December 2017 Vol. 4 Issue 9

civil + structural ENGINEER

CELEBRATING THE DESIGNERS OF THE WORLD AROUND US

ELIZABETH RIVER TUNNELS IN DEPTH

Composite shear wall 'revolutionizes' high-rise construction

Detroit revitalization supports new construction

Envision v3: Raising the bar for sustainability

Shear resistance of pavement and waterproofing systems

zweig group

Photo 2: This ACP-membrane overlay on a parking structure experienced a widespread failure. During ACP demolition, we observed a large area where the waterproofing membrane was completely debonded from the underlying concrete deck. We have also investigated other projects where the failure occurred between the ACP and the waterproofing membrane. This photo was previously published in ASTM STP 1590.

Photo 1: This roadway ACP failed a few months after placement. The top ACP top course was not well bonded to the ACP binder course below. The top layer moved laterally 2 feet due to shear stresses from vehicle braking forces.

SHEAR RESISTANCE OF PAVEMENT AND WATERPROOFING SYSTEMS

TEST METHOD PROPOSED TO QUANTIFY THE INTERLAYER SHEAR-STRENGTH OF MEMBRANE-PAVEMENT SYSTEMS.

By Phil Moser, P.E.; Tony Khoury, P.E.; and Jonathan Haydu

FOR MORE THAN 40 YEARS, many U.S. states and Canadian provinces have used waterproofing membrane systems on bridge decks as a standard corrosion-prevention strategy. Asphalt concrete pavement (ACP) is typically constructed over the waterproofing to protect it and to provide a surface suitable for vehicular traffic. Despite the long track record of this type of design, regional differences in material specifications, construction details, and climate have led to mixed results in some jurisdictions.

One of the most-common problems reported on waterproofed bridge decks is poor adhesion of the ACP overlay to the waterproofing membrane (NCHRP Synthesis 425, 2012), which can lead to premature pavement failure. These problems have led some agencies to discontinue the use of waterproofing membranes in favor of other, potentially less-effective (or more-costly), corrosion-prevention strategies. However, many agencies still use waterproofing membranes successfully, despite the challenges.

While design standards for ACP roadways are well established, the design and construction of ACP over waterproofed bridge decks (and similar structures such as parking decks) pose special challenges that differ from roadway construction on grade. Those challenges can include membrane-level drainage, interlayer shear strength (adhesion), compactor size and operation limitations due to structural constraints, challenges of compaction on soft asphaltic membranes, and ACP thickness limitations due to structural constraints. This article, the second in a series, focuses on interlayer shear strength; membrane-level drainage was discussed in our June 2017 article (Civil + Structural Engineer, "Membrane-level drainage on highway bridge decks"; https://csengineermag.com/article/membrane-level-drainage-highway-bridge-decks).

This article describes recent laboratory testing performed by the authors to evaluate the interlayer shear strength of ACP and waterproofing membrane systems. This work builds on a previous phase of research presented in ASTM STP 1590 (Moser et al, 2015) and incorporates new data to propose a test method that the authors recommend for evaluating the shear resistance of pavement and waterproofing systems.

Shear forces in paving and waterproofing systems

Vehicular loads are transmitted through paving systems to the structural system below. In-plane shear stresses are generated directly by vehicles braking, accelerating, and turning; and indirectly as the pavement flexes under concentrated loads from vehicle wheels. Pavement systems are typically constructed in multiple layers, and rely on interlayer shear bond to transfer these stresses to the underlying structure. Poor shear bond can result in premature failure of the pavement system, whether on grade (Photo 1) or on a waterproofed, elevated structure (Photo 2).

Testing

Test method — There are currently no nationally accepted standards that define the requirements for shear resistance of ACP systems with

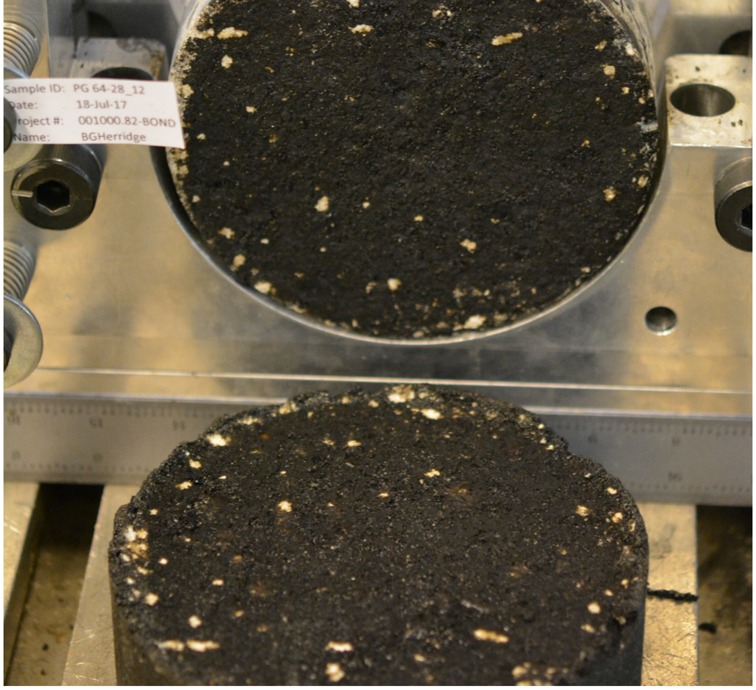

Photo 4: Specimen without waterproofing membrane, after shear testing. The light-gray spots on the shear interface are interlocked aggregate that abraded or fractured during testing.

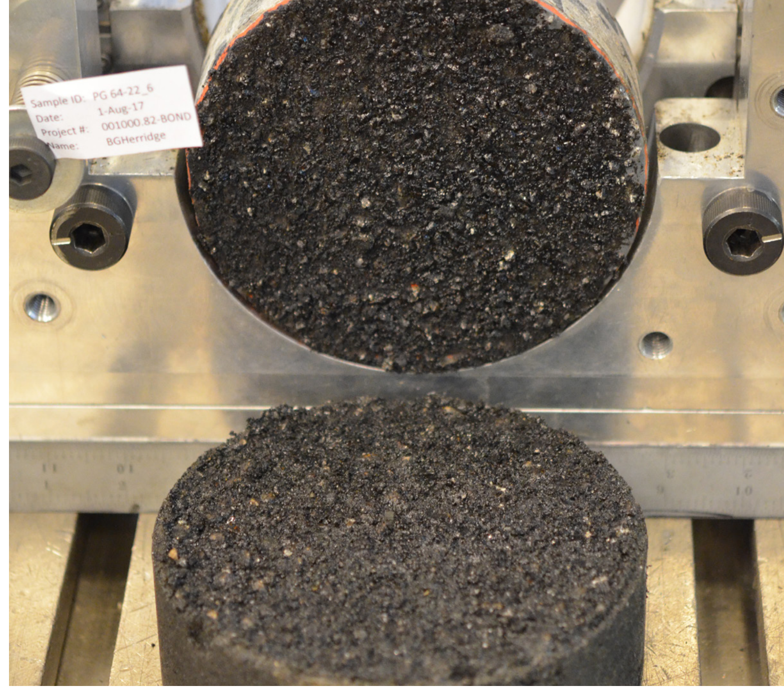

Photo 5: Specimen with waterproofing membrane, after sheer testing.

waterproofing membranes. At least three test methods — one in the U.K. (BS EN 13653:2004), one in China (Zhou and Xu, 2008), and one in the U.S. (Moser et al, 2015) — have been developed specifically for evaluating the shear resistance of these pavement-membrane systems, but none of these methods have been widely-adopted in the U.S. More recently, a shear test method developed at the University of Louisiana (NCHRP Report 712, 2012) has been adopted as a standard test method, AASHTO TP114-15 (AASHTO TP 114-15, 2015). Although this test method has in the past been used primarily for testing the shear strength at the interface of two ACP layers, or of ACP directly to a concrete substrate, it can test the shear strength at any interface in a cylindrical specimen. In this research project, we evaluated its use for testing the interlayer shear strength of ACP-waterproofing assemblies.

We performed testing at SGH's Waltham, Mass., laboratory using the Louisiana Interlayer Shear Strength Test (LISST) Apparatus (Photo 3, page 55). We generally followed the AASHTO TP114-15 test standard, but conditioned the specimens a full 24 hours before testing (more than the specified minimum of two hours), and the testing room was conditioned to 73F° ±3° (slightly cooler than the specified 77F° ± 2F°).

Test variables — The shear bond at the ACP-to-membrane interface is likely affected by many variables, such as ACP mix design and compaction; tack coat type and application rate; environmental conditions; waterproofing membrane chemistry, stiffness, and surfacing; and construction workmanship. For this research project, we evaluated the following variables:

Two substrates:
- bare concrete
- spray-applied polymeric waterproofing membrane with graded basalt aggregate embedded in the top surface

Three tack coats:
- PG 64-22
- CQS-1hP
- RS-1

Two normal forces:
- 0 psi
- 20 psi

Test specimens — We prepared 38, 6-inch-diameter by 4-inch cylindrical specimens for shear testing. Each specimen consisted of a cored concrete base with laboratory-compacted ACP on top. Various combinations of membrane and tack coat were introduced between the concrete and ACP to evaluate their effect on the shear resistance at the ACP-to-substrate interface. The following describes major components of the test specimens:

Concrete substrates — We cored 38, 6-inch-diameter cylinders from a concrete slab, and cut them to 2-inch length. Prior to coring, the concrete slab was shot blasted to provide an ICRI surface profile of CSP-4 to comply with the waterproofing manufacturer's recommendations.

Waterproofing membrane — Twenty-five out of the 38 concrete cylinders received a polymeric spray-applied waterproofing membrane with graded basalt aggregate surfacing on the top surface. Bridge Preservation LLC donated and applied the waterproofing membrane.

Tack coat — Tack coats were applied to the test surfaces of the specimens as indicated in Table 1, at a residual application rate of 0.05 gsy, based on published guidelines for surfaces of similar roughness (NCHRP Report 712, 2012).

ACP pavement — A 6-inch-diameter by 2-inch ACP layer was

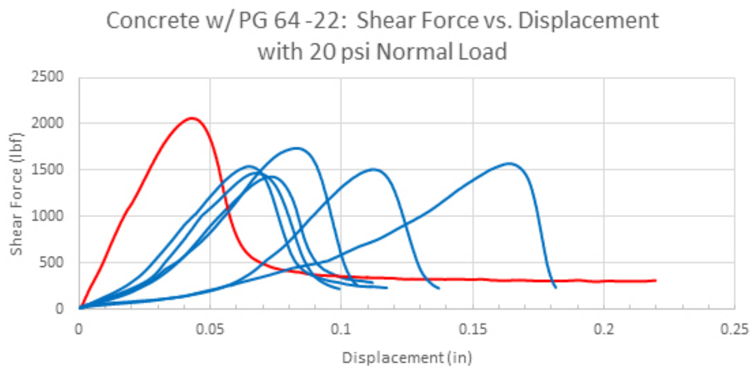

Figure 1: Concrete with PG 64-22, no membrane, tested with 20 psi normal load

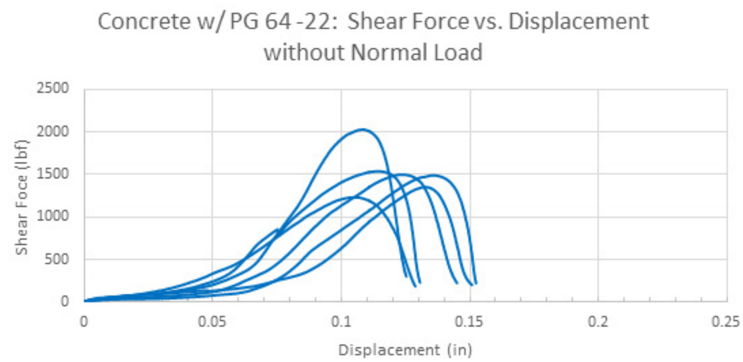

Figure 2: Concrete with PG 64-22, no membrane, tested without normal load

constructed on the test surfaces using a cylindrical mold. The ACP is a Superpave 3/8-inch mix with PG 64-28 binder, similar to MassDOT's standard bridge deck mix. The ACP was compacted onto the substrate using a Superpave gyratory compactor to 7 percent target air avoids. The tack coat and ACP were installed by our subconsultant, AMS LLC.

Results and discussion

Results are summarized in Table 1. Figures 1 through 3 show the Shear Force vs. Displacement curves for each specimen, organized by surface type (bare concrete or waterproofing membrane), tack coat type (PG 64-22, CQS-1hP, or RS-1), and normal load (20 psi vs. 0 psi). We rejected six specimens (one of which was tested twice) as outliers from the final results, due mostly to anomalies observed in the course of the testing such as specimens coming loose in the apparatus. The rejected results are excluded from Table 1 but are included in Figures 1 through 3 in the interest of full transparency, and are highlighted in different colors for identification.

- The bare concrete specimens (Figure 1) were tested with and without a normal load. Adding a 20-psi normal load caused the data to scatter along the x (displacement) axis, but surprisingly, the effect on the average ultimate load was negligible (1.3 percent). For subsequent testing, we elected to omit the normal load to avoid the excessive scatter along the x axis.
- The introduction of the waterproofing membrane to the specimens with PG 64-22 tack coat reduced the shear strength by 42 percent.
- The CQS-1hP tack coat produced a significantly higher shear strength than the PG 64-22 and RS-1 tack coats.
- Securing the specimens in the apparatus consistently is important to achieving consistent results, but can be difficult when using cored specimens whose geometry varies slightly.
- The amount of aggregate interlock between the ACP and waterproofing membrane can have a significant impact on the results; the amount of interlock varies both in laboratory-prepared specimens (Photos 4 and 5) and in the real world.
- Additional testing would be valuable to determine the optimal tack coat application rate for a given waterproofing membrane, and to evaluate the shear strength after environmental conditioning, as well as other variables.

Conclusions

The corrosion-prevention benefits of waterproofing membranes are obvious, but introducing a membrane between pavement and the underlying concrete structure can reduce the shear strength at the interface. While empirical experience has shown many of these assemblies can perform adequately in the field, care needs to be taken when designing ACP membrane overlays, especially in areas with heavy traffic, deceleration (e.g., ramps), and thinner pavement systems.

AASHTO TP114-15 is a useful test method for quantifying the interlayer shear strength of membrane-pavement systems. Our hope is that the testing presented in this article will lead to further research and standards development regarding interlayer shear strength of these assemblies, and ultimately contribute to the durability of bridges by promoting the successful use of ACP-membrane systems as a corrosion prevention strategy.

PHIL MOSER, P.E., is a senior project manager at Simpson Gumpertz & Heger (www.sgh.com), a national engineering firm providing engineering of structures and building enclosures. He specializes in investigating and designing waterproofing and paving systems on a variety of structures (pedestrian plazas, bridges, and parking garages), and other types of building enclosure systems. He can be reached at psmoser@sgh.com.

TONY KHOURY, P.E., is a senior staff member at SGH. He specializes in investigation, design, management and construction of bituminous pavement, site development, underground utility design, material quantity takeoffs for large civil projects, complex data visualization, and building/structure settlement. He can be reached at tkhoury@sgh.com.

JONATHAN HAYDU is the chief operating officer of Bridge Preservation LLC, a company that designs, manufactures, and tests all types of spray-applied waterproofing systems for civil engineering structures. He has more than 16 years of experience. He can be reached at jonathan@bridgepreservation.com.

Surface	Tack Coat Type	# of Specimens		# of Valid Results	Normal Load (psi)	Avg. Displace-ment at Ultimate Load (in.)	Avg. Ult. Shear Load (lb)	Avg. ISS (psi)	Std. Dev. ISS
Bare Concrete	PG 64 -22	38	7	6	20	0.126	1,543	62	4
			6	6	0	0.136	1,523	61	11
Membrane	PG 64 -22		13	11	0	0.173	656	26	9
	CQS-1hP		6	4	0	0.138	939	38	2
	RS-1		6	5	0	0.126	538	22	5

Table 1: Interlayer Shear Strength (ISS) test results

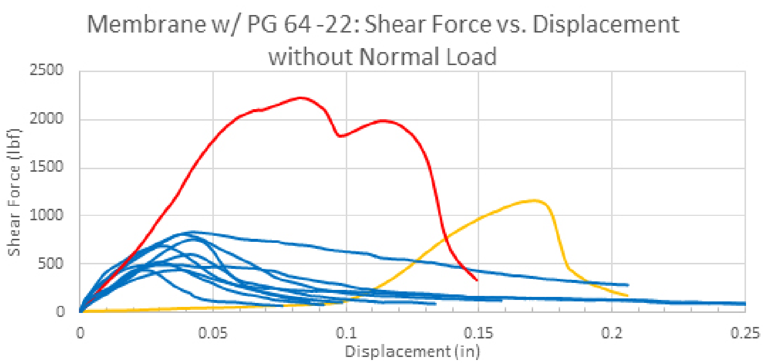

Figure 3: PG 64-22 and membrane

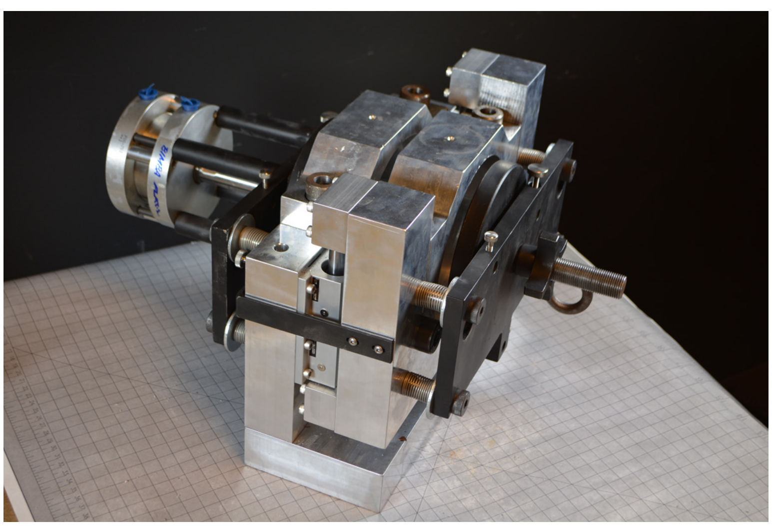

Photo 3: Louisiana Interlayer Shear Strength (LISST) apparatus at SGH's Waltham, Mass., lab.

REFERENCES

- NCHRP Synthesis 425, 2012, Waterproofing Membranes for Concrete Bridge Decks, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C.
- Moser, P.S.; G. Doelp; and J. Haydu, 2015, "Shear Resistance of Paving and Waterproofing Systems," Roofing Research and Standards Development: Eighth Volume, ASTM STP 1590, Sudhakar Molleti, and Walter Rossiter, Eds., ASTM International, West Conshohocken, Pa.
- BS EN 13653:2004, Flexible sheets for waterproofing – Waterproofing of concrete bridge decks and other concrete surfaces trafficable by vehicles – Determination of shear strength, British Standards Institution, London.
- Zhou, Q. and Xu, Q., 2008, "Experimental Study of Waterproof Membranes on Concrete Deck: Interface Adhesion under Influences of Critical Factors," Materials and Design 30, Elsivier.
- NCHRP Report 712, 2012, Optimization of Tack Coat For HMA Placement, Transportation Research Board.
- AASHTO TP 114-15, 2015, Standard Method of Test for Determining the Interlayer Shear Strength (ISS) of Asphalt Pavement Layers, American Association of State Highway and Transportation Officials, Washington, D.C.