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Photo 1: Membrane-level drainage pipes extend from the underside of a bridge.
Photo: Phil Moser

MEMBRANE-LEVEL DRAINAGE ON HIGHWAY BRIDGE DECKS

DESIGN AND CONSTRUCTION OF ASPHALT PAVEMENTS OVER WATERPROOFED BRIDGE DECKS DIFFER FROM ROADWAY CONSTRUCTION ON GRADE.

By Phil Moser and Greg Doelp

DRIVE UNDER HIGHWAY BRIDGES in some parts of the U.S. and you may notice a series of small-diameter PVC pipes that extend down a few feet from the edge of the bridge and end in mid-air (Photo 1). The often-irregular spacing and skew angles of these pipes may appear haphazard, but their appearance belies the fact that this system of pipes is a carefully designed feature that serves a critical purpose. These pipes are drains, but they do not typically drain the surface of the pavement. Instead, they provide a drainage outlet for the waterproofing membrane on the structural bridge deck to relieve water that infiltrates the pavement layer due to its inherent porosity or at cracks and joints.

The use of waterproofing membrane systems on bridge decks as a corrosion-prevention strategy has been standard practice in many U.S. states and Canadian provinces for more than 40 years. Asphalt concrete pavement (ACP) is typically constructed over the waterproofing to protect it and to provide a surface suitable for vehicular traffic. While design standards for ACP roadways are well established, the design and construction of ACP over waterproofed bridge decks poses special challenges that differ from roadway construction on grade. One of those challenges is membrane-level drainage.

Subsurface drainage is critical to pavement durability. Poor subsurface drainage causes accelerated deterioration of the pavement system in the form of potholes, frost heaving, cracking, and stripping. To avoid these problems, subsurface drainage of highways on grade is typically achieved by constructing the pavement well above the groundwater elevation on a well-draining granular layer with good drainage outlets. This allows any water that infiltrates the pavement to drain out at the shoulders or through buried drain structures, rather than remaining trapped in the pavement and causing deterioration.

Importance of membrane-level drainage for bridges

In contrast to roadways on a granular base, pavement-membrane overlays on bridge decks inherently involve pavement construction on a layer that, by definition, is impermeable to liquid water and will create a "bathtub" if no outlets are provided. The waterproof substrate, combined with the fact that bridges in cold climates experience more freeze-thaw cycles than the adjacent roadways on grade, creates a severe environment for the pavement on the bridge deck. Therefore, membrane-level drainage on bridge decks is widely recommended in the published literature, both domestically and internationally. These recommendations have been published in the U.S. on a regular basis since the 1960s.

For example, NCHRP Synthesis 220 (Manning, 1995) contains several references to membrane-level drainage, including the following:

- "Bituminous surfacings used on bridge decks in North America and most of Europe are both porous and permeable. This results in salt-laden water being trapped on the deck surface…"
- "… it is therefore important to ensure that the drains are slotted at the membrane-asphalt interface to allow water that reaches the membrane surface to drain away."
- "… seepage drains should be provided at the lowest points to drain water passing through the asphalt from the surface of the membrane…"

As another example, AASHTO Bridge Design Specifications (AASHTO, 2014), Section 2.6.6.5, states: "Cavities in structures where there is a likelihood for entrapment of water shall be drained at their lowest point. Decks and wearing surfaces shall be designed to prevent the ponding of water, especially at deck joints. For bridge decks with nonintegral wearing surfaces or stay-in-place forms, considerations shall be given to the evacuation of water that may accumulate at the interface." The commentary on this section states that "weep holes in concrete decks and drain holes in stay-in-place forms can be used to permit the egress of water."

Similar recommendations have been published in Europe (for example, from the European Asphalt Pavement Association and the UK's Highways Agency, which includes example details) and in Asia.

Photo 2: Waterproofing membrane (orange-colored) on a highway bridge deck. *Photo: courtesy of Bridge Preservation LLC*

Photo 3: The new pavement, with no membrane-level drainage provisions, was saturated at the downslope edge of the bridge. *Photo: courtesy of SGH*

State of current practice

Despite the consistent recommendations for membrane-level drainage on bridge decks in industry literature, and the availability of example details, the approaches taken to bridge deck drainage — and to bridge deck waterproofing in general — seem to vary around the country and around the world. We reviewed current standard details or recent project bid documents from 16 U.S. states, and in seven of the 16 we were not able to find any references to membrane-level drainage requirements. The other nine states that we reviewed include provisions for drainage off the structural deck in at least some circumstances, but the requirements vary widely:

- In Maine, the standard details for bridge drains show bi-level drains with a grate at the pavement surface and 1/2-inch-diameter weep holes through the sides of the frame.
- In Massachusetts, Rhode Island, and Connecticut, the standard details show PVC drain pipes (3/4 inch to 2 inches in diameter; varies depending on the state) to drain water off the membrane level.
- In Pennsylvania, the standard curb drain detail for bridges with ACP shows the drain set flush with the top of the structural deck, allowing for drainage both off the wearing surface and off the structural deck. The standard details in Idaho, and recent project bid documents in Alaska (Alaska DOT&PF, 2014) are similar.
- In Nebraska, recent project bid documents include references to membrane-level drainage in the Cold Liquid-Applied Membrane specification.
- Oregon's Standard Drawing BR157 contains details showing 2-inch-diameter drain holes through the deck or parapet/barrier adjacent to plug joints. (According to a note on the drawing, this requirement applies for Type "F" pavement only).

We also reviewed Federal Highway Administration (FHWA) guidelines and found that they provide hydraulic methods for designing surface drainage on bridges and subsurface drainage on soil subgrades, but we did not find any FHWA guidelines that address the topic of membrane-level drainage on bridge decks. We have also observed that, even in states where membrane-level drainage is included in the standard highway details, not all bridges have membrane-level drainage. Clearly, there is an opportunity for improved sharing of knowledge and consistency across jurisdictions, and a need to identify and understand the obstacles that prevent membrane-level drainage from being incorporated on some projects.

Project examples: Lack of membrane-level drainage

On structures where membrane-level drainage is omitted, we have seen that the pavement is water-saturated for long periods of time and deteriorates prematurely under traffic loading and freeze-thaw cycling.

For example, in Photo 3, the new ACP was saturated at the downslope edge of the bridge, even on days with only light precipitation and on subsequent days of dry weather. Where asphalt plug joints impeded drainage along the length of the bridge, water welled to the surface of the pavement and flowed across the surface.

On another bridge, a similar phenomenon occurred and progressed into visible damage of the pavement when a pothole formed at the upslope side of one of the plug joints. In winter, a stream of ice on the surface of the pavement emanated from the pothole. Through the winter, the deterioration rapidly accelerated in the wheel paths of the truck lanes, as potholes progressed upslope from the plug joints (Photo 4).

When sample areas of the pavement were cut out, we found damage below the surface in some areas. The plane of failure was generally within the ACP just above the surface of the waterproofing membrane. The lower portion of the pavement was saturated (Photo 5).

We also found that the asphalt binder was often stripped from the aggregate at the plane of failure, a sign of moisture damage. In a few locations, we chipped out the pavement down to the waterproofing membrane and the hole slowly filled up with water that seeped out of the adjacent saturated pavement.

Photo 4: Progression of deterioration in new pavement with no membrane-level drainage provisions. *Photo: courtesy of Joe Haydu; used with permission*

Photo 5: The lower portion of the pavement, with no membrane-level drainage provisions, was saturated. *Photo: courtesy of SGH*

Challenges

Despite the obvious benefits to membrane-level drainage on bridge decks, there are several challenges to implementing it:

Constraints on outlet locations — Bridge deck drains must be coordinated with structural components, and they must be designed to resist clogging and be maintainable. Drain outlets must be designed to prevent splashing or blow-back onto structural members, and the outlets must drain to acceptable locations (i.e., not onto roadways, railroads, wetland habitat, or erosion-prone slopes below). If the bridge drain inlets are configured to allow membrane-level drainage only and not surface drainage, the flow rates will be very small, which should ease concerns about erosion or environmental impact on wetlands.

However, the ideal locations for membrane-level drain outlets on the bridge (at the low points along the curb and at expansion joints or other obstructions to drainage) may not always coincide with acceptable locations on the ground below. This may require compromise, or create a need for sloped runs of pipe to redirect the outlets to acceptable locations.

Existing bridges — Adding drains into existing bridge decks that lack them may be particularly challenging because it requires some field investigation of the existing structure and reinforcing steel spacing to allow the drains to be located to avoid interference. However, even on existing bridge decks, we believe that some membrane-level drainage can often be provided through careful design and field verification. Projects to re-pave and replace waterproofing provide the ideal opportunity to incorporate these improved drainage features, if the organizational challenges noted below can be overcome.

Organizational challenges — NCHRP Synthesis 220 notes that for most agencies, requirements for placing ACP on bridge deck membranes are "contained in the specifications for hot-mix asphalt, which are concerned primarily with the construction of bituminous pavements. As such, the requirements for placing asphalt surfacings on membranes are a minor part of a much larger specification. Further, because the responsibilities for bridges and pavements are split in most agencies, there may be insufficient recognition of the special requirements for paving over membranes on the part of those responsible for hot-mix asphalt specifications."

Lateral drainage — When a monolithic, isotropic pavement material is applied directly onto the waterproofing membrane, the rates of lateral seepage through the pavement toward the membrane-level drainage outlets are inherently slower (due to the lower hydraulic gradient) than the rate of vertical, downward seepage when the pavement surface is wet. This results in water accumulating within the pavement during times of precipitation. The severity and consequences of this problem depend on several factors, including the following:

- frequency of precipitation versus dry weather in the climate zone where the project is located;
- spacing of the membrane-level drainage outlets; and
- slope of the bridge deck.

Even where slow lateral drainage is a limiting factor, providing membrane-level drainage outlets improves durability on bridge decks by allowing the pavement to eventually drain. To further improve the performance of pavement systems on bridge decks, some jurisdictions (including Maine, France, Germany, Italy, the UK, and Denmark) have designed pavement systems with enhanced lateral drainage provisions at the membrane level. More research and sharing of best practices is needed in this area.

On most bridges, these challenges can be overcome, and at least some membrane-level drainage can be provided to improve the durability of the pavement. The benefits of improved pavement durability, waterproofing longevity, and traffic safety are worth the effort of installing membrane-level drains.

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LOCAL RESOURCES FULFILL SUSTAINABLE GUIDELINES

QUEBEC'S MISTISSINI BRIDGE IS THE WORLD'S FIRST GLULAM SEMI-CONTINUOUS ARCHED WOOD BRIDGE.

By Marilyn Thompson

TRANSPORTATION

Laminated wood was formed into four sections of straight beams. Each beam was supported by a series of semi-continuous arches with pivot-type connectors.
Photo: courtesy of Stantec

THE AWARD-WINNING Mistissini Bridge in Quebec, Canada, is the world's first glued laminated (glulam) semi-continuous arched wood bridge. Spanning 525 feet, the bridge brings together innovative design, sustainable building practices, and a long-term investment in local business. Stantec, an international professional services design company, chose glulam to take advantage of locally sourced timber from the region's vast natural resources. The bridge is a sterling example of how the innovative use of glulam can successfully combine design, safety, durability, and sustainability principles.

Glulam is advantageous as a building material because of its strength and performance. Denis Lefebvre, senior associate at Stantec who served as discipline manager, designer, and examiner during construction of the Mistissini Bridge, used glulam wood in part to overcome the project's unique challenges. Construction needed to be completed under strict guidelines: The Mistissini Bridge was required to be environmentally sustainable, carry a carbon negative footprint, and weather the difficult environmental conditions of the region.

Design

Gracefully spanning the Uupaachikus Pass, the bridge was commissioned on behalf of the local Cree Nation to expand socio-economic