By Tom Kuennen, Contributing Editor

In daylight, lighted pavement markers *resemble raised pavement markers as they define the adjacent three left-turn lanes in Sugar Land, Tex.*

At night, lighted pavement markers *provide positive guidance to drivers in the three adjacent left-turn lanes, reducing errors and lane-keeping violations.*

Photos courtesy of Stevens, Tydlacka, Voight and Worley

Research that could change The Way We Work

Some top picks from Transportation Research Board's papers presented at its 90th annual meeting in D.C.

It is always a meeting filled with new ideas and stunning research breakthroughs in the transportation industry. This year was no exception. A lot of the research stood out. We have assembled this selection based on space and the works' potential value to readers.

Eurostyle wet-on-wet, two-lift PCC/PCC paving was tested in 2010 at the Minnesota Road Research Project (MnROAD), the world's largest and most comprehensive outdoor pavement laboratory. This paving technique was discussed on these pages in 2008 (see *Roadbuilders to Get Fresh Look at Two-Lift Concrete Paving,* June 2008, pp. 22-29).

Now we know more about PCC/PCC paving in the United States. In a paper at the 90th annual meeting of the Transportation Research Board in Washington, D.C., held this January, research at MnROAD demonstrated that two-lift, PCC/PCC paving has potential benefits in terms of durability, and can be executed with existing concrete production and paving infrastructure in this country, but glitches must be resolved.

That paper was one of more than 4,000 scheduled presentations and peer-reviewed papers on every facet of multimodal transportation construction, materials, policy and operations presented at the TRB meeting, and *Better Roads* was there.

Following is a brief wrap-up of

Dynamic message sign installed 900 feet ahead of intersection *displays allow travel movements for the three left-turn lanes, and alternate message reminding drivers to stay in their lane.*

Photo courtesy of Stevens, Tydlacka, Voight and Worley

some of the most interesting research for the readers of *Better Roads*. For more information, visit www.trb.org.

MnROAD Examines Two-Lift PCC/PCC Slipform Paving

Two-lift PCC/PCC paving will work in the United States, but practical issues will have to be worked out, say Derek Tompkins, associate director, Pavement Research Institute, University of Minnesota-Minneapolis; Mary Vancura, research associate, University of Minnesota; Shreenath Rao, senior engineer, Applied Research Associates, Champaign, Ill.; Lev Khazanovich, associate professor, Department of Civil Engineering, University of Minnesota; and Michael I. Darter, principal engineer, Applied Research Associates, in their paper, *Construction of Sustainable Pavements: Two-Layer Concrete Pavements at the MnROAD Facility.*

"Recent efforts under the Strategic Highway Research Program (SHRP 2) project R21, *Composite Pavements*, led to the design and construction of composite portland cement concrete pavement sections at the Minnesota road research facility," the authors write. Part of the R21 work includes research into a composite pavement system featuring a thin portland cement concrete (PCC) layer immediately placed over another PCC layer.

"The goals of that research," they write, "were to determine the behavior and identify critical material and performance parameters for PCC/PCC; develop and validate performance models and design procedures consistent with the *Mechanistic-Empirical Pavement Design Guide;* and recommend specifications, construction techniques and quality management procedures."

To that end, construction of PCC/PCC test sections took place over three days of paving, for a full-scale, 200-foot-long demonstration slab, and two full-scale, two-lane 500-foot-long sections along I-94 at MnROAD.

Exposed Aggregate Surface

PCC on PCC sections to be constructed at MnROAD were designed to feature a 3-inch, high-quality exposed aggregate concrete (EAC) PCC lift over a 6-inch "low-cost" or recycled concrete aggregate (RCA) PCC lower lift. The term "low-cost" signifies that the PCC design was such that the lowest possible amount of cement and most inexpensive coarse aggregates were used by the contractor, and this reflects European practice.

The upper layer was specified to be placed between 15 and 90 minutes after the placement of the lower layer. This specification was in response to concerns of German and Austrian consultants to the R21 project and observations collected on a R21 scanning tour of European composite pavements.

"The general consensus among the research team was that the placement of the second lift – as soon after the first lift as possible – was important to eliminating problems that might be associated with the heterogeneity of the two concretes in the PCC/PCC pavement," they state.

These problems include differential shrinkage, different rates of hydration, and the compound problem of bonding at the interface of the two PCCs. While the use of two pavers was an initial step to meeting this specification, there were other logistics that needed to be fulfilled to ensure the lifts were placed within a maximum of 90 minutes of one another, they say.

The R21 project included embedding thermocouples, moisture sensors, dynamic strain gauges, and vibrating wire strain gauges in the MnROAD sections. This effort involved considerable efforts in the installation, documentation and activation of these sensors before, during and after construction, the authors write.

Many members of the R21 project team had reservations over the use of alternatives to more conventional materials as constituents in the concrete for the lower lift of the PCC on PCC pavement, they say. These alternatives included the replacement of 50 percent of the coarse aggregate with the RCA, and the replacement of 60 percent of portland cement with a supplementary cementitious material (SCM).

While the paving operation planned to use two pavers in a manner similar to the European methods, the MnROAD construction was to use one batching plant and not two. The use of one ready-mix plant was immediately recognized as a challenge to the project, both in terms of maintaining a consistent mix in alternating between batches and in terms of delivering both the upper and lower concrete mixes in a timely fashion.

"The R21 project elected to use an exposed aggregate concrete surfacing for the demonstration slab and mainline sections," the authors write. "One initial problem that the project team resolved was the specified gradation curve for the PCC mix to be used for the upper lift. The challenge was achieving a gradation curve that attempted to meet the EAC standard observed by the R21 team in Europe, yet was within the means of the contractor and its ready-mix supplier."

Paving at MnROAD began last April 28, with the construction of a 200-foot demonstration slab, and concluded on May 10 with the completion of 1,000 feet total of test sections along the mainline I-94 test area, say Tompkins, Vancura, Rao, Khazanovich and Darter. The two-lift paving used two GOMACO model GHP-2800

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A paving train constructing R21 research sections along I-94 at MnROAD: *From the left, a mixer truck, first paver, material transfer device and second paver.* *Photo courtesy of Tompkins, Vancura, Rao, Khazanovich, Darter*

pavers and a material transfer device spaced between the two pavers, to place fresh mix for the upper lift.

The pavement design included 1.25-inch dowels, placed at the mid-depth of the full slab using dowel baskets, they say. Furthermore, the design included 0.5-inch tie bars to reinforce longitudinal joints, which the project contractor accommodated through the use of a tie-bar inserter attachment on the first paver.

One difference in the use of two pavers in PCC/PCC versus single-layer PCC is that the upper lift paver was adjusted to "crown" the lower lift slab by 0.75 inch on each side, that is, the second paver paved a lift 1.5 inches wider than the first paver in the train.

The only complications in the paving itself were those brought about by delays in the delivery of PCC for the two lifts. While the construction specifications indicated that paving of the second lift was to occur no later than 90 minutes after the first lift, on all three occasions of PCC/PCC paving at MnROAD, the paving was frequently stalled for more than 90 minutes while waiting on batched upper lift PCC to arrive. Delivery delays led to 90- to 100-foot stretches of the placed lower lift being exposed to the environment for more than 120 minutes before the second lift was placed.

Challenging Concrete

One of the most challenging aspects of the R21 PCC/PCC sections was the concrete itself. This challenge presented itself, they say, in:

- the development of a mix design that uses alternative materials and/or meets "low-cost" specifications; and
- the logistics behind batching and delivering concrete to meet the demands of the paving operations.

The most conventional of the three mixes was the EAC mix used for the upper lift, whereas the PCC used for the lower lifts presented challenges to the project in its use of high fractions of fly ash and/or RCA. The specification for up to 60 percent fly ash in the lower-lift PCC was inspired by the high fraction of SCM replacement in the new St. Anthony Falls (I-35W) bridge in Minneapolis, which used as much as 81 percent SCM replacement.

As is the practice in Europe, the lower lift was viewed as an opportunity to use a lower-quality aggregate that would normally not be used for PCC paving. The team concluded that RCA was a viable coarse aggregate for the lower lift PCC – provided the RCA came from a known source, fines were excluded, and the stockpile was properly maintained (i.e., kept saturated to eliminate variable absorption as a concern).

The MnROAD R21 paving revealed a larger problem for the concrete in terms of consistency from batch to batch. "The challenge of providing a consistent batch from truck to truck was thought to be overcome after the demonstration slab," the authors write. "However, paving on the mainline again suffered from the consistency problem, particularly in the case of the lower mixes, whose as-delivered slump oscillated between 0.25 and 2.75 inches (the target slump was 1 inch)."

Why the inconsistency? "The ready-mix supplier used by the contractor did not frequently design concretes using a large fraction of fly ash," they say. "As a result, it is very possible that the ready-mix supplier's inexperience in fly ash led to the mix designs being inadequately composed to handle such large amounts of this SCM (in terms of water demands, admixtures, so on)."

Furthermore, they write, the use of RCA required close attention. "The contractor had secured RCA of a known source and had washed the RCA of fines; however, the preparation of the RCA for batching – most notably, its degree of saturation – was not consistent," they say. "One explanation of the inconsistency from batch to batch, as evident in the variable slump, is the inadequate maintenance of the RCA stockpile. It is possible that the stockpile had been allowed to dry."

Problems aside, their overall impression was that PCC/PCC paving can be conducted in the United States using the existing infrastructure for conventional single-lift paving. "Furthermore,

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EAC mix *is placed in front of the second paver onsite at MnROAD, using a GOMACO GHP-2800 concrete paver model.*

Photo courtesy of Tompkins, Vancura, Rao, Khazanovich, Darter

many of the complications in the construction were foreseen in the preliminary work leading up to construction: for instance, the challenge of the mix designs, the use of a single ready-mix batching plant, or the need to understand EAC brushing," say Tompkins, Vancura, Rao, Khazanovich and Darter.

"First, the use of a single batching plant for the production of two distinct mixes was not viewed as a major obstacle if conducted differently," they write. "The mix designs, and difficulties with the subcontractor for the concrete, could be traced directly to logistics and planning more than the fundamental need for two distinct batching plants."

Lighted-Pavement Markers Provide Positive Guidance

Lighted pavement markers appear to reduce lane-keeping violations and illegal movements in three adjacent left-turn lanes, say Roma G. Stevens, P.E., and Jonathan Tydlacka, P.E., assistant research engineers, and Anthony P. Voigt, P.E., research engineer, Texas Transportation Institute; and David C. Worley, P.E., assistant public works director, City of Sugar Land, Tex., in their paper, *Evaluation of a Lighted-Pavement Marking System for Lane Delineation.*

The lighted pavement markers (LPMs) were used to delineate a triple left-turn movement at a signalized diamond intersection in Sugar Land. The lighted pavement markers are activated at the beginning of the green traffic signal indication for the triple left-turn movement, and the markers stay on until the end of the yellow signal indication.

The intended impact of the pavement markers is to provide positive guidance for lane keeping and reduce illegal movements and crashes on the intersection approach with the triple left-turn assignment. In addition, a dynamic message sign (DMS) is installed 900 feet ahead of the intersection, and its displays allowed travel movements for the three left-turn lanes and an alternate message reminding drivers to stay in their lane.

An evaluation study was conducted with and without the LPMs operating to compare traffic volumes, lane changes, lane-keeping violations and illegal movements between the two study periods (LPM ON and LPM OFF).

"During the LPM ON period, the lighted pavement marker system was in place and active, and during the LPM OFF period, the lighted pavement marker system was in place but was inactive," say Stevens, Tydlacka, Voigt and Worley. "The DMS stayed active during both study periods. It was determined that the lighted pavement markers appeared to reduce lane-keeping violations and illegal movements. Furthermore, a comparison of six months before and six months after crash data showed some positive results, but due to the small time increment, no statistically significant conclusions could be made."

The interchange of U.S. 59 at State Highway (SH) 6 in Sugar Land experiences high demand during the peak hours, especially high-directional turning movements from the U.S. 59 southbound (SB) frontage road to SH 6 SB. "The design of the U.S. 59 SB approach was signed and marked to allow two lanes to turn left to the south on SH 6 (one dedicated left-turn only lane and one shared left through lane)," they write. "However, traffic demand for this movement is such that at least two dedicated lanes for left turns are needed during peak hours, with three turn lanes recommended to provide optimal traffic signal operations."

The City of Sugar Land identified the triple left-turn concept as a potentially beneficial treatment for the left-turn movement from the U.S. 59 SB approach. But triple left-turn operations are not commonly encountered by motorists, so the city planned to provide multiple means of motorist guidance (i.e., signing and marking) to ensure safe operation.

The triple left-turn operation for U.S. 59 SB at SH 6 in Sugar Land began on Nov. 20, 2009, and the LPM system was activated at the same time. The LPMs were installed along the painted dashed lane line tracks along the curve between the left-turn lane on the far left and the middle left-turn lane, as well as between the middle left-turn lane and the far right left-turn lane.

"Each marker emits a white light from multiple light-emitting diodes, and the LPM system is operated 24 hours a day

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in a steady-burn mode during every traffic signal cycle," say Stevens, Tydlacka, Voight and Worley. The steady burn pattern mimics the appearance of standard raised pavement markers.

For each cycle, the markers are activated at the beginning of the green traffic signal indication for the U.S. 59 SB movements, and the markers stay on until the end of the yellow signal indication.

Video was recorded with and without the LPMs operating to compare traffic volumes, lane changes, lane-keeping violations and illegal movements between the two periods of recording (LPM ON and LPM OFF). In addition, crash data for a before and an after period were compared to assess the safety effects of LPM system.

Findings of the study include:

- A comparison of the traffic volumes between LPM ON and LPM OFF showed similar traffic volumes and turning movements for both periods. Furthermore, the percentage of left turns in each lane remained similar between both periods.
- A comparison of lane-keeping violations showed a statistically significant increase in the number of drivers who drove on or over the left lane lines during the LPM OFF period, as compared to the data observed during LPM ON. This indicates that the LPMs may help drivers navigate the left turns better and stay in the designated lanes.
- A comparison of illegal movements showed that there were six through movements from lane three when the LPMs were not active, and only one when the LPMs were active, indicating that the LPMs may help reduce the number of illegal through movements from a left-turn only lane.
- Based upon review of the video data collected for this study, the LPMs do not appear to be causing any unintended consequences of either safety or operational concern.

TRB researchers articulate means to process hog wastes from manure lagoons *into bio-binder suitable for use with liquid asphalt in HMA or crack sealants.*

Hog Wastes Can Be Processed into Binder for Hot-Mix Asphalt

Hog slaughterhouses say they use every part of the pig but the squeal. But new research at TRB indicates there also may be able to use what comes out of the hog as a binder in hot-mix asphalt pavements.

It's no laughing matter, because while society benefits from the low pork prices that humane factory farming brings, the manure lagoons used to receive tons of waste are unwelcome additions to the landscape, even in rural locations.

But a thermochemical liquefaction process can convert that swine manure to bio-binder, which can reduce the amount of liquid asphalt in HMA, say Elham (Ellie) H. Fini, assistant professor of civil engineering, North Carolina A&T State University, Greensboro; Eric W. Kalberer, lead scientist, Western Research Institute, Laramie, Wyo.; and Ghasem Shahbazi, professor and director of the Biological Engineering Program, Department of Natural Resources and Environmental Design, North Carolina A&T State University-Greensboro, in their paper, *Application of Bio-Binder from Swine Manure in Asphalt Binder.*

The process also can sequester carbon and greenhouse gases otherwise released into the atmosphere from manure decomposition in lagoons.

"The conversion process reforms the organic matter in swine manure into oil with heat and pressure in an anoxic [devoid of oxygen], aqueous environment," the authors say. "The product oil consists of mainly asphaltenes and resins. The specific gravity is around 1.01 (similar to that of petroleum asphalt binder, 1.03) with a boiling point of 300 degrees C and sulfur content of about 0.6 percent."

As the chemical composition of bio-oil from swine manure is similar to that of petroleum, it is a promising candidate for the production of a bio-binder to be used in asphalt pavement, Fini, Kalberer and Shahbazi write. "To produce a bio-binder for use in asphalt pavement and as a crack sealant, the material should be engineered with the specific rheological and interfacial properties that are desirable for each application," they state.

For instance, adhesives used in pavements and crack sealers require adequate creep and relaxation characteristics (to release stresses developed due to thermal and traffic loading) to be able to resist cracking, they say. In addition, because asphalt pavements are exposed

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to varied and extreme environmental conditions, a bio-binder's resistance to aging and oxidation – as well as the corresponding temperature sensitivity and water susceptibility – will affect its performance.

Their paper presents the chemical and rheological characteristics of a biobinder and compares them with a typical bituminous binder. The authors found that the use of bio-binder from swine manure as a partial replacement for liquid-petroleum asphalt would enhance the asphalt binder's rheological properties to provide better performance.

"Application of bio-binder in an asphalt mixture can allow for reduced mixing and compaction temperatures and enhanced workability," they say. "This reduces fuel consumption and resultant CO_2 emissions during plant production and pavement placement. Furthermore, bio-binder could enhance mixture workability to facilitate the production of high-RAP (reclaimed asphalt pavement) mixtures at lower temperatures with [warm mix asphalt] technologies."

Use of this bio-binder should also reduce the cost of pavement construction due to its relatively low cost (50 cents per gallon), and reduce carbon emissions related to land application and storage of manure, they conclude. "Furthermore, it will minimize the pollution caused by odor and spillage from manure storage lagoons through reduced need for manure disposal," they write. "Lastly, it provides potential sources of additional income for farmers through reducing the risk of unexpected spillage from lagoons, from marketing of the bio-binder, additional nutrient value in fertilizer, and potential carbon credits."

Cold-in-Place Recycling Performance Benefits from Strong Foundation

Counter-intuitively, performance of cold-in-place recycled (CIR) pavements in New York State appears to be longest for highways carrying heavy traffic loads, compared to the low-volume rural roads it's typically used for, say Warren H. Chesner, Ph.D., P.E., Christopher W. Stein, Henry G. Justus and Edward R. Kearney, Chesner Engineering, P.C., Long Beach, N.Y.; and Stephen A. Cross, Ph.D., P.E., professor, School of Civil and Environmental Engineering, Oklahoma State University-Stillwater, in their paper, *Evaluation of Factors Affecting the Long Term Performance of Cold In-Place Recycled Pavements in New York State*.

As described two months ago in these pages (see *Hot, Cold and Green (and the 3Es)*, February 2011, pp. 20-29 or on our website at www.betterroads.com), cold-in-place recycling is an onsite recycling process in which an asphalt pavement with structural failures is reconstructed using 100 percent RAP to a typical treatment depth of 2 to 6 inches, using a mobile train of equipment that may include tanker trucks, a milling machine, crushing and screening equipment, a mixer, binder rejuvenating additives and a paver.

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With CIR, existing pavement materials are removed, crushed, sized (if needed) and rejuvenated with a recycling agent. Its benefits include major pavement structural improvement via overhaul of the existing pavement materials, and CIR can cure most types of pavement distress. As with hot-in-place recycling, material hauling costs are minimized, while the blue smoke associated with HIR is eliminated.

In New York State's Catskill Mountains, *an Ulster County road is cold-in-place recycled using foamed asphalt. New research indicates 11-year life extension for CIR pavements, even longer for high-level pavements with high annual average daily traffic.*

"Foamed" or "expanded" asphalt is a type of CIR recycle or full-depth reclamation – depending on depth – in which hot performance-grade asphalt is foamed with water and air, and is injected into reclaimed materials and aggregate in a mixing chamber of a mobile unit or stationary plant, and offers a cost-effective option for FDR.

"In New York State, cold-in-place recycling (CIPR used by authors) is one of a series of asphalt pavement rehabilitation options designed to extend the service life of pavements," the authors write. "Recycling pavements using CIPR has the potential to decrease energy consumption, and reduce the environmental burden and cost associated with asphalt pavement rehabilitation."

However, one of the drawbacks to increased CIPR usage has been uncertainty about expected service life and factors that affect long-term CIPR performance, they say. "These uncertainties generally limit the use of CIPR to low-volume pavements to minimize the exposure of CIPR-rehabilitated pavements to aggressive traffic conditions," they add. Thus they studied the effect of daily traffic, truck traffic, base thickness, base plus subbase thickness (total pavement thickness), geographical pavement location (environment and climate) and the condition of the pavement prior to CIPR rehabilitation on service life of CIPR pavements in New York State.

Data used in the analysis were compiled from the 2008 New York State DOT *Pavement Management Group Highway Sufficiency Ratings Database*, which represented 163 CIPR projects covering a pavement distance of 756 miles.

"It was determined that CIPR rehabilitated pavements can be expected to increase the service life of pavements on average approximately 11 years, and that when CIPR is used on higher-trafficked (better designed) pavements that have thicker supporting bases and subbases, CIPR performance will benefit and the service life of the pavement will be extended," the authors write.

Chesner, Stein, Justus, Kearney and Cross find:

- On average, CIPR can be expected to increase the service life of rehabilitated pavements by approximately 11 years.
- Pavements constructed with thicker pavement base, base plus subbase and total pavement thickness exhibit longer CIPR service lives.
- Pavements subjected to higher average annual daily traffic (AADT) and higher truck traffic – due in great part to the thicker pavement base associated with higher-trafficked pavements – exhibit longer service lives than pavements with lower AADT and lower truck traffic.
- The environment and climate for CIPR-rehabilitated pavements examined in this study did not significantly affect the expected service life of the pavement.
- And the service life of pavements that were rehabilitated with CIPR *prior* to severe pavement deterioration were approximately 50 percent longer than those pavements rehabilitated with CIPR *after* severe pavement deterioration.

From this, they conclude:

On the basis of the CIPR service life projection analysis, CIPR-rehabilitated pavements can be expected to increase the service life of pavements on average approximately 11 years; however:

- When CIPR is used on better-designed pavements that have thicker supporting bases and subbases, CIPR performance will benefit and the service life of the pavement will be extended. This could significantly expand the locations that CIPR can be employed.
- When CIPR is used on poorly supported pavements the service life of the pavement, can be expected to decrease.
- When pavement rehabilitation is implemented prior to severe pavement deterioration, the service life of the pavement can be expected to increase.
- And a general policy of employing CIPR as a rehabilitation strategy on low AADT and lightly traveled pavements with low truck traffic may be misleading. The data generated in the CIPR service life projection analysis tend to support the opposite conclusion. CIPR pavements last longer if applied on pavements with higher AADT and higher levels of truck traffic.

It is concluded, however, that the primary factor is not traffic but the pavement support structure. Higher trafficked pavements tend to be designed with greater base and subbase thickness, thereby providing enhanced support to the CIPR section, which increases the service life of the pavement.

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Flowable Fill for Pavement Repairs Can Cut Settling

Use of cement-based flowable fill for utility and pavement repairs provides a reliable patch that is placed more quickly and easily than conventional repairs involving packed aggregate and patch, say Jonathon R. Griffin and E. Ray Brown, U.S. Army Engineer Research and Development Center, in their paper, *Flowable Fill for Rapid Pavement Repair.*

"Federal, state and local highway authorities in the United States invested $3.9 billion in the rehabilitation of roughly 8,000 miles of pavement in 2008," the authors write. "This significant investment emphasizes the importance of ensuring that rehabilitation techniques perform well to help reduce the high annual cost for repairs."

Conventional repair of pavement base layers using compacted lifts of crushed aggregate requires specialized labor and equipment, contributes significantly to total construction time and is very difficult to perform, particularly in restricted access areas. This often results in a poorly constructed repair and loss in performance, they say. Adding flowable fill technology has shown some success when used for backfilling patches and utility cut repairs.

"Flowable fill is a viscous, grout-like material used in place of traditional compacted aggregate in backfilling operations," they say. "Flowable fill is also referred to as controlled low-strength material, controlled density fill, soil-cement slurry, soil-cement grout, unshrinkable fill and K-Krete."

Common applications of flowable fill include backfill, structural fill, pavement base, void fill, pipe bedding and in-closure projects for tanks, pipes and culverts, Griffin and Brown write. The material is commonly a blend of portland cement, fine aggregate, water and waste materials including fly ash, foundry sand and bottom ash. Chemical admixtures commonly used in PCC, such as air-entrainers, water reducers, set accelerators and retarders, can be used to modify the performance characteristics of flowable fill.

"The material is self-leveling, self-compacting and possesses other desirable properties, including flow under gravity, rapid hardening capability, strength selectability, material uniformity and reduced construction requirements," they say.

Griffin and Brown present the performance and cost advantages of using preblended flowable fill for rapid repair of damaged areas in highway and airfield pavements. Eleven commercially available flowable fill blends were evaluated using both laboratory and field testing methods. The laboratory evaluation consisted of standard material characterization, including compressive strength, flowability, hardening time and what they call "excavatability."

"Field testing included constructing- and trafficking-simulated utility cuts and full-depth patches in existing pavements," they write. "An examination of structural capacity, surface deformation and visible surface distress was conducted for each repair at regular traffic intervals. Additionally, construction time, difficulty and cost were compared to a traditional aggregate repair."

Testing results indicate that backfilling utilities and patches in pavements using flowable fill reduces the potential for premature failure, reduces construction time and reduces total project cost while increasing repair performance, they conclude.❖