

A SURVEY OF WATERPROOFING MEMBRANE SYSTEMS
FOR BRIDGE DECKS

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The spalling of a concrete bridge deck — the weakening of the surface over the top reinforcing steel — presents a serious maintenance problem. The needed repairs are often extensive and difficult; and, if the problem is ignored, the distress can become severe enough to necessitate replacement of the deck. The basic cause of spalling is corrosion of the reinforcement in the presence of water and salt in ionic form, which has gained access either through cracks or by migration through the pores of the concrete. ^(1,2) Many precautions can be taken in the design and construction of a bridge to alleviate spalling; one of these, the subject of this paper, is the application of a waterproof membrane to the surface of the deck to prevent the entry of water and salt solution into the concrete. At present, membranes are often placed on distressed bridge decks when repairs are made, but there is growing evidence to suggest that the membrane is much more effective when applied before the deck is exposed to deicing salts.

The widespread interest in finding an effective means of protecting bridge decks is evidenced by the initiation of a National Cooperative Highway Research Program project, "Waterproof Membranes for Protection of Concrete Bridge Decks", in August 1970. The objective of the research is to develop or discover one or more effective waterproofing systems. Phase I of the project, which is scheduled for completion in October 1972, includes the development of service requirements, field inspections, and a program of laboratory studies. ⁽³⁾ While the researchers originally considered about 140 materials, all but approximately 75 were eliminated before testing in the laboratory. Approximately 15 membranes of various materials were examined in the field at about 50 sites. Although the final analysis of the data is just beginning at this writing, the principal researcher believes that some currently available commercial materials, possibly with slight modifications, will meet the requirements of Phase I of the study. It is envisioned that perhaps 4 to 7 materials will be found suitable, and these will be field tested in Phase II, which is yet to be started.

This paper will not concern itself with 75 membrane sealing systems. Instead, it will concentrate on fewer systems and attempt to introduce the judgments of various highway agencies on the performance of the systems. Highway engineers familiar with the materials were contacted personally, and their cooperation is greatly

appreciated, as there is little in the way of written reports covering the newer systems. The comments of these individuals tend to reinforce the opinion of the NCHRP researchers that there are available materials which promise success in sealing concrete bridge decks.

GENERAL INFORMATION

A membrane seal is defined as a waterproof barrier placed on the surface of a bridge deck, as opposed to a penetrating sealer that enters the pores of the concrete. In general a membrane requires a hot asphaltic concrete wearing course, $1\frac{1}{2}$ to 2 inches thick, to protect it from traffic. Exceptions are thick epoxy mortar overlays, which can serve as both a seal and a wearing surface, and possibly some urethane materials, which the manufacturers claim do not require protective overlays under normal traffic conditions. (2)

The service requirements of a bridge deck overlay were listed in a recent article by members of the Bridge Department of the California Division of Highways. (2) The requirements, which are quoted below, are applicable regardless of the type of membrane system used, although the lower temperature limit, 0°F , may be questioned by some northern states.

1. It must bond to the concrete deck at least as well as an asphalt concrete blanket.
2. It must remain flexible throughout the entire range of deck temperatures, which means down to at least 0°F .
3. It must remain stable throughout the higher range of temperatures, up to 120°F .
4. It must be 100 percent effective as a moisture barrier.
5. It must be capable of bridging cracks up to $1/16$ in. without rupturing or losing its bond with the concrete deck.
6. It must be resistant to wear or be capable of having an asphaltic-concrete overlay bonded to it to provide a waterproof system.
7. It must be chemically inert to oil, salt, and the usual highway liquids.

MULTILAYERED BITUMINOUS SYSTEMS

The most widely accepted membrane for sealing bridge decks is probably a multilayered — or interlayer — system such as that shown in Figure 1. Such systems, using 3 to 5 applications of either coal tar emulsion slurry or roofing asphalt with 2 layers of coated glass fabric, are used on all important bridges in Main, New Hampshire, Massachusetts, and Rhode Island, and on selected bridges in Tennessee, Ohio, Michigan, Illinois, and California.⁽¹⁾ A membrane composed of 3 layers of fabric and 4 coats of asphalt is described in the Virginia specifications.⁽⁴⁾ The Koppers Company has been active in the development of a similar membrane using a plasticized coal tar.

California uses, as one of its standards, an interlayer system like that depicted in Figure 1, which is composed of 5 coats of coal tar emulsion applied at a rate of not less than 1/8 gallon per square yard and 2 plies of coal tar coated glass fabric.⁽²⁾ Experience there indicates that a membrane placed during the summer is much more effective than one placed during the fall.

An interlayer membrane utilizing 3 heavy coats (1.08 gallons per square yard) of roofing asphalt has been used quite successfully by New Hampshire. They report no deck distress in 20 years of routine application of the membrane at the time of construction. The roofing asphalt is specified because the highway agency believes the coal tar emulsion to be too brittle at low temperatures. Steep-pitch roofing asphalt, which melts at 200°F, must be used to prevent slipping of the overlay during hot weather. The glass fabric strips are placed on the first and second coats of asphalt, and the strips are lapped by slightly more than one half of their width. A 2-inch asphalt concrete wearing course is placed on the membrane.

The deficiencies associated with the interlayer membranes are largely associated with the time consuming and rather difficult technique of application. The difficulties in handling the materials are solved in New Hampshire by employing skilled roofing contractors to apply the membrane. The time delay is inescapable; each coat of the asphalt or coal tar must be allowed to dry before the next layer — other than the glass fabric — is applied. Thus, the application of the complete membrane system will require more than a day's time. New Hampshire is investigating the suitability of other membrane systems, not because of dissatisfaction with the effectiveness of their standard membrane, but as a means of saving time and labor costs.

Difficulties may be encountered in the case of the interlayer membrane and most others, except epoxies, when the asphaltic concrete wearing course is placed. Protrusions or foreign matter on the deck surface can puncture the membrane during passage of the paving machine. California reports that the effectiveness of the apparently perfect waterproof seal has been known to drop as much as 30 percent after placement of the wearing course.⁽²⁾

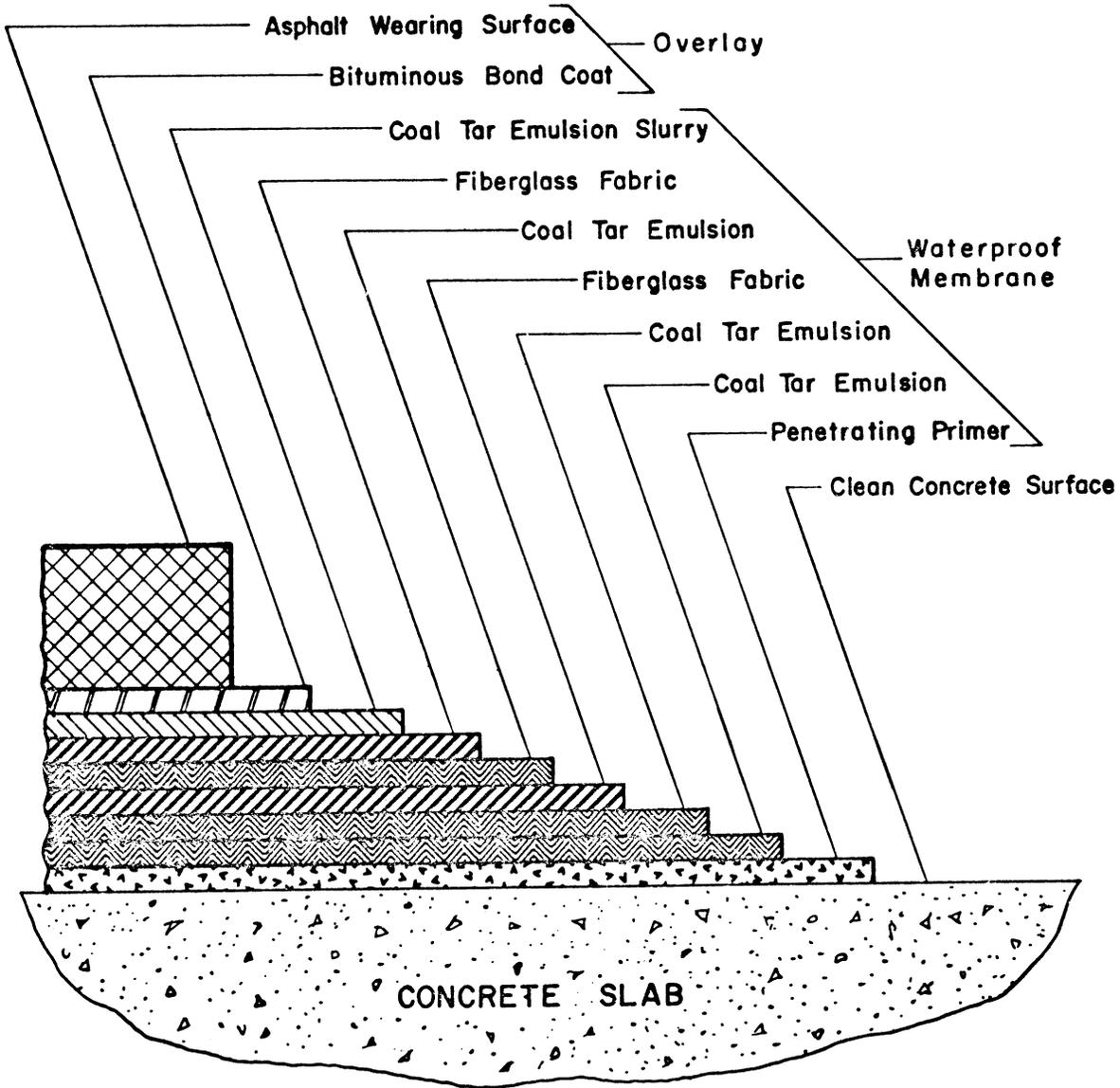


Figure 1. A typical interlayer membrane.
(From reference 1.)

It should be realized, however, that a membrane which is only 70 percent watertight will still extend the life of a bridge deck. Despite the difficulties inherent in its application, the interlayer membrane is the standard against which other systems must be compared.

SINGLE-LAYER BITUMINOUS SYSTEMS

In an effort to find a less costly and more easily applied seal than the interlayer systems described previously, the Pennsylvania Department of Transportation is experimenting with a membrane composed of a thin layer (1/2 to 5/8 inch) of a rich, asbestos-modified plant mix applied at temperatures above 300°F. (5) The plant mix has an asphalt content of 14.5 percent with 5 percent asbestos fiber by weight. Ninety-five percent of the aggregate passes the number 8 sieve and 12 percent passes the number 200 sieve. Their experimental installations have been in place only a few months, and the only information available is that the plant mix is stable and properly bonded. Much additional data, including readings from moisture gages under the membrane, will be available in the future. The system was selected for trial on the basis of 2 years of favorable experience by the New Jersey Turnpike Authority.

The Richmond-Petersburg Turnpike Authority has sealed bridge decks for 10 years with rubberized Jennite J-16-R, a coal tar emulsion slurry. In their method, the sound decks are cleaned of all foreign matter, dried for 24 hours, and given an application of a penetrating primer. Care is taken to ensure that all cracks are filled during priming. The deck is dampened and a mixture of the Jennite with 4 to 6 pounds of sand per gallon is applied at a rate of 0.10 to 0.15 gallon per square yard. When the first application has set sufficiently to resist scuffing under traffic, a second application of a mixture of Jennite with 5 to 7 pounds per gallon of sand is made at the same rate. A 1½ inch asphaltic concrete overlay is placed over the membrane on a majority of the decks. The Turnpike Authority reports that some of the decks were stripped after 10 years to replace the wearing course; no major distress of the concrete due to leakage of the seal was noted.

EPOXY MEMBRANES

The usual policy of the Virginia Department of Highways is to seal decks in a maintenance capacity using a thin coal tar modified epoxy membrane upon which grit is cast before the epoxy cures. An asphaltic concrete wearing course is then added to improve the durability of the system.

While this method of sealing decks is widely used, there are indications that it is less than satisfactory. Foremost, it is doubtful that any system which involves the casting of aggregate on the liquid epoxy can provide a completely impervious sealcoat, due to the possibility of the formation of open voids, or pinholes. Systems of this type have not proved to be very effective during the initial field inspections of the NCHRP research project. Pinholing can be minimized through the use of small-grained, rounded aggregate. Whenever possible an epoxy sealcoat should be placed during a period of falling temperature, as this minimizes the possibility of blistering of the overlay due to the expansion of moisture in the concrete or bubbles trapped in the epoxy.

There are two recent developments which promise to increase the effectiveness of epoxy sealcoats. One of these is the development of a 2-course application of the epoxy, in which the first layer, possibly of a low viscosity material, is allowed to cure before a second layer is placed. Such an application should provide both an effective seal and a thick (1/8 to 3/16 inch) coating, which will resist wear under moderate traffic volumes without an asphalt concrete wearing course. Although California has reported the failure of a 2-course application,⁽²⁾ there is reason to believe that success can be attained through proper formulation of the epoxy. A subsequent application of an epoxy system that is 100 percent reactive can be bonded to a cured layer. Use of such a system would allow the patching of a worn overlay as opposed to complete removal and reapplication of the epoxy.

The second promising development in application technology is that of raising the temperature of the deck about 100°F just before placing the liquid epoxy. The heating of the deck provides better penetration and faster curing of the epoxy at the deck surface, and it assures a falling deck temperature during curing. Weather conditions are also somewhat less critical.

In addition to their use as thin membranes, epoxy resin systems can be applied in the form of a mortar overlay, 1/2 inch in thickness. Virginia has had poor experience with 3 such applications, all using the same oil-extended epoxy system. Future applications should require a 100 percent-solids system and priming of the deck surface with the raw epoxy (not performed in the previous applications) to ensure bonding of the overlay.

Regardless of the type of application used, epoxy systems have one common drawback; they require thorough deck preparation, including sandblasting. Because of the combination of the strength of the epoxy and its high coefficient of thermal expansion, it will not bond to weak concrete. It is usually recommended that the deck be sandblasted until the coarse aggregate can be seen, and this accounts for a high percentage of the installation cost.

URETHANE MEMBRANES

Urethane materials are rather recent developments in the sealing of bridge decks. They cure to a flexible, rubber-like consistency and offer good adhesion and excellent extensibility in bridging cracks.

One urethane seal which has been widely tested is the Polytok 165 membrane manufactured by the Toch Bros. Division of the Carbolene Company. The material has been tested in California, Missouri, Kansas, Illinois, and Indiana. Although there were some difficulties in the placement of the overlay in California and Missouri -- the 2 states that were contacted -- the final results were considered good. Electrical resistivity readings (California) and corrosion detection ratings (Missouri) both were good.

Polytok membrane 165 is generically a modified polyurethane elastomer, a 2-component system. It is sprayed on the deck to a thickness of 40 mils. After 20 minutes (at 70°F), a 50-pound asphalt impregnated sheet is rolled onto the membrane, covering the surface to protect it during paving. A hot asphalt concrete wearing course is added after 5 hours. The hot asphalt wearing course (placed at 300°F in California) tends to combine the asphalt impregnated paper and the urethane elastomer.

Installation difficulties have involved the handling of the mats and the elimination of entrapped solvent that has slowed the curing process. However, the membrane placement was completed in 1 day on the Missouri bridge.

Two other urethanes that are regarded as promising by the Bridge Department of the California Division of Highways are Chevron 2294, by the Chevron Asphalt Company, a material developed but not yet marketed; and Edoco Urethane, manufactured by the Edoco Technical Products Company. Other poured elastomers are produced by Firestone (Rubber-Road) and Uniroyal.

SHEET MEMBRANES

A promising development in recent years has been the availability of membrane materials in rolled sheets. The sheet membrane is unrolled on the deck, which has been primed, and an asphalt wearing course is added later. The joints between adjacent sheets are lapped 3 - 4 inches. The systems offer the protection of the interlayer system described previously without the very difficult and time consuming application procedure.

Bituthene, a sheet material manufactured by Grace Construction Products, is available in 2 weights. The standard weight membrane consists of a heavy polythene sheet coated on one side with a .060 inch thick layer of adhesive-consistency rubberized asphalt. The heavy duty membrane consists of a woven plastic braid coated with the rubber bitumen adhesive on one side and a dry bituminous tack coat on the other. While the heavy duty material is intended and now recommended for bridges, successful applications of the standard weight membrane were made earlier in California and New Hampshire. California experienced only one problem, that of removing the release paper from the sheet. Otherwise the installation and subsequent bond were good and electrical resistivity readings were very good. New Hampshire was well satisfied, and plans are under way for a second installation. However, both states indicated that they would use the heavy duty grade in subsequent applications. Bituthene has been widely used in England, and 4 bridges are scheduled for water-proofing in Missouri.

Heavy duty Bituthene is supplied in rolls 36 inches wide by 15 yards long. A sand asphalt protective layer, applied at a maximum temperature of 140°C, should be placed on the membrane immediately after laying and before the hot asphaltic concrete wearing course is placed.

A second sheet-formed membrane system is Protecto Wrap manufactured by the Protecto Wrap Company. This membrane is a laminate of vinyl reinforced coal tar and a non-woven synthetic fiber mat, having a thickness of 70 ± 5 mils. The material can be applied by using equipment developed by the Protecto Wrap Company after the primer has dried to a tack free state. The manufacturer recommends that the asphaltic concrete wearing course be placed in layers at least 1 inch thick on the bare membrane to avoid puncturing. A California test installation had a water barrier effectiveness slightly better than that of the interlayer membrane. (2)

The U. S. Steel Company manufactures a thermoplastic sheet membrane called the Nexus System. The system consists of a primer, followed by a coal tar base adhesive, over which is placed a thermoplastic sheet 30 mils in thickness. The asphaltic concrete wearing course is then placed at a high temperature in order to melt the thermoplastic sheet. The material showed a water barrier effectiveness in a California test that was somewhat higher than that of the interlayer membrane. (2) Subsequently, the author found information on the product to be hard to get from the manufacturer, and it is possible that there are deficiencies which are being corrected. California did note that paving operations tended to be more difficult than with the interlayer membrane due to tearing of the thermoplastic sheet.

WHEN TO PLACE THE MEMBRANE

There is only one ideal time to apply a waterproof membrane on the deck surface — at the time of construction. There are two factors that lead to this conclusion. California cites the costs of installation: they estimate that the cost of deck restoration on a heavily travelled highway is generally about the same as that of an entirely new structure in a similar location, while a seal on a new bridge accounts for about 10% of the total cost.⁽²⁾ This is, no doubt, higher than the costs in Virginia, but the cost differential between placing a membrane on an existing bridge under heavy traffic and placing a similar seal on a new structure is still significant. For reasons of economy, California does specify a seal for major bridges at the time of construction.

Of more importance than cost is the effectiveness of the membrane. Obviously, a waterproof seal — or even a predominately waterproof seal — applied before the bridge is salted can delay corrosion and extend the life of a bridge deck. There is evidence, however, that a membrane applied on a deck contaminated with chlorides may be ineffective and may even accelerate corrosion.^(6,7,8) At present, however, many states, including Virginia and California, apply membranes in a maintenance capacity. It is possible that the membrane does serve a useful purpose, at least in stalling corrosion of the lower reinforcing steel, but there is no doubt that membranes applied at the time of construction are more effective. California estimates that they extend the service life of the deck by 10 - 15 years.

DISCUSSION

The results of this survey indicate that there are commercially available systems which show promise of effectively waterproofing concrete bridge decks. There are indications that several of these systems are more effective than the epoxy seals currently used in Virginia and more easily applied than the interlayer membrane. Field tests of some of the more promising systems would appear to be justified, and such tests should include both evaluations of factors such as ease of application and stability and measurements of effectiveness by the electrical resistivity method.⁽⁹⁾ The field experiment should include a wide range of materials applied to both old and newly constructed bridge decks, and it should include measurements of the effectiveness of the epoxy seal coats now in place for comparative data.

The NCHRP project, which is proceeding on schedule, will be completed through its first phase in October 1972. The findings of the study should provide service requirements and an indication of effective products. It promises much useful information, and it may result in further improvements in commercially available materials.

The placement of a membrane on a new bridge deck, before any salt is applied, is more effective than deck sealing during maintenance operations. Certainly, it appears that -- once an effective membrane system is selected -- this policy should be considered for Virginia bridges in areas of high traffic volume. There are, of course, construction methods, such as the use of 2-course bridge deck construction in which the top course is a high quality, possibly modified, concrete, which promise to greatly improve deck durability. Two-course construction is being investigated in Virginia, and, if successful, the research could present an alternative to the use of membranes.

FUTURE RESEARCH

In the near future, the Virginia Highway Research Council will present to the Department of Highways a proposal to field test several promising membrane systems. As part of the investigation the Council will obtain electrical resistivity data, using widely accepted techniques, on existing sealcoats. The project will, to some extent, duplicate others, including the NCHRP project, but it will provide valuable information on the application techniques and serviceability of the systems under local conditions. Ideally, the system or systems selected should be suited to application by state forces using a minimum of special equipment. Preliminary findings would be available by early 1973.

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The cooperation of the representatives of many of the suppliers mentioned in this paper is also appreciated. Many of these individuals contributed the names of contacts in highway agencies — including some critical references — as well as detailed information on their products.

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