVE. The adhesive shall be a general-purpose solvent containing neoprene-based contact cement with a drying time at 77 ± 3°F of 20 to 60 min, and providing pressure-sensitive bond to itself after drying for a minimum of 4 hr at 77 ± 3°F. Naphtha or naphtha-like solvents shall not be used.

3.2. WATERPROOFING MEMBRANE

3.2.1 *Description.* The waterproofing membrane shall be a preformed buffed sheet, 0.060 to 0.065 in. in thickness, of vulcanized chloroprene. The sheet shall be impermeable, black in color, flexible, nontacky, and packaged in rolls without release paper.

3.2.2. *Tensile Strength and Elongation.* When tested in accordance with ASTM D412 (specimens cut from longitudinal direction of the roll, using Die C) the ultimate tensile strength shall be 1,900 to 2,200 psi at 77 ± 3°F and 1,400 to 1,800 psi at 140 ± 3°F, and the elongation at break shall be 260 to 300% at 77 ± 3°F and 230 to 270% at 140 ± 3°F.
3.2.3. *Deflection Temperature:* When tested in accordance with ASTM D648 (specimen prepared by laminating with adhesive, oil bath replaced by isopropanol/dry ice, and using 264 psi load) the deflection temperature shall be 45° to 55°F.
3.2.4. *Water Absorption.* When tested in accordance with ASTM D570, using 1x3-in. specimens, the absorption after 7 days in distilled water at 77 ± 3°F shall be not more than 0.65%.
3.3 BOND COAT. The bond coat shall be an asphalt emulsion meeting the requirements of ASTM D-977, Grade SS-1h.
3.4 PROTECTIVE BOARD. The protective board shall consist of 4x8-ft sheets, 1/8 in. in thickness, of APOC Board, as manufactured by Asphalt Products Oil Corp., or equal.

4. CONSTRUCTION

4.1 PREPARATION OF THE SURFACE. The surface of the deck shall have a smooth, fine-textured finish similar to that obtained by machine troweling. All honeycombed areas and surface cavities shall be cleaned and filled with approved patching materials. All sharp protrusions which, in the opinion of the Engineer, would puncture the membrane shall be removed. The surface shall be clean, dry, and free of laitance, oil, or other contaminants. Residual curing compound need not be removed if, in the opinion of the Engineer, it will not interfere with adhesion of the adhesive. Immediately prior to application of the adhesive, the deck shall be cleaned by brooming and blowing with a compressed-air jet.
4.2. APPLICATION OF ADHESIVE AND MEMBRANE. Adhesive shall not be placed when the air or deck temperature is less than 50°F, or during rain or fog. The adhesive shall be thoroughly mixed prior to application. One coat of adhesive shall be applied to the entire area to which the membrane is to be applied, and one coat to the entire underside of the membrane sheet. Application shall be by brush or roller at the rate of 120 to 150 sq ft/gal. The adhesive shall be allowed to become dry to the touch before placing the membrane. (Note: A convenient method of application is to unroll a length of membrane immediately adjacent to its intended position, apply the adhesive to the deck and the membrane in one operation, and, after the adhesive has dried, turn and roll the sheet longitudinally into position.) After placing, the membrane shall be lightly rolled with a hand roller or brushed with a stiff-bristle broom to firmly bond the membrane to the deck. The adhesive and membrane shall overlap previously applied membrane by at least 4 in. at the sides and 6 in. at ends. Membrane shall be applied with the longitudinal roll direction parallel to the direction of traffic on the bridge. Application shall begin at the lower points of the deck, in order that the direction of water flow will be over, rather than against, lapped edges and ends.
4.3. APPLICATION OF PROTECTIVE BOARD. A bond coat of asphalt emulsion shall be applied to the surface of the membrane at the rate of approximately 0.05 gal/sq yd and allowed to dry until tacky. The sheets of protective board shall then be placed on the bond coat, with edges and ends of boards either loosely butt-jointed or overlapped, at the contractor's option.
4.4. APPLICATION OF WEARING COURSE. A tack coat of emulsified asphalt and a wearing course of asphaltic concrete shall be applied to the surface of the protective board. No unnecessary traffic shall be permitted on the surface of the protective board, and trucks and paving equipment shall be operated in such a manner as to minimize the possibility of damage to the protective board and to the underlying membrane. Any damage to the protective board which, in the opinion of the Engineer,

indicates possibility of damage to the underlying membrane shall be investigated by removing the protective board and examining the membrane. If the membrane is damaged, it shall be repaired and new protective board placed before paving will be permitted to proceed.

SPECIFICATION FOR MEMBRANE WATERPROOFING SYSTEM 21

1. SCOPE. This specification covers materials and construction for a waterproofing membrane system for portland cement concrete bridge decks to provide an impervious barrier to water and deicing salts.

2. DESCRIPTION. The waterproofing membrane system shall consist of two coats of adhesive; a preformed sheet of waterproofing membrane; an asphalt emulsion bond coat; and a layer of protective board. A tack coat of emulsified asphalt and an asphaltic concrete wearing course shall be placed on the membrane system.

3. MATERIALS

3.1. ADHESIVE. The adhesive shall be a general-purpose solvent containing neoprene-based contact cement with a drying time at 77 ± 3°F of 20 to 60 min, and providing pressure-sensitive bond to itself after drying for a minimum of 4 hr at 77 ± 3°F. Naptha or naptha-like solvents shall not be used.

3.2. WATERPROOFING MEMBRANE

3.2.1. *Description.* The waterproofing membrane shall be a preformed sheet, 0.0600 to 0.065 in. in thickness, of vulcanized butyl rubber. The sheet shall be impermeable, black in color, flexible, nontacky, and packaged in rolls without release paper.

3.2.2. *Tensile Strength and Elongation.* When tested in accordance with ASTM D412 (specimens cut from longitudinal direction of the roll, using Die C) the ultimate tensile strength shall be 1,200 to 1,500 psi at 77 ± 3°F and 1,100 to 1,400 psi at 140 ± 3°F, and the elongation at break shall be 300% to 350% at 77 ± 3°F and 280% to 320% at 140 ± 3°F.

3.2.3. *Deflection Temperature.* When tested in accordance with ASTM D648 (specimen prepared by laminating with adhesive, oil bath replaced by isopropanol/dry ice, and using 264 psi load) the deflection temperature shall be not greater than -70°F.

3.2.4. *Water Absorption.* When tested in accordance with ASTM D-570, using 1x3-in. specimens, the absorption after 7 days in distilled water at 77 ± 3°F shall be not more than 0.15%.

3.3. BOND COAT. The bond coat shall be an asphalt emulsion meeting the requirements of ASTM D-977, Grade SS-1h.

3.4. PROTECTIVE BOARD. The protective board shall consist of 4x8-ft sheets, 1/8 in. in thickness, of APOC Board, as manufactured by Asphalt Products Oil Corp., or equal.

4. CONSTRUCTION

4.1. PREPARATION OF THE SURFACE. The surface of the deck shall have a smooth, fine-textured finish similar to that obtained by machine troweling. All honeycombed areas and surface cavities shall be cleaned and filled with approved patching materials. All sharp protrusions which, in the opinion of the Engineer, would puncture the membrane shall be removed. The surface shall be clean, dry, and free of laitance, oil, or other contaminants. Residual curing compound need not be removed if, in the opinion of the Engineer, it will not interfere with adhesion of the adhesive. Immediately prior to application of the adhesive, the

deck shall be cleaned by brooming and blowing with a compressed-air jet.
4.2. APPLICATION OF ADHESIVE AND MEMBRANE. Adhesive shall not be placed when the air or deck temperature is less than 50°F, or during rain or fog. The adhesive shall be thoroughly mixed prior to application. One coat of adhesive shall be applied to the entire area to which the membrane is to be applied, and one coat to the entire underside of the membrane sheet. Application shall be by brush or roller at the rate of 120 to 150 sq ft/gal. The adhesive shall be allowed to become dry to the touch before placing the membrane. (Note: A convenient method of application is to unroll a length of membrane immediately adjacent to its intended position, apply the adhesive to the deck and the membrane in one operation, and after the adhesive has dried, turn and roll the sheet longitudinally into position.) After placing, the membrane shall be lightly rolled with a hand roller or brushed with a stiff-bristle broom to firmly bond the membrane to the deck. The adhesive and membrane shall overlap previously applied membrane by at least 4 in. at the sides and 6 in. at ends. Membrane shall be applied with the longitudinal roll direction parallel to the direction of traffic on the bridge. Application shall begin at the lower points of the deck, in order that the direction of water flow will be over, rather than against, lapped edges and ends.
4.3. APPLICATION OF PROTECTIVE BOARD. A bond coat of asphalt emulsion shall be applied to the surface of the membrane at the rate of approximately 0.05 gal/sq yd and allowed to dry until tacky. The sheets of protective board shall then be placed on the bond coat, with edges and ends of boards either loosely butt-jointed or overlapped, at the contractor's option.
4.4. APPLICATION OF WEARING COURSE. A tack coat of emulsified asphalt and a wearing course of asphaltic concrete shall be applied to the surface of the protective boards. No unnecessary traffic shall be permitted on the surface of the protective board, and trucks and paving equipment shall be operated in such a manner as to minimize the possibility of damage to the protective board and to the underlying membrane. Any damage to the protective board which, in the opinion of the Engineer, indicates possibility of damage to the underlying membrane shall be investigated by removing the protective board and examining the membrane. If the membrane is damaged, it shall be repaired and new protective board placed before paving will be permitted to proceed.

SPECIFICATION FOR MEMBRANE WATERPROOFING SYSTEM 24

1. SCOPE. This specification covers materials and construction for a waterproofing membrane system for portland cement concrete bridge decks to provide an impervious barrier to water and deicing salts.

2. DESCRIPTION. The waterproofing membrane system shall consist of a primer applied to the prepared deck surface; an adhesive; a preformed sheet of waterproofing membrane; an asphalt emulsion bond coat; and a layer of protective board. A tack coat of emulsified asphalt and an asphaltic concrete wearing course shall be placed on the membrane system.

3. MATERIALS

3.1. PRIMER. The primer shall be an asphalt meeting the requirements of ASTM D41.
3.2. ADHESIVE. The adhesive shall be an asphalt meeting the requirements of ASTM D312, Type III or Type IV. (Type IV shall be used unless Type III is designated by the Engineer.)
3.3. WATERPROOFING MEMBRANE
3.3.1. *Description.* The waterproofing membrane shall be a preformed sheet of

vulcanized butyl rubber, 0.030-in. minimum thickness, laminated to asphalt-saturated asbestos fiber felt, 0.030-in. minimum thickness. The sheet shall be impermeable, black in color, flexible, nontacky, and packaged in rolls without release paper.
3.3.2. *Tensile Strength and Elongation.* When tested in accordance with ASTM D412 (specimens cut from longitudinal direction of the roll, using Die C) the ultimate tensile strength shall be 1,500 psi minimum and the elongation at break shall be 310% minimum when tested at 77 ± 3°F.
3.3.3. *Deflection Temperature.* When tested in accordance with ASTM D648 (specimen prepared by laminating with adhesive, the butyl portion of the sheet only, oil bath replaced by isopropanol/dry ice, and using 264 psi load) the deflection temperature shall be not greater than -77°F.
3.4. BOND COAT. The bond coat shall be an asphalt emulsion meeting the requirements of ASTM D-977, Grade SS-1h.
3.5. PROTECTIVE BOARD. The protective boards shall consist of 4x8-ft sheet, 1/8 in. in thickness, of APOC Board, as manufactured by Asphalt Products Oil Co., or equal.

4. CONSTRUCTION

4.1. PREPARATION OF THE SURFACE. The surface of the deck shall have a smooth, fine-textured finish similar to that obtained by machine troweling. All honeycombed areas and surface cavities shall be cleaned and filled with approved patching materials. All sharp protrusions which, in the opinion of the Engineer, would puncture the membrane shall be removed. The surface shall be clean, dry, and free of laitance, oil, or other contaminants. Residual curing compound need not be removed if, in the opinion of the Engineer, it will not interfere with adhesion of the primer or adhesive. Immediately prior to application of the primer, the deck shall be cleaned by brooming and blowing with a compressed-air jet.
4.2. APPLICATION OF PRIME COAT. The primer shall be thoroughly mixed prior to application. Primer shall not be applied when the air or deck temperature is less than 50°F, or during rain or fog. The primer shall be applied at the rate of 90 to 150 sq ft/gal to the entire area to which the membrane is to be applied. The primer shall be completely dry and all solvent evaporated prior to application of the membrane. (Note: This may require up to 24 hr, depending on temperature, humidity, and wind conditions.)
4.3. APPLICATION OF ADHESIVE AND MEMBRANE. The adhesive shall not be applied when the air or deck temperature is less than 50°F, or during rain or fog. The adhesive shall be preheated in a thermostatically controlled roofing kettle to a temperature no higher than required for application by the method used. The adhesive shall be applied to the primed surface by pouring and distributing by a roofer's mop to the width of the membrane sheet. The membrane shall be immediately rolled and pressed into the adhesive, asbestos felt side up, in one continuous operation. (An alternative method of application is by means of a roofing machine which mechanically applies the adhesive and membrane in one continuous operation.) The adhesive and membrane shall overlap previously applied membrane by at least 4 in. at the sides and 6 in. at ends. Membrane shall be applied with longitudinal roll direction parallel to the direction of traffic on the bridge. Application shall begin at the lower points of the deck in order that direction of water flow will be over, rather than against, lapped edges and ends.
4.4 APPLICATION OF PROTECTIVE BOARD. A bond coat of asphalt emulsion shall be applied to the surface of the membrane at the rate of approximately 0.05 gal/sq yd and allowed to dry until tacky. The sheets of protective board shall then be placed on the bond coat, with edges and ends of boards either loosely butt-jointed or overlapped, at the contractor's option.
4.5. APPLICATION OF WEARING COURSE. A tack coat of emulsified asphalt and a wearing course of asphaltic concrete shall be applied to the surface of the protec-

tive board. No unnecessary traffic shall be permitted on the surface of the protective board, and trucks and paving equipment shall be operated in such a manner as to minimize the possibility of damage to the protective board and to the underlying membrane. Any damage to the protective board which, in the opinion of the Engineer, indicates possibility of damage to the underlying membrane shall be investigated by removing the protective board and examining the membrane. If the membrane is damaged, it shall be repaired and new protective board placed before paving will be permitted to proceed.

SPECIFICATION FOR MEMBRANE WATERPROOFING SYSTEM 135

1. SCOPE. This specification covers materials and construction for a waterproofing membrane system for portland cement concrete bridge decks to provide an impervious barrier to water and deicing salts.

2. DESCRIPTION. The waterproofing membrane system shall consist of two coats of adhesive; a preformed sheet of waterproofing membrane; an asphalt emulsion bond coat; and a layer of protective board. A tack coat of emulsified asphalt and an asphaltic concrete wearing course shall be placed on the membrane system.

3. MATERIALS

3.1. ADHESIVE. The adhesive shall be a general-purpose solvent containing neoprene-based contact cement with a drying time at 77 ± 3°F of 20 to 60 min, and providing pressure-sensitive bond to itself after drying for a minimum of 4 hr at 77 ± 3°F. Naphtha or naphtha-like solvents shall not be used.

3.2 WATERPROOFING MEMBRANE

3.2.1. *Description.* The waterproofing membrane shall be a preformed sheet, 0.060 to 0.065 in. in thickness, of vulcanized EPDM rubber. The sheet shall be impermeable, black in color, flexible, nontacky, and packaged in rolls without release paper.

3.2.2. *Tensile Strength and Elongation.* When tested in accordance with ASTM D412 (specimens cut from longitudinal direction of the roll, using Die C) the ultimate tensile strength shall be 1,300 to 1,600 psi at 77 ± 3°F and 1,000 to 1,300 psi at 140 ± 3°F, and the elongation at break shall be 380% to 430% at 77 ± 3°F and 350% to 400% at 140 ± 3°F.

3.2.3. *Deflection Temperature.* When tested in accordance with ASTM D648 (specimen prepared by laminating with adhesive, oil bath replaced by isopropanol/dry ice, and using 264 psi load) the deflection temperature shall be not greater than -70°F.

3.2.4. *Water Absorption.* When tested in accordance with ASTM D-570, using 1x3-in. specimens, the absorption after 7 days in distilled water at 77 ± 3°F shall be not more than 0.20%.

3.3. BOND COAT. The bond coat shall be an asphalt emulsion meeting the requirements of ASTM D-977, Grade SS-1h.

3.4. PROTECTIVE BOARD. The protective board shall consist of 4x8-ft sheets, 1/8 in. in thickness, of APOC Board, as manufactured by Asphalt Products Oil Corp., or equal.

4. CONSTRUCTION

4.1. PREPARATION OF THE SURFACE. The surface of the deck shall have a smooth, fine-textured finish similar to that obtained by machine troweling. All honeycombed areas and surface cavities shall be cleaned and filled with approved patching materials. All sharp protrusions which, in the opinion of the Engineer, would puncture the membrane shall be removed. The surface shall be clean, dry, and free

of laitance, oil, or other contaminants. Residual curing compound need not be removed if, in the opinion of the Engineer, it will not interfere with adhesion of the adhesive. Immediately prior to application of the adhesive, the deck shall be cleaned by brooming and blowing with a compressed-air jet.

4.2. APPLICATION OF ADHESIVE AND MEMBRANE. Adhesive shall not be placed when the air or deck temperature is less than 50°F, or during rain or fog. The adhesive shall be thoroughly mixed prior to application. One coat of adhesive shall be applied to the entire area to which the membrane is to be applied, and one coat to the entire underside of the membrane sheet. Application shall be by brush or roller at the rate of 120 to 150 sq ft/gal. The adhesive shall be allowed to become dry to the touch before placing the membrane. (Note: A convenient method of application is to unroll a length of membrane immediately adjacent to its intended position, apply the adhesive to the deck and the membrane in one operation, and, after the adhesive has dried, turn and roll the sheet longitudinally into position.) After placing, the membrane shall be lightly rolled with a hand roller or brushed with a stiff-bristle broom to firmly bond the membrane to the deck. The adhesive and membrane shall overlap previously applied membrane by at least 4 in. at the sides and 6 in. at ends. Membrane shall be applied with the longitudinal roll direction parallel to the direction of traffic on the bridge. Application shall begin at the lower points of the deck, in order that the direction of water flow will be over, rather than against, lapped edges and ends.

4.3. APPLICATION OF PROTECTIVE BOARD. A bond coat of asphalt emulsion shall be applied to the surface of the membrane at the rate of approximately 0.05 gal/sq yd and allowed to dry until tacky. The sheets of protective board shall then be placed on the bond coat, with edges and ends of boards either loosely butted-jointed or overlapped, at the contractor's option.

4.4. APPLICATION OF WEARING COURSE. A tack coat of emulsified asphalt and a wearing course of asphaltic concrete shall be applied to the surface of the protective board. No unnecessary traffic shall be permitted on the surface of the protective board, and trucks and paving equipment shall be operated in such a manner as to minimize the possibility of damage to the protective board and to the underlying membrane. Any damage to the protective board which, in the opinion of the Engineer, indicates possibility of damage to the underlying membrane shall be investigated by removing the protective board and examining the membrane. If the membrane is damaged, it shall be repaired and new protective board placed before paving will be permitted to proceed.

RECOMMENDED PROCEDURES FOR MONITORING PERFORMANCE

The following program of field tests on the systems is recommended as the primary basis for their evaluation. It is proposed that such tests be performed over a period of two years from the time of construction. A total of five test rounds should be performed on each system at each site during the two-year period. The initial round should be at the time of placement, and the four additional rounds at approximately six-month intervals, with actual times to be selected to coincide with the beginning and end of the winter seasons. For example, if placement is in April 1974, the test rounds would be completed approximately as follows:

Round 1 --April 1974, at time of placement.
Round 2 --October 1974, at beginning of first winter season.
Round 3 --April 1975, at end of first winter season.
Round 4 --October 1975, at beginning of second winter season.
Round 5 --April 1975, at end of second winter season.

The following tests are recommended for each system during each test round:

1. Electrical resistance test, as described herein. On the first round, measurements should be made both on the surface of the membrane systems before the asphaltic concrete wearing course is placed, and on the surface of the asphaltic concrete wearing course after placement. Subsequent measurements can be on the asphaltic concrete wearing course only.

2. Resistance measurements using conductive strips at the deck-membrane interface. A series of closely spaced copper tapes should be placed on the deck prior to placing each membrane. Initial measurement of resistance between the two strips in each pair should be made at the time of membrane placement, and measurements should be repeated during subsequent test rounds.

3. Tensile bond test, as described herein. Core samples also should be taken immediately adjacent to the bond test locations for visual inspection of the condition of the membrane system, and for possible laboratory evaluation of the electrical resistance and adhesion under controlled conditions. Core holes should be patched carefully to restore fully the integrity of the waterproofing.

4. Determination of chloride content of deck concrete. Determination should be made on samples taken from the deck before placement of the membrane, and from cored samples taken during subsequent test rounds.

In addition to these tests and sampling, a series of photographs should be taken of each system during each test round. The primary purpose of these photographs is to serve as a record for later reference and reporting. During the initial test round, the physical characteristics of the deck (including grade, slope, width, structural condition, and surface smoothness) should be recorded. The following additional information will also be useful:

1. Average daily traffic, with seasonal variation.
2. Percentage of trucks, classified by number of axles.
3. Traffic speeds.
4. Temperature and precipitation records for the study period.
5. Amount and type of deicing salt used.

RECOMMENDED METHODS OF TEST FOR FIELD EVALUATION

ELECTRICAL RESISTANCE TEST, HALF-CELL

Equipment

V-O-M meter, Simpson model 269, with leads.

Electrode, cellulose sponge in metal holder, 7x8 3/4x2-in., with small bolt and wing nut attached for connecting one lead of V-O-M meter.

Additional cellulose sponges, approximately same size as the electrode sponge, for wetting the pavement.

Metal C-clamp, approximately 6-in. size, with small bolt and wing nut attached for connecting one lead of V-O-M meter.

Water container, approximately 1-gal capacity, with pouring spout and side handle.

Materials

Wetting agent, Aerosol OT, 0.38% solution.

Procedure

Lay out and mark on the surface of the pavement the points at which resistance readings are to be taken. (It is suggested that at least two lines of readings be taken, one in the wheelpath area and one in the line of least traffic, such as the shoulder area; and that each row consist of at least ten readings, at intervals of approximately 5 to 10 ft, depending on the length of the deck area under consideration.) Saturate wetting sponges with Aerosol OT solution, and place one on each marked point on the pavement. Keep sponges saturated by frequent addition of Aerosol OT solution by pouring from the water container. Make first resistance readings after sponges have been in position approximately one-half hour.

To make resistance readings attach the C-clamp to the bridge railing in such a manner as to make a good electrical contact with the reinforcing steel in the bridge deck. (Usually simply by tightening the clamp on a nut or bolt of the metal rail. If railing is entirely of concrete, it may be necessary to chip out a small area of concrete to expose the reinforcing steel. Corrosion on metal should be completely removed by filing or scraping before attaching the clamp.) Attach one lead from V-O-M meter to the connection on the C-clamp. Saturate the electrode sponge and attach the other lead from the V-O-M meter to the connection on the metal sponge holder. Check zero setting of V-O-M meter. Pick up one of the saturated wetting sponges from the pavement; replace it with the saturated electrode sponge; record the resistance indicated on meter; pick up the electrode sponge and replace the wetting sponge in its original position on the pavement. Repeat this operation until a complete round of measurements has been made on all points. Make additional rounds of measurements at about one-half hour intervals, being careful to maintain all sponges in a saturated condition. Continue to make additional rounds of measurements until the results of successive rounds remain essentially unchanged; except that if readings remain at essentially infinity, measurements should be continued until at least 4 hr after initial placement of the wetting sponges.

Recheck the zero reading of the meter before starting each measurement round, and when changing from one meter scale to another. When using meter scales of 1K or less, make one reading, reverse the leads on the meter, make a second reading, and average the two readings.

TENSILE BOND TEST

Equipment

Concrete coring machine, equipped with 2-in. I. D. core barrel.

Cylindrical wooden blocks, 1 3/4-in. diameter by about 2 in. long, with a screw eye inserted in the center of one end (wooden blocks can be made by cutting lengths from 1 3/4-in. diameter fir handrail stock, and the screw eyes should be of 7/32-in. diameter stock with an eye of approximately 7/8-in. diameter.)

Spring scale, 100-lb capacity x 1-lb divisions (such as Chatillon, Type-160, capacity 100 lb x 1-lb) with hook on lower end and pulling handle on the upper end.

Hammer, 1 to 2 lb.

Cold chisel, 1/2 to 3/4-in. width by any convenient length over 6 in.

Materials

Rapid-setting, high-strength epoxy adhesive (such as Le Page's 5-Minute Epoxy Resin, or Devcon 2-ton Epoxy Super Glue).

Procedure

With the coring machine, core through the asphaltic concrete wearing course, the membrane, and approximately 1 in. into the portland cement concrete deck. Withdraw the core barrel, leaving the core in place. (To reduce the possibility of binding and breaking off the core, operate the coring machine at moderate speed and do not shut off the cooling water supply while withdrawing the core barrel.) Repeat the operation approximately 1/4 in. from the first core. Thoroughly clean and dry the surface of one of the cores, and bond a cylindrical wooden block to the center of the core with rapid-setting, high-strength epoxy adhesive. After the adhesive has set, insert the hook of the spring scale into the screw eye of the cylindrical wooden block, and slowly pull straight up on the pulling handle until failure occurs in the core. Record the maximum reading of the spring scale, to the nearest pound, as the bond strength. Examine the removed portion of the core, and record where failure occurred.

From the core hole, use the hammer and cold chisel to remove the second core by cracking the portland cement concrete horizontally at least 1/2 in. below the membrane. Record the thickness of the membrane and the asphaltic concrete wearing course, and the appearance of the portland cement concrete, the membrane, and the asphaltic concrete wearing course. (The core so removed may be retained for record or for laboratory testing, if desired.