Low-albedo concrete pavements pose no benefits in ice control

New research in ready-mixed and cast-in-place concrete was presented earlier this year at the 95th annual meeting of the Transportation Research Board. *Concrete Products* was there, among the 12,000-plus transportation professionals from around the world who came to see more than 5,000 presentations in nearly 800 sessions and workshops.

Below are summaries of some of the most significant peer-reviewed papers covering ready mixed concrete or cast-in-place practice. In our March 2016 issue we looked at new research in precast/prestressed concrete products for the transportation industry (see "Precast Barriers, Double Tee Girders Get Look at TRB 2016," pp. 52-58, view at http://concrete.epubxp.com/i/646755-mar-2016). For more information about the 2017 meeting, or to obtain the full 2016 papers, visit www.trb.org.

DARK CONCRETE PAVEMENTS WON'T REDUCE ICE CONTROL COSTS

In the war between rigid (concrete) and flexible (asphalt) pavements, bituminous interests imply that black asphalt surfaces can lead to lower deicing costs in winter maintenance. But darker portland cement concrete pavements won't lead to lower winter maintenance costs, say W. Spencer Guthrie, Ph.D., and Tenli Waters, B.S., E.I.T., Department of Civil and Environmental Engineering, Brigham Young University, and Jaren T. Knighton, M.S., E.I.T., Kiewit Infrastructure Engineers Co., Omaha, in their 2016 paper, *Thermal Behavior of Typical and Darkened Portland Cement Concrete Pavement: Applications to Winter Maintenance*. And while they studied PCC pavements, their research also casted doubt on asphalt pavement claims.

"While portland cement concrete pavement offers a durable surface and long service life when designed and constructed properly, selected concrete pavement sections require expensive winter maintenance treatments to clear snow and ice," Guthrie, Waters and Knighton say.

Architectural tinting and darkening of concrete is common for aesthetic reasons, they add. Common pigments include red mud from the aluminum industry, titanium dioxide, zinc oxide, zinc phosphate, micronized talc, diatomaceous silica, micronized calcium carbonate, and barite. Iron oxide pigment is also available for darkening concrete, and its effect on the thermal behavior of concrete pavement, especially with respect to freezing conditions, was the focus of this research.

"Darkening the concrete reduces its albedo, or whiteness, and should therefore promote higher pavement surface temperatures through increased absorption of radiation energy from the sun," Guthrie, Waters and Knighton observe. "In winter, darkened concrete pavement should then melt snow and ice more quickly, all other factors the same, than typical concrete pavement. In addition to increasing the surface temperature, darkened concrete should also increase the subsurface temperature of the pavement and provide greater frost protection to subsurface layers and buried utilities during winter in cold regions."

To confirm this, the effects of lower concrete albedo on the thermal behavior of concrete pavement was investigated by directly comparing surface and subsurface temperatures of darkened concrete with typical concrete. Utah Department of Transportation constructed a new 9-in.-thick concrete pavement along 1000 West in Logan, north of Salt Lake City, during the summer of 2013. At the intersection of 1000 West and 1400 North, one section each of typical and darkened concrete pavement was placed on the west side, while two sections each of typical and darkened concrete pavement were placed on the east side.

Both typical and darkened concrete pavement sections were instrumented with temperature sensors to monitor surface and subsurface temperatures on hourly intervals. At one typical and one darkened concrete pavement site on each side of the intersection, one location within a wheel path was selected for installation of sensors at the top and bottom of the concrete slab; this allowed for computation of the temperature gradient at the selected locations. To position the sensors at the desired depths, the researchers mounted them on a non-conductive plastic stake secured in the subbase prior to concrete placement.

The sensors were 1.25 inches in height and placed 7.25 inches apart so that approximately 0.25 inches of clear space would exist between the sensors and the top and bottom of the concrete slab.

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Utah portland cement concrete pavement albedo experiment site instrumentation: left, temperature sensors for monitoring concrete pavement; center, sensor cables in PVC pipe; and right, utility box mounted on signal pole. IMAGES: Guthrie, Waters and Knighton.

The sensor cables were carefully routed through 0.75-in.-diameter polyvinyl chloride pipe that was buried just below the surface of the subbase layer. The PVC pipe conveyed the cables from the sensor locations to a nearby signal pole, where the cables were terminated in a steel utility box mounted approximately 12 feet high.

- The results of the study show that a strong positive correlation exists between the surface and subsurface pavement temperatures and the air temperature.
- The difference between the surface temperatures of the darkened and typical pavements decreases as the air temperature decreases.
- When the air temperature is 32°F, the surface temperature of the darkened concrete is just 0.2°F higher than that of the typical concrete; therefore, the darkened pavement is unlikely to melt snow and ice faster than the typical pavement at this site.
- The difference between the subsurface temperatures of the darkened and typical pavements also decreases as the air temperature decreases. In this case, when the air temperature is 32°F, the subsurface temperature of the darkened concrete is 1.1°F higher than that of the typical concrete; therefore, the darkened pavement is unlikely to provide significantly greater frost protection to subsurface layers and buried utilities during winter.

HIGH-DOSAGE FIBER-REINFORCED HPC RESTRAINS CRACKS OVER PIERS

High-dosage, fiber-reinforced high-performance concrete protects pier cap PCC placement by controlling cracking, say Celik Ozyildirim, Ph.D., P.E.; Evelina Khakimova, E.I.T.; Harikrishnan Nair, Ph.D.; P.E.; and, Gail M. Moruza, E.I.T., Virginia Center for Transportation Innovation and Research, Charlottesville, in their peer-reviewed paper, *High-Performance Fiber-Reinforced Concrete in Closure Pours over Piers*.

Concrete with cracks or high permeability facilitates the penetration of chloride solutions, the authors write. These deicing solutions also seep through leaking joints and penetrate into the substructure elements and beam ends, resulting in extensive corrosion damage. "Joints can be eliminated by constructing continuous decks or closure pours, and infiltration through concrete can be minimized by using low-permeability concrete and fiber-reinforced concrete that controls cracks," say Ozyildirim, Khakimova, Nair and Moruza.

Their study investigated low-permeability fiber-reinforced concretes that use polyvinyl alcohol, polypropylene, or 5D steel fibers to control cracking in closure pours. "The addition of a small amount of discontinuous fibers to a conventional concrete matrix minimizes cracking, but the cracks are still wide enough to permit the intrusion of harmful solutions," the authors observe. "High volumes of suitable fibers used in high-performance fiber-reinforced concrete enable strain and deflection hardening. In these concretes, multiple very tight cracks (< 0.1 mm wide) occur. These cracks do not allow for the ingress of water and other harmful solutions."

Leaking joints can cause extensive damage to substructures and beam ends, requiring costly repairs, the researchers add. In new construction, jointless bridge structures are planned such that the deck is made continuous over the piers. In existing structures, joints are eliminated by placement of a closure pour or link slab that provides deck continuity.

Cracks also occur in the deck concrete, which also facilitate the intrusion of solutions. "For example, load-related cracks occur in concrete over the piers because of tension resulting from the negative

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moments," note Ozyildirim, Khakimova, Nair and Moruza. "In addition, cracks occur in concrete because of volumetric changes caused by moisture and temperature differentials."

Penetration of solutions can also occur through high-permeability concretes, they add. "In closure pours, another source of infiltration is due to poor bonding at the interface between the existing concrete and new concrete that leads to a gap or separation," they write. "The ingress of water and chemicals damages the bridge deck sections and the bridge substructure through corrosion of reinforcing steel, and concrete through alkali-silica reactions, sulfate attack, and freeze-thaw damage."

To reduce the penetration of liquids through concrete, high-performance concrete with low permeability is used. Concrete is a brittle material and has low tensile strength and a low strain capacity at fracture, the researchers note. When concrete elements are subjected to deformation, tensile stresses occur that can exceed the tensile strength of the material, and consequently cause cracking.

These cracks facilitate the penetration of solutions, thus increasing the permeability, Ozyildirim, Khakimova, Nair and Moruza write, adding, "Cracks form in fresh concrete through plastic shrinkage and settlement. In hardened concrete, cracks form through loading and environmental factors such as the temperature change and moisture loss (drying shrinkage). Design and construction methods also affect cracking. For example, in design, large skews would result in more cracks at the joints, and poor curing during construction would lead to undesirable cracking."

An effective way to control cracks is to use fibers, the authors write. The amount and type of fibers used for different applications vary. Specifically, the inclusion of synthetic fibers in small amounts

In the Virginia I-64 bridge experiment, researchers studied high-performance fiber reinforced concrete pours over pier caps. IMAGES: Ozyildirim, Khakimova, Nair and Moruza.

(about 0.1 percent by volume; 1 to 1.5 lb./yd.) is expected to reduce the loss of water from the fresh concrete, thus reducing plastic shrinkage cracking. However, the addition of synthetic or steel fibers in large amounts (0.5 to 2 percent by volume) is expected to increase toughness, provide residual strength, and minimize the occurrence and width of cracks in hardened concrete.

"High-performance, fiber-reinforced concrete (HPFRC) undergoes large deflection and exhibits deflection or strain hardening, causing multiple tight (less than 0.1 mm in width) microcracks instead of wide localized cracks," Ozyildirim, Khakimova, Nair and Moruza state. "In deflection or strain hardening after the first crack, an increase in stress occurs with further deformations. Cracks less than 0.1 mm in width inhibit the intrusion of corrosive chemicals. Such tight cracks have little effect on concrete permeability and hinder the penetration of chlorides. Concretes with tight cracks would be highly desirable in closure pours."

To test these concepts, closure pours with high dosages of the same three fibers were placed on two adjacent Interstate 64 bridges near Covington, Va. The initial results indicate no cracking, or cracking limited to a width of 0.1 mm as desired.

- The concretes using Rapid Set latex modified concrete had very high early strengths; 3,000 psi was achieved within the first test age of three hours. Even though these concretes had low permeability, they exhibited cracks exceeding 0.1 mm in width that would facilitate the infiltration of harmful solutions.
- Overall, the HPFRC mixtures reached the required strength of 3,000 psi in about 24 hours.
- Specimens exhibiting higher temperatures had higher early strength. The closure pour had a higher temperature development than the specimens, indicating that the specified early strength could be reached sooner.
- Engineered cementitious composite (ECC) mortar mixes with polyvinyl alcohol (PVA) fibers, and HPFRC with 5D steel fibers displayed deflection hardening behavior; HPFRC with polypropylene (PP) fibers had high residual strengths but did not exhibit deflection hardening.
- All HPFRC mixtures performed satisfactorily with no cracks or tight cracks (< 0.1 17 mm) in early visual surveys weeks after the placement.
- Proper mixing procedures are needed to achieve desired fresh concrete properties, workability and fiber dispersion.
- The Rapid Set LMC exhibited minor shrinkage but still had the

widest cracks in the closure pours. It is apparent that the addition of fibers was beneficial to crack control in the closure pours.

- Engineered cementitious composite mortar mixes displayed the most shrinkage, and the concretes with PP fibers and 5D steel fibers exhibited less, which was also evident by the narrower gaps between the closure pours and the existing concrete. The water content for mixtures with ECC was 571 lb./yd., and with PP fibers was 328 lb./yd. Concrete with 5D steel fibers had a water content less than 270 lb./yd. and exhibited the tightest gap. The gaps were easily closed by the subsequent overlay placements. The Rapid Set LMC did not contain fibers; even though shrinkage values were low, wide gaps were found between the closure pour and the existing deck.
- Surveys of closure pours after placement indicated satisfactory behavior with either no cracks or very tight cracks (< 0.1 mm) when fibers were used. Further surveys are planned for the coming years.

COST-WISE, MODIFIED CEMENTITIOUS COMPOSITES BEAT PMCS FOR DECKS

Use of modified engineered cementitious composites (MECC) for bridge decks is more expensive than portland cement concrete (PCC), but beats polymer modified concretes (PMC) by a long shot, say Elie Y. Hajj, David H. Sanders and Nicholas D. Weitzel, University of Nevada-Reno, in their TRB paper, *Evaluation of Modified Engineered Cementitious Composite (MECC) Using Local Materials.*

Engineered cementitious composite (ECC) is a fiber-reinforced mortar consisting of cement, fly ash, sand, water, and polyvinyl alcohol (PVA) microfibers. Chemical admixtures can also be added, as needed, to modify ECC workability or set times.

"The first ECC mixes were developed at the University of Michigan, where an extensive amount of research has been conducted," the authors write. "These past studies showed that ECC has better performance than traditional PCC mixes. However, almost all of the past work was performed on ECC material consisting of a very fine silica sand that is not commonly supplied by most aggregate pits. This silica sand consisted of more than 90 percent passing the No. 100 sieve. Because of the scarcity of stockpiles with this gradation, the costs associated with using the silica sand would dramatically increase the price of the ECC material."

A Minnesota Department of Transportation study evaluated the use of coarse aggregates in ECC using a 3/8-in. maximum aggregate size gradation. The results showed that ECC made with coarse aggregates did not exhibit the desired tensile properties or ductile behavior that is unique to ECC.

"Hence, in this study, commonly available and economically viable concrete sands conforming to ASTM C33 Specification for Concrete Aggregates were used as the only aggregate in the material," note Hajj, Sanders and Weitzel. "The ECC made with the concrete sands in lieu of the silica sand is referred to as modified ECC (MECC) material in this study."

Hajj, Sanders and Weitzel's purpose of evaluating MECC was to see if the material would be suitable for use as a bridge deck overlay instead of the polymer concrete for all non-structural overlays on bridge decks used by the Nevada Department of Transportation. "This polymer concrete has proven to have superior performance compared to both asphalt and concrete bridge deck overlays," the

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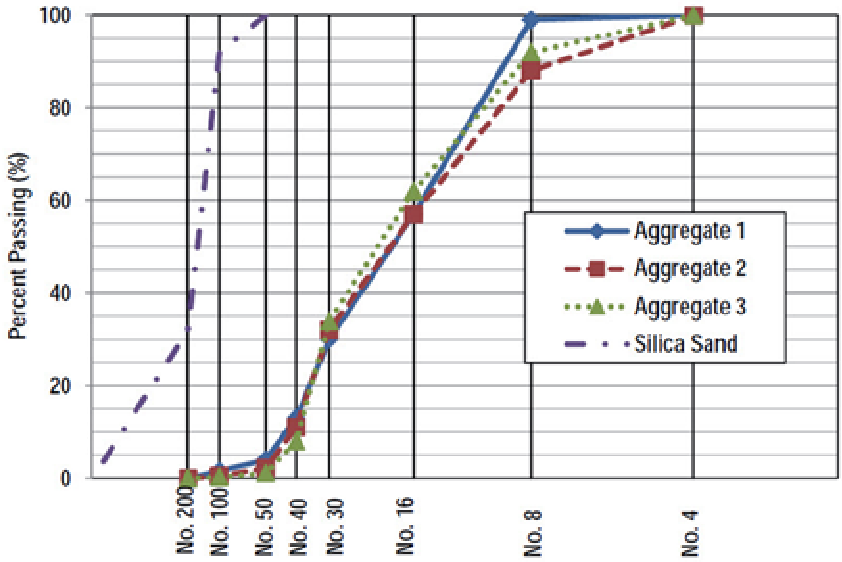
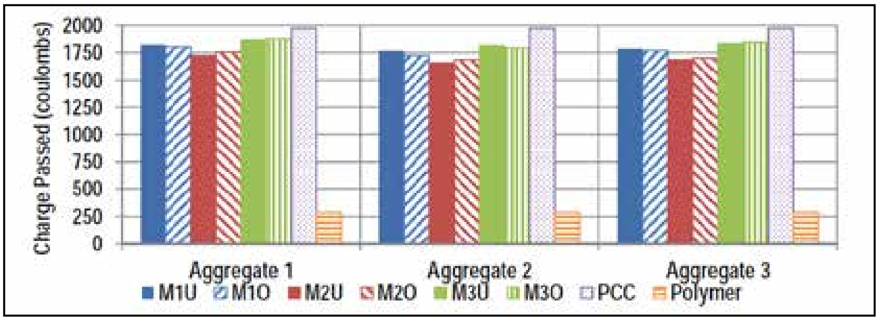
researchers write. "However, this polymer concrete is a proprietary material that has been only available from one supplier, resulting in high material cost. It's believed that the tensile properties and ductile behavior of MECC made with locally sourced materials could potentially replace the polymer concrete as the material for these overlays and save the agency a significant amount of money."

Locally sourced raw materials—three different concrete sands, three different mix proportions, and two different fibers—were used to develop 18 different MECC mixes. The performance of MECC was compared to that of a typical PCC mix and the polymer concrete mix currently used for bridge deck overlays in Nevada. The objective was to determine if MECC could replace the polymer concrete as the material for these overlays. Based on the findings, Hajj, Sanders and Weitzel observed:

- The results of the bond strength tests showed that shot-blasting allowed for a much stronger bond between the MECC and PCC samples. Water-blasting did not provide the necessary strength to meet Nevada DOT specifications. Therefore, shot-blasting is the preferred surface preparation for a bridge deck prior to an MECC overlay.
- The large-scale trial batches showed that 6 yd. of MECC could be produced in both central and transit mixed plant configurations. MECC batched on the large scale also had very similar properties to lab-mixed MECC, showing the material does not lose its hardened properties when batched on a large scale. These successful trial batches show that MECC can be transported in commonly available concrete trucks and delivered to the jobsite in a timely and uninterrupted manner.
- Initial cost estimates showed that the MECC material has a cost of $450/yd. This is higher than the traditional PCC, typically costing $100/yd. However, the polymer concrete costs about $1,600/yd., making the MECC an economically viable alternative to the polymer concrete.
- The laboratory test results show that MECC performed better than PCC in almost every test, and the MECC had comparable performance to the polymer concrete in most of the tests. The ductile behavior of MECC, combined with the material's superior durability and mechanical properties, make MECC a feasible material for bridge deck overlays in Nevada.



Gradations for evaluated locally sourced aggregate (concrete sands) for modified engineered cementitious composite (MECC), and silica sand typically used for engineered cementitious composite (ECC); use of locally sourced aggregate proved big savings over straight silica sand, and all were substantially less expensive than polymer modified concrete for Nevada DOT bridge decks. CHARTS: Hajj, Sanders and Weitzel



Chloride ion penetration for MECC, polymer concrete and PCC mixes.

"MECC has many desirable properties that make it an ideal material for bridge deck overlays," the authors conclude. "However, this is based solely on laboratory test results. A full-scale trial MECC overlay is recommended to fully evaluate the short-term and long-term performance of MECC overlays to determine if MECC is suitable for replacement of the polymer concrete bridge deck overlays in Nevada."

Additionally, the development of a performance-based specification for MECC was recommended to allow for the use of a variety of aggregate sources and mix proportions. "An MECC specification will facilitate the implementation of MECC overlays in Nevada," Hajj, Sanders and Weitzel affirm.

SURFACE RESISTIVITY LOW-COST OPTION TO RAPID CHLORIDE TEST

Surface resistivity testing is a useful option to costly rapid chloride penetrability tests for concrete placement testing, say John T. Kevern, Ph.D., P.E., Ceki Halmen, Ph.D., P.E., University of Missouri-Kansas City; Dirk P. Hudson, E.I.T., ESI Contracting Corp., Kansas City, Mo.; and Brett Trautman, P.E., Missouri DOT, Jefferson City, in their 2016 TRB paper, *Evaluation of Surface Resistivity for Concrete Quality Assurance in Missouri.*

Concrete permeability is arguably the most important factor affecting the long-term durability of both plain and reinforced concrete structures, the authors say. As

DOTs and the Federal Highway Administration move toward end result and performance-based specifications, concrete permeability is becoming an increasingly important consideration, and is evaluated using the rapid chloride penetrability (RCP) test as a surrogate.

"The RCP test is a highly utilized method for evaluating and predicting concrete performance," Kevern, Halmen, Hudson and Trautman write. "However, the equipment necessary to run the test is expensive and testing requires significant personnel training and time-consuming sample preparation. While RCP has been an excellent measure of future concrete performance, the cost for equipment, manpower required to perform testing, and the duration of the testing limits the use of RCP testing for quality assurance in all but the most important projects."

In response, other researchers have investigated surface resistivity (SR) testing as an alternative to RCP testing. Louisiana has recently accepted surface resistivity testing to be used as a quality control tool. There, researchers predicted over $1.5 million in savings per year by using surface resistivity in place of rapid chloride penetrability testing. That's because surface resistivity testing equipment is relatively inexpensive (under $5,000), does not require consumable items, requires little training, has been shown highly repeatable, and is non-destructive.

Although the Missouri Department of Transportation currently performs little RCP testing, this study was initiated because of the potential for improved concrete performance and data for decision making without impacting cost. Kevern, Halmen, Hudson and Trautman evaluated a series of agency concrete mixtures to verify relationships between surface resistivity, rapid chloride penetrability, and the AASHTO penetrability classes. Eleven mixtures were produced in the lab, which represent a range of currently allowable mixtures, and several mixtures with potential for the future. Classes of concrete mixtures included paving, bridge deck, structural and repair.

Results showed excellent correlation between SR and RCP, which matched existing relationships provided by AASHTO and other state DOTs. The structural mixture containing 50 percent Class F fly ash had the best performance with "very low" chloride ion penetrability at 90 days. A ternary paving mixture with 20 percent Class C fly ash and 30 percent slag replacement for cement also demonstrated low penetrability as well as high compressive strength with an average value of over 9,000 psi at 90 days.

The two repair mixtures showed moderate to low penetrability readings and high early strength consistent with their desired purpose. The extensive amount of surface resistivity testing (> 4,500 tests) on 14 concrete mixtures at ages from three hours to 90 days using multiple labs, equipment, operators and curing conditions has verified RCP.

"Surface resistivity presents an opportunity to improve MoDOT concrete mixtures and specifications to increase durability without adding significant additional testing costs," the authors conclude.