LONG TERM DECK WATERPROOFING OF HIGHWAY AND RAIL BRIDGES

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ABSTRACT

Bridge deck deterioration is a major problem in North America resulting in high repair costs, which consume a significant portion of the infrastructure funding. It is estimated that of the 225,000 highway bridges in the U.S. that are in need of repair approximately 162,000 are suffering from severe corrosion of their decks. (4) At a White House briefing in June 1997 the administration spoke about the impact of corrosion on our structures and the need for preventive measures.

With effective waterproofing on bridge decks their service life can be greatly extended. Information will be presented pertaining to the development, testing and applications of a spray applied polyurethane membrane that has proven to be a long-term solution to this problem.
INTRODUCTION

In 1945 the Ministry of War Transport in the U.K. published Memorandum No. 577 on Design and Construction of Bridges. A section in this document addressed the need for bridge decks to be waterproofed. (5)

From about 1960 the increasing usage of deicing salts on bridge decks has increased this need for an effective waterproofing system. (2) This, however is not the only cause of deterioration, carbon dioxide and acid rain cause the pH of concrete to be lowered, resulting in corrosion of the reinforcing steel. (1) Penetration of chlorides, etc. into the concrete and subsequent corrosion of the reinforcing bars had to be stopped if bridge decks life expectancy was to be increased. Reinforcing bar corrosion eventually results in surface spalling and the unit costs of patching spalled concrete decks is quite high, comparable to those of new deck construction. (1)

In 1965 the Ministry of Transport in the U.K. directed that the waterproofing of bridge decks be mandatory for all mainline bridges. This directive led to the introduction of many types of waterproofing systems to bridge decks. Initially, many of the same products that were used to waterproof the roofs of buildings were used, but as will be detailed later, their inherent weaknesses make them poorly suited to this new application. (2)

To ensure that only effective, long lasting membranes were used on their bridges, the UK Transport Road and Research Laboratory (TRRL) conducted an evaluation of some fifty candidate membrane systems. Their test reports, # 185,248, and 317 detailed that there was the need for more durable products and that performance standards were required.
The long term cost effective protection of bridge structures was deemed essential by the UK Highways Agency, to mitigate premature and daunting maintenance costs and a new performance standard was developed for effective waterproofing durability. This stringent test standard ensures that the waterproofing systems used will provide long term performance and protection of the nations bridges. A certificate is issued to the membrane systems that meet these standards and the PmB (Baytec) membrane has been issued such a certificate.

INITIAL DEVELOPMENT AND APPLICATIONS

In 1967 the chemists at Bayer AG in Germany, a major supplier of chemical products around the world were trial applying a polyurethane membrane for waterproofing, that they had in development since 1960, on the deck of the trawler M/S Skarheim. This ship, which had just been completed, had been built for fishing expeditions between Greenland and Newfoundland that would be continuous for a six-month period. In these waters, the steel sections of ships are exposed to very severe corrosion, being further aggravated by the relatively large quantities of salt used to preserve the catch. Conventional protective coatings usually had to be renewed after each fishing period.

In this application a 5 mm thick coating of the Baytec Reactive Coating was applied to the steel deck after sandblasting the deck as well as flame cleaning and brushing where required. As soon as the coating was applied, the surface was sprinkled with sand for skid resistance.

At the completion of the first fishing period the coating was in perfect condition, whereas all the exposed steel sections which had been given a conventional anti-corrosion treatment had begun to rust badly. After three years of service even the thinly coated areas showed no signs of corrosion.
In 1973 an inspection of the original coating and other areas that the ship owner had decided to protect showed that all were providing effective protection. In this same year the coating underwent fire tests at the Trondheim Technical University and was approved for use as a coating for ships by the Norwegian Maritime Directorate.

The last reported inspection in 1984 indicated that the coating had suffered serious damage as a result of ice being chipped off over a period of 17 years. However, after this amount of time the membrane did not suffer any loss of physical properties as a result of continuous exposure to the elements. (3)

**DEVELOPMENTS FOR BRIDGE APPLICATIONS**

With the success the membrane was having in difficult waterproofing applications, attention was then turned to applying this technology to the highway industry in the U.K. for the waterproofing of structural components. The Bayer technicians and engineers teamed with Pitchmastic, PLC a large contractor based in the U.K. The goal of this team was to take this polyurethane technology and further enhance it into a user-friendly membrane that could be applied at construction sites within the constraints of time and weather conditions that are typical to the highway and rail industry.

Among these requirements was the recognized need to have the membrane gel very rapidly, in order to conform to the interface texture of the substrate without pooling and to minimize the occurrence of pinholes in the membrane. Water vapor escaping from the concrete substrate will create these voids or pinholes in the wet resin. The longer the membrane remains in the liquid state the greater are the chances for the formation of pinholes.
The enhanced polyurethane membrane was initially submitted to the U.K. Department of Transport for certification as a waterproofing membrane on highway bridge decks. In order to achieve this certification the membrane had to successfully complete a series of tests devised by TRRL. Successful completion of these tests resulted in the award of BBA (British Board of Agreement) certification. To date, the membrane has been successfully applied to more than 3 million square meters.
QC/QA TESTS

Since any waterproofing membrane is only effective if applied properly, the bridge owners should require that the applicator conduct the following QC/QA testing at the jobsite to assure that the resinous membrane applied meets the published performance criteria:

Mixing of components

Resinous membrane systems are typically two component systems while some require the in field blending of additional components. The mixing and proportioning of these components is critical if the owner of the structure is to have assurance that the physical properties of the membrane that has been placed meets the specified values. Construction sites are busy places and if the mixing of the components is not continuously monitored changes may go unnoticed.

For this reason the PmB membrane uses computer controlled mixing equipment that monitors the flow rate of the two components. If the prescribed mixing ratio goes out by more than a few percentage points, caused for example by a slightly clogged supply line, the system sounds an audible alarm and the system shuts off preventing the application of poorly proportioned material.
Pinholing

A liquid applied membrane will have a tendency to pinhole as the water vapor in the concrete slab pushes up to the surface. The longer a membrane takes to gel the greater the opportunity to pinhole. The PmB polyurethane membrane has taken that into account and the gel time has been reduced to seconds after the membrane has been applied.

The British Department of Transport recommends that all membrane systems be checked for pinholes prior to application of the wearing course. For resinous membranes this testing is conducted by applying an 11,000-volt current to the surface of the membrane via a conductive wiper bar. If there are any defects in the membrane the detector, which is grounded to the deck, emits an audible signal and the defect is then marked for additional treatment.

Once repairs are made by overcoating the pinhole with additional membrane an additional pinhole test is conducted in the repaired area applying the voltage through a smaller whisk, making sure that it is defect free. Only then will the application of the tackcoat and wearing course be permitted to commence.

The British Concrete Society Interim report recommends the use of liquid membrane systems for their post-tensioned concrete bridges. These membranes can be applied in either one or two coats but however applied it should be proved with pinhole detection equipment to give assurance of membrane integrity. (6)

Membrane thickness checks
It is recommended that the membrane be applied at a thickness of 2mm above the peaks of the substrate. Typically the membrane is applied at a nominal thickness of 2.75 mm.

Since the PmB membrane has almost an instantaneous gel time the membrane thickness is verified during application by cutting a small coupon of material, for example, in an area where a sharp piece of aggregate is protruding above the concrete. The membrane can then be scrapped off of the surface using a putty knife and measured for thickness. If necessary, the area could then have additional resin applied to build to the correct thickness. These coupons can then be kept as part of the records of the installation along with the data sheets recording all of the bond strength readings.

**Bond strength to substrate**

The PmB membrane is tested for adequate bond strength to the concrete substrate by using an Elcometer tensile adhesion tester. As the membrane is being applied a 40mm diameter aluminum dolly is placed onto the wet resin and after allowing an cure of one hour the dolly is pulled straight off of the substrate using the Elcometer to measure the load at failure. In the U.K. the standard is at least 100 psi tensile bond strength or failure in the concrete substrate. This test measures the tensile adhesion of membrane and primer to the substrate and should always be conducted on the in-place membrane.

**PHYSICAL PROPERTIES**

The physical properties of the applied membrane are critical for the longevity of the structure. Some of the properties that should be addressed in the project specifications are detailed below:
Crack bridging

Concrete, although a very durable material exhibits poor tensile properties and will develop cracks, either from shrinkage during the curing process from the live loads and dynamics that the bridge is subjected to. The waterproofing membrane that is applied to the surface must be capable of bridging these cracks effectively.

The PmB membrane exhibits a nominal 300% elongation capacity and retains its physical qualities through the full service range of -42 °C to 110 °C. It has recently been tested to bridge cracks of 14mm at -10 °C. One reason for this high degree of flexibility is that the membrane is pure resin containing no fine fillers. Fillers are typically added to reduce the resin content of the membrane but they can also reduce the physical properties of the membrane. With no filler content, there is no concern over long term degradation of the fillers and extended service life and protection of the structure is assured.

Since many of our northern States and Canada will experience very low temperatures in the winter months the issue of glass transition temperature, or when the membrane will embrittle becomes and important property to consider. The PmB membrane glass transition temperature has been tested at -42 °C.

Environmental concerns

Any material that is being used on a project should be reviewed for safety and health considerations. The manufacture recommendations for proper handling and placement should be followed to ensure that the workers and the public are not being exposed to unnecessary risks.
**Bond strength to asphalt**

A key requirement is that the membrane system on highway bridges is that it develop a strong bond with the asphalt overlay placed as the wearing course. For this crucial interface bond a cold applied bitumen/polymer based tack coat was developed. The design requirement for this tack coat was that it effectively bond to both the membrane and the asphalt overlay and is simple to apply, either with a broom, squeegee or spray application. The tack coat also has to initially cure dry to the touch but not prematurely soften on a hot day. The tack coat must re-melt when the hot asphalt mix is placed over it.

The tack coat that was developed meets these requirements with a softening temperature of 80 °C. This prevents premature softening with summertime conditions and a deck surface temperature exceeding 60 °C. This avoids situations where the tires of the asphalt placing equipment can begin to pick the tack coat off of the surface of the membrane.

When the hot asphalt mix is placed over the tack coat it is reactivated and it melts into the asphalt to develop an excellent bond. Asphalt temperatures of greater than 120 °C during placement are recommended when working with this membrane but the membrane is capable of accepting asphalt temperatures as high as 240 °C. After asphalt placement, as the entire system cools asphalt becomes bonded to the membrane.

This system works well when the depth of the asphalt placed is at least 60mm. With thinner asphalt surfacing applications there is some concern that the shear forces developed by vehicles braking will cause the asphalt to shove on the membrane. In order to develop a positive interlock and mechanical key to prevent this shearing action a chemically bonded polyurethane resin based tack coat was developed. This tack coat is spray or squeegee applied and into the
wet resin a 2mm aggregate is broadcast. The aggregates become highly bonded in the resin and prevent future slip plane concerns.

Tensile and shear bond strength tests conducted with the membrane system bonded to various asphalt mix designs yield interfacial failures within the body of the asphalt.
Test properties

The following is a summary of the test properties of the PmB spray applied waterproofing membrane:

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>ASTM D-638</td>
<td>9.0 N/mm²</td>
</tr>
<tr>
<td>Gel Time</td>
<td></td>
<td>3-5 seconds</td>
</tr>
<tr>
<td>Cure Time</td>
<td></td>
<td>20 minutes</td>
</tr>
<tr>
<td>Full property cure</td>
<td></td>
<td>24 hours</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>ASTM D 638</td>
<td>&gt; 250%</td>
</tr>
<tr>
<td>Puncture Resistance</td>
<td>ASTM E 154</td>
<td>174 kgf</td>
</tr>
<tr>
<td>Tear Strength</td>
<td></td>
<td>32 N/mm²</td>
</tr>
<tr>
<td>Shore Hardness</td>
<td></td>
<td>A-74</td>
</tr>
<tr>
<td>Crack bridging</td>
<td></td>
<td>14 mm at -10 °C</td>
</tr>
<tr>
<td>Glass transition temp</td>
<td></td>
<td>-42 °C</td>
</tr>
<tr>
<td>Filler content</td>
<td></td>
<td>none, 100% resin solids</td>
</tr>
<tr>
<td>Adhesion to concrete</td>
<td>ASTM D 4541</td>
<td>1.0 MPa minimum or failure in concrete</td>
</tr>
<tr>
<td>Adhesion to steel</td>
<td>ASTM D 4541</td>
<td>3.75 MPa ( limit of test apparatus)</td>
</tr>
<tr>
<td>Water Vapor Transmission</td>
<td>ASTM E-96 Proc. BW</td>
<td>1.7 grams/m²/24hrs.</td>
</tr>
<tr>
<td>Artificial Weathering</td>
<td>ASTM D 4587</td>
<td>+6% (Elongation at Break)</td>
</tr>
<tr>
<td>Artificial Weathering</td>
<td>ASTM D 4587</td>
<td>+0.9% (Tensile Strength)</td>
</tr>
<tr>
<td>Electrical resistivity</td>
<td>ASTM D 257</td>
<td>91x10⁶ Ohm-cm</td>
</tr>
</tbody>
</table>

REFERENCES

(C) AREMA (R) 2000
1 - Preventive Maintenance of Concrete Bridge Decks by Paul D. Carter, November 1989 in Concrete International


3- Pitchmastic PLC, Baytec membrane- Technical literature and various publications

4- Prevention better than cure -World Highways, March 1996


6- Extracts from Concrete Society Interim Technical Report TR CS111 Durable Bonded Post-Tensioned Concrete Bridges. August 1995