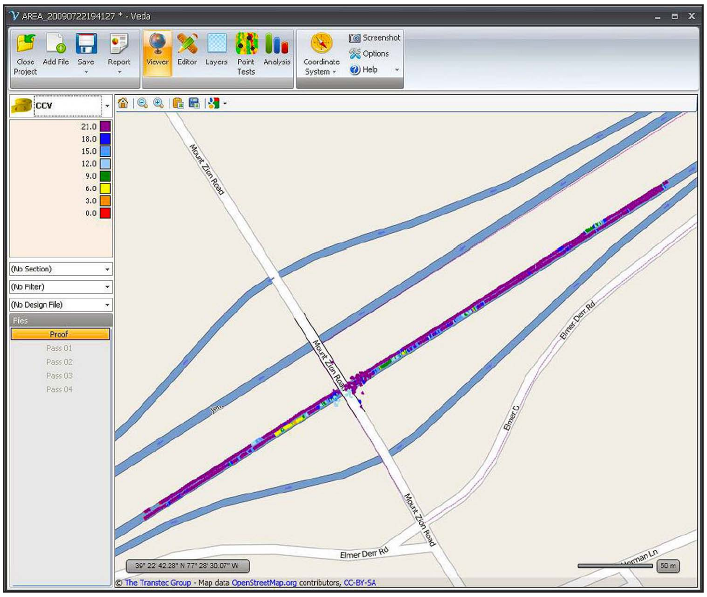
RoadScience

By Tom Kuennen, Contributing Editor

Photo courtesy of: Horan, Chang, Xu, Gallivan



Intelligent Compaction data may be viewed using overall project view, here viewed using Veda Software.

EUREKA!

Research that makes a difference.

Intelligent compaction ... application of reclaimed asphalt pavement (RAP) and recycled concrete aggregate (RCA) ... prefabricated bridges and pavements. They're just a few of the themes of research papers presented at the 91st Transportation Research Board meeting in Washington, D.C., Jan. 23-27.

For the first time, registration reached 12,000 at TRB (www.trb.org), where delegates faced more than 4,000 peer-reviewed technical papers or poster presentations on transportation design, planning, construction, materials and operations.

Better Roads was there, and reviewed some of the new research potentially of significant value to readers.

Smart Rolling

Increasing benefits of intelligent compaction

Intelligent compaction of asphalt pavements is a powerful tool available to highway agencies that will help them ensure quality control, according to Robert D. Horan, P.E., The Asphalt Institute; George K. Chang, Ph.D., P.E., Qinwu Xu, Transtec Group; and Victor L. Gallivan, P.E., Federal Highway Administration (FHWA), in their paper, *Improving Quality Control of Hot Mix Asphalt Paving Using Intelligent Compaction Technology*.

The authors posed the question "Can existing intelligent compaction (IC) technology be used in a practical way to improve the quality control (QC) process for hot-mix asphalt (HMA) paving projects?" To find out they investigated the use and benefits of IC technology for tandem-drum vibratory rollers used to construct HMA pavements.

The paper is based on the findings of the *Intelligent Compaction Pooled Fund* (ICPF) project that included 16 field demonstration projects in 12 participating states. "The ICPF projects were actual highway construction projects where various pavement materials were placed and compacted using both conventional compaction equipment, and rollers that were equipped with IC technology from various suppliers," they say. Ten of the projects included placement and compaction of HMA, with IC used for only a portion of the project.

The authors define QC as the responsibility of the producer/contractor for testing, inspection and oversight of all of the materials and processes involved in a project, with the goal of ensuring a quality product that meets the specifications.

"Intelligent Compaction is a maturing technology in the United States that provides beneficial QC tools during construction of HMA pavements," the authors write. "These tools offer unprecedented information and capabilities that could revolutionize the compaction industry."

Considered "intelligent" are tandem-drum rollers that are equipped with hardware such as an **accelerometer**, **global positioning system**, **temperature sensors**, an **onboard computer**, and software such as a **real-time reporting system**. Components of IC necessarily include **GPS technology**, **accelerometer-based measurement systems** and **temperature readings**.

"It is important to first have an understanding of the shortcomings of both the conventional compaction equipment and QC practices currently being used in order to comprehend the role that IC can take in improving QC of HMA paving," say Horan, Chang, Xu and Gallivan. "First, there are shortcomings in the conventional compaction process itself. Conventional compaction equipment does not allow for any, or very little, 'on the fly' feedback to project personnel."

Typically, using a standard vibratory roller, a fixed number of passes are applied to the material being compacted. The problem is that critical factors can vary during construction, including support from underlying materials, lift thickness, materials type and asphalt mat temperature, the authors write.

Photo courtesy of: BOMAG USA

On tandem asphalt roller, automatic mat temperature sensing system (AMTSS) data can be logged with roller speed and vibrations per minute; these data can be stored as to position on mat using GPS.

The changes in these critical factors are invisible to the roller operator during conventional compaction operations.

The result is that either too little or too much compaction effort may be applied to the pavement material, says the report. IC provides a better method because constant information is continually reported to the roller operator related to pass count, the in-place pavement material density levels, or other density-related properties such as material stiffness.

"The second major shortcoming of conventional compaction equipment is that over-compaction can easily occur, and actually reduce the density that has already been obtained with previous passes," the authors say. "Over-compaction occurs when pavement materials that are already adequately compacted have one or more additional passes of a vibratory roller. When this occurs, displacement of the material does not occur and the vibratory roller can enter into the undesirable 'double jump' mode where the roller is perceptively or imperceptibly bouncing on the pavement surface. This roller mode can be destructive to the pavement and actually cause a reduction in material density (and shear failure/dilation in soil materials)."

It's also possible to under-compact pavements, they say. "This occurs when insufficient compactive effort is applied," they write. "IC would provide a better method to help the roller operator avoid over-compaction (and under-compaction) by providing continual feedback that allows the operator to obtain the optimum number of roller passes. IC is able to address both shortcomings in current QC methods by providing the roller operator and QC personnel with access to unprecedented insight into the compaction process."

The paper was based on the new Intelligent Compaction Pooled Fund (ICPF) project, No. 954, *Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials*, completed July 2011.

The immediate benefits include:

- real-time feedback to the roller operator,
- permanent records of compaction data,
- statistical and geospatial analysis of IC data and mapping of underlying materials prior to paving/compaction.

New IC tools available to contractors and agencies include onboard, color-coded displays, capability to measure underlying material support prior to paving, and capability to collect data for statistical analysis of the effectiveness of compaction operations.

As part of the ICPF, a software program named *Veda* was developed that is designed to manage and evaluate IC data. "This software is a great first step in addressing one of the biggest barriers to IC implementation, which is a myriad of issues related to handling the massive amount of data produced during the compaction process," the authors say. "The Veda software is available to the public."

"This software is a great first step in addressing one of the biggest barriers to IC implementation."

A case study of the Wisconsin ICPF research was profiled to demonstrate how IC can improve QC of HMA paving. The project consisted of a two-lift HMA overlay on rubblized concrete pavements. Based on the ICPF findings, the authors concluded if IC had been used for the entire project, it could have:

- provided a tool to evaluate the concrete pavement rubbliza tion process while it was underway, including the optimum degree of rubblization;
- decreased variability in pavement density by improving the consistency of roller patterns during the HMA compaction operation by training the roller operator to use the onboard color-coded display; and
- provided an independent analysis (separate from agency requirements) of quality by using Veda software to perform a statistical analysis of IC data.
- The authors maintain barriers remain to full implementation of IC technology, including the:
- availability of equipment that meet the FHWA criteria of IC equipment, which includes GPS, intelligent compaction

measurement values and temperature measurement;
- complexity of data collection, management and analysis, including simplification, standardization of data, development of analysis software, and to training for field personnel; and
- acceptance by agencies and contractors to replace or augment existing QC practices.

Dust Buster

Among other things, RAP fights dust

Reclaimed-asphalt pavement (RAP) can be used to suppress dust on local roads, but even more cost-effective applications can be justified with a cost/benefit analysis of its use, say Burt Andreen and Harry Rocheville, University of Wyoming-Laramie, and Khaled Ksaibati, Ph.D., P.E., director, Wyoming T2 / LTAP, of the Department of Civil and Architectural Engineering, University of Wyoming, in their paper, *A Methodology for Cost/Benefit Analysis of Recycled Asphalt Pavement (RAP) in Various Highway Applications*.

The Wyoming T2/LTAP (Local/Tribal Technology Assistance Program) recently completed a study on the use of RAP in gravel roads, which explored RAP as a means of dust suppression while considering road serviceability. The study found that RAP in gravel roads reduces dust without affecting the serviceability of roadways. This has become more important as expanded oil and gas exploration in the state has put new stresses on unpaved roads.

Now, Wyoming DOT and local agencies need to determine – out of the many possible uses – which use of RAP is the most cost-efficient. In this study, the T2/LTAP evaluated three possible RAP uses: RAP in hot plant mix, RAP in base and RAP on gravel roads. Using a method developed by the National Asphalt Pavement Association (NAPA) entitled *Calculating the Value of Using Reclaimed Asphalt Pavement*, a system was devised to assess the costs and benefits of using RAP in hot plant mix, and a similar process was developed to evaluate the value of using RAP in gravel roads and bases.

"The system normalizes all of the costs and benefits into savings per ton of RAP as a means equal comparison," the authors write. "The method includes factors such as savings from dust loss, layer coefficients, haul and decreased need of virgin aggregates. A case study was then conducted using the three different applications. It was determined that using RAP in hot plant mix was the most cost effective in this case study. In addition, it was concluded that using RAP in gravel roads may be more cost-effective than using it in bases due to the additional benefit of dust loss reduction."

Following the economic analysis, the authors found:
- RAP can be a very effective material in highway construction applications. It is very economically feasible to use RAP because the recycled material greatly reduces the need for virgin aggregates, and does not decrease pavement performance.
- Added RAP significantly reduces the dust loss on gravel

Pervious portland cement concrete pavement permits down-drain of water, charging subsurface water supplies and keeping heavy metals from entering bodies of water.

roads from traveling vehicles.

- For every ton of RAP included in hot plant mix, $40.87 was saved. Also there were savings of $17.07 for every ton of RAP used in gravel roads.
- The implementation of RAP in road base also saved money, but it was the least effective of the three applications. For every ton of RAP used in road base, $15.71 was saved.
- This analysis shows that regardless of the construction use of RAP, a savings always is realized.

"Clearly, the application of RAP in highway construction is cost effective," the authors conclude. "The amount of savings can increase exponentially when large quantities are used and when a greater percentage of RAP is included," they say. "The use of RAP in any situation has no shortfalls; RAP saves money, does not impact performance, and has the ability to help the environment due to dust loss in gravel roads."

Pervious and RCA

Limits to recycled concrete aggregate in pervious concrete

Recycled concrete aggregate (RCA) can increase compressive strength of environmentally sustainable pervious concrete, but there's a limit to how much can be used in place of virgin coarse aggregates, say Bradford M. Berry, Mark J. Suozzo, Ian A. Anderson, and Mandar M. Dewoolkar, The University of Vermont, in their paper, *Properties of Pervious Concrete Incorporating Recycled Concrete Aggregate.*

Their work investigates using RCA in pervious concrete, specifically the effects on the density, strength and permeability. Cylindrical specimens of pervious concrete with different percentages of RCA and conventional aggregate were cast. The coarse aggregate was substituted with 0, 10, 20, 30, 50 and 100 percent RCA. As percent RCA increased, both compressive strength and permeability generally decreased.

The strength and hydraulic characteristics of mixes examined in this study compared generally well with other studies, on pervious concrete without RCA, found in the literature. The results indicate that up to 50 percent substitution of coarse aggregate can be used in pervious concrete without compromising strength and hydraulic conductivity significantly. Further testing evaluating freeze-thaw durability is necessary if pervious concrete with RCA is to be used in cold weather climates.

Conventional paving surfaces prevent water from entering the subsoil beneath them. "These impervious surfaces increase runoff, cause flooding and contribute to siltation and other water pollution," the authors say. "Pervious surfaces allow stormwater to infiltrate into the ground, recharging the water table, and thus reduce the amount of runoff. This reduction in stormwater runoff also lessens resulting environmental pollution. For these reasons the use of pervious concrete is among the *Best Management Practices* recommended by the Environmental Protection Agency."

Ready-mix concrete is normally specified in accordance with the requirements of ASTM C94, *Standard Specifications for Ready-Mixed Concrete,* they say. For concrete in parking areas, a minimum compressive strength of 24 MPa (3,500 psi) is recommended; however, in areas where freeze-thaw durability is a concern, a minimum compressive strength of 28 MPa (4,000 psi) is advised. But typical pervious concrete mixtures can develop compressive strengths in the range of 3 to 28 MPa (500 to 4,000 psi).

For this reason, pervious concrete is generally limited to low-traffic areas where reduced compressive strength is often acceptable. Applications include parking lots, bike paths and pedestrian footpaths.

"The ecological benefits of pervious concrete can be taken a step further by incorporating recycled-concrete aggregate (RCA) into the mix design," the authors write. "Concrete recycling has gained importance because it minimizes the need for disposal by reducing dumping at landfills and it protects the natural environment by reducing gravel mining of virgin aggregate."

"The ecological benefits of pervious concrete can be taken a step further by incorporating recycled-concrete aggregate (RCA) into the mix design,"

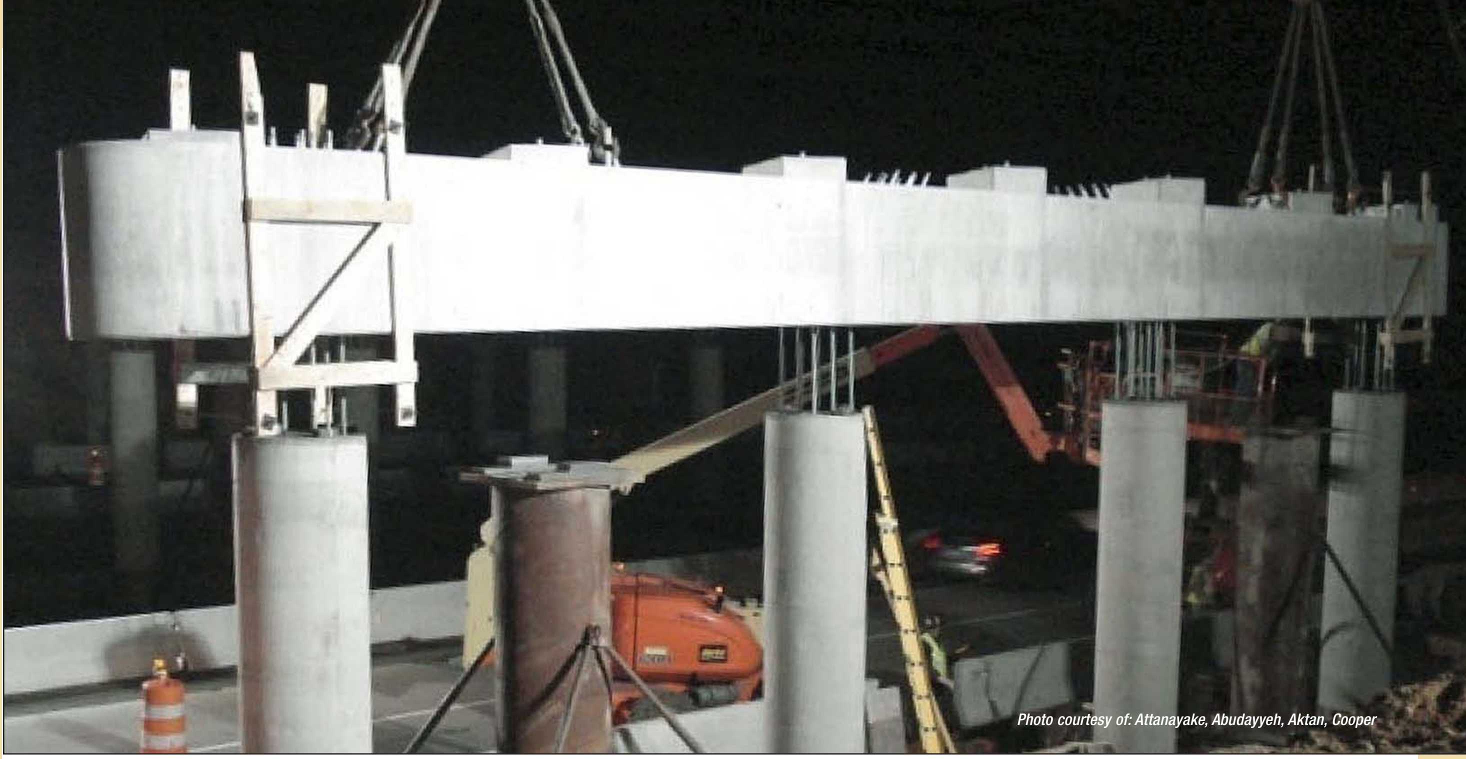
The U.S. DOT reports that 38 states use RCA as an aggregate base and 11 states recycle concrete into new portland cement concrete. The states that do use recycled concrete as an aggregate source for new concrete report that concrete with RCA has performed as well as concrete with virgin aggregates. Additionally, the quality of concrete with RCA depends on the quality of the recycled material used.

"From an environmental and economic standpoint, the optimum RCA content replacement of virgin aggregates will be 100 percent," they say. "It is likely RCA will not be able to replace virgin aggregate completely unless the minimum compressive strength and hydraulic conductivity criteria are met. Recycled concrete aggregates contain not only the original aggregates, but also low-density, hydrated cement paste, resulting in lower density compared to virgin aggregate."

This lab study examines some of the effects of incorporating varying amounts of RCA on the strength and hydraulic properties of pervious concrete. The experiments include compressive strength and hydraulic conductivity testing on specimens of varying mix designs substituting coarse aggregate with RCA, ranging from 0 to 100 percent.

The researchers conclude:

- Density values are generally similar with increasing RCA content; however, 100 percent replacement of RCA results in lower density values. There are several factors, including differing aggregate densities and angularities that could be the cause of this difference.
- Increasing RCA generally decreases compressive strength, with 100 percent RCA content still providing strength values above 10 MPa (1,400 psi).
- Hydraulic conductivity measurements indicate that increasing RCA content decreases hydraulic conductivity. Nonetheless, all mixes yielded acceptable



In Michigan, precast pier cap is placed on precast piers mounted on cast-in-place footing.

hydraulic conductivity.

- Angularity of the RCA likely results in a more inefficient distribution of pore spaces, resulting in fewer pore spaces for water to flow.

"The relationship of compressive strength to hydraulic conductivity showed that pervious concrete with RCA display a similar relationship to pervious concrete with conventional aggregates, and falls within an expectable range to be considered an adequate substitute," the authors say. "Based on the results of this study, the particular RCA can be substituted up to 50 percent and provide strength and hydraulic conductivity values similar to the control mix design."

Easy as ABC

Lessons from Michigan's first fully prefab bridge

There are lessons to be learned from construction of Michigan DOT's first fully prefabricated bridge that followed accelerated bridge construction (ABC) principles, according to Upul Attanayake, Ph.D., P.E., Osama Abudayyeh, Ph.D., P.E., Haluk Aktan, Ph.D., P.E., Western Michigan University Department of Civil and Construction Engineering, and Janine Cooper, P.E., Michigan DOT, in their paper, *The First Fully Prefabricated Bridge System in Michigan: Observations and Recommendations*.

"Implementation of accelerated bridge construction technologies and structural systems is gaining momentum as the bridge community is educated through workshops and demonstration projects," the authors say, adding that component tolerances are critical when using prefabricated components. (Also see *"Speeding Uptime: the Multiple Values of Accelerated Bridge Construction," Better Roads*, December 2011, pp. 28-37).

After many years of service, the Parkview Bridge over U.S. 131 in southwest Michigan needed a major repair or a complete replacement. A decision was made to replace the existing bridge using rapid bridge construction techniques.

The replacement bridge was designed to have a 23-degree skew with four spans to carry three lanes of traffic, the authors write. All the major bridge elements including piers, abutments, I-girders and full-depth deck panels were prefabricated off-site. The superstructure is composed of PC-I Type III AASHTO girders, and the deck is composed of forty-eight 9-inch-thick, partial-width, precast reinforced concrete panels.

Precast girders were pre-tensioned and flared coil inserts were embedded in their top flanges, used to insert shear studs that facilitate girder-deck connection through shear pockets. Once the north and south panels were installed onsite, they were connected transversely using a reinforced cast-in-place closure.

"The north and south panels were cast to different widths; thus, the closure was about 5-feet offset from the bridge centerline," Attanayake, Abudayyeh, Aktan and Cooper say. "Transverse connection between full-depth deck panels was established using grouted shear keys and longitudinal post-tension. The special provisions required the use of nonshrink grout."

In the substructure, each abutment consists of two precast stems, they wrote. The stem splice was formed using cast-in-place concrete. Each abutment is supported on 16 H-piles. The plans specified placing of precast abutment on the grade level, maintaining pile embedment of 2.5 feet and filling the pile sleeve with grout. Each pier consists of four precast concrete columns that are mounted on a cast-in-place footing. The design specified connecting the pier columns to the footing using square pockets casted in the footing. The pier columns support a precast pier cap.

Special provisions to implement this new technology were prepared by Michigan DOT and were supplied to the contractor.

"Precast full-depth deck panels were placed in four days," they write. "After placing the panels on the girders, longitudinal post-tensioning duct misalignment was noticed. This was due to a calculation error by the contractor during the prefabrication process. Bridge owner, design engineers and the contractor explored all potential solutions to salvage some or all of the deck panels that were already placed on the girders. Several options were considered, however, the contractor chose to re-cast the deck panels after accurately incorporating the skew in the calculations. The 'cast-match' technique was used to ensure the correct alignment of post-tensioning ducts."

Promoting the prefabrication at the jobsite or at a nearby location owned by the department may reduce construction costs and can minimize the impact of load restrictions, say Attanayake, Abudayyeh, Aktan and Cooper. However, setting up a certified plant at or near the site for a small bridge can be costly.

"Casting of large components such as abutment stems, pier columns and pier caps can be an option due to their weight and less-complicated details," they add. "Fabrication of circular columns requires vertical formwork while pouring concrete and curing. Columns with rectangular section can make the fabrication process easier, hence allowing onsite production. Language should be considered in the special provisions to complete prefabrication of components before demolition of the existing structure."

Precast Slabs on I-66

A Virgina Interstate test and comparison to CIP

Both standard precast and precast, prestressed pavement slabs are performing in a high-level Interstate highway installation, say M. Shabbir Hossain, Ph.D., P.E., and Celik Ozyildirim, Ph.D., P.E., Virginia Center for Transportation Innovation & Research, Charlottesville, Va., in their paper, *Precast Concrete Pavement on I-66 in Virginia*.

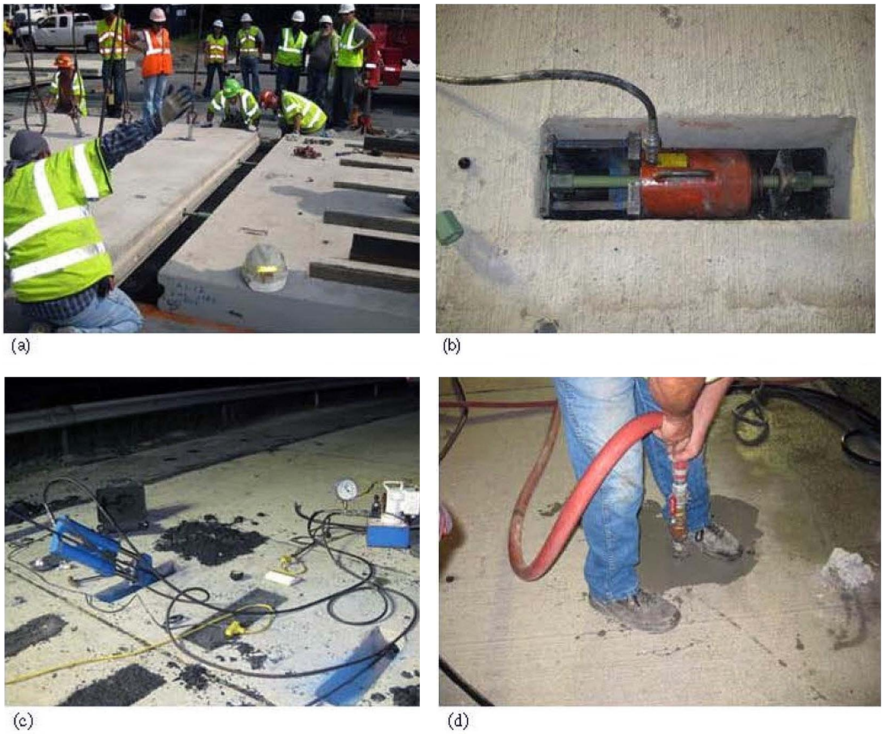
"To expedite construction and reduce the associated traffic delay and provide longevity, precast concrete slabs have been used for more than 10 years with successive improvements in processes and systems," the authors write. "The Virginia DOT has recently tried two precast systems along with conventional cast-in-place repairs on I-66 near Washington, D.C."

There, the existing pavement was jointed, reinforced-concrete pavement. One precast system used reinforced slabs with doweled joints and is called Precast Concrete Pavement (PCP). The other system used transversely prestressed slabs, post-tensioned in the longitudinal direction, and is called Prestressed Precast Concrete Pavement (PPCP).

Three different mixtures were used for the CIP patches, PCP panels and PPCP panels, with varying cement contents of 846, 518 and 602 lb./cu. yd., respectively, and water/cement ratios of 0.32, 0.34 and 0.36, respectively, they report. PCP panel mixtures used 172 lb./cu. yd. of slag, and PPCP panel mixtures had 150 lb./cu. yd. of Class F fly ash. Cast-in-place cylinders were cured using a standard wet cure, but the cylinders for both precast systems were cured using radiant heat.

Concrete placed in both precast systems exhibited satisfac-

Photo courtesy of: Hossain and Ozyildirim



Precast concrete panel installation on Virginia's I-66: (a) slab alignment, (b) temporary post-tensioning of threaded bars, (c) permanent post-tensioning, and (d) grouting operation

> "Both the PCP and PPCP systems are performing satisfactorily after one year of traffic and the contractor was also satisfied with the constructability."

tory workability, air content and strength, Hossain and Ozyildirim say. All 15 batches of cast-in-place concrete achieved required 2,000-psi compressive strength in four hours, except one batch that reached 1,990 psi.

The cementitious materials for the PCP system contained 25-percent slag cement and had a low w/cm, leading to low permeability values that averaged 1,493 coulombs, they write. The compressive strengths were higher than the 4,000 psi design strength at both the seven and 28 days. Compressive strength requirements for PPCP systems were 3,500 psi for detensioning and 5,000 psi at 28 days. Strengths were higher than the specified values. One set of two cylinders was tested for permeability and exhibited a very low average value of 601 coulombs.

CIP patches were placed 9 inches deep, while both PPCP and PCP slabs were 8-3/4 inches deep. A total of four lanes on I-66, including shoulder, were replaced using PPCP panels, each 10 feet long. The inside two 12-foot lanes were installed first, then the outer lane along with the shoulder was repaired using one 27-foot-wide slab. The whole system consisted of several types of panels: joint panels, anchor panels, base panels and closure pours. Several PPCP panels were post-tensioned together, creating 100- to 160-foot sections. Each section was tied to another with a doweled expansion joint. At both ends of each section, were joint slabs containing five block-out slots for longitudinal post-tensioning.

"Both the PCP and PPCP systems are performing satisfactorily after one year of traffic and the contractor was also satisfied with the constructability," Hossain and Ozyildirim say. "One of the major concerns is the potential for wide expansion joints in the PPCP and eventual loss of support there. There were very few cracks in the PPCP section, mainly originating from grouting holes, cracks in the block-out patches, cracks and loss of epoxy at lifting hook holes, and corner breaks. PCP slabs showed some mid-slab cracks immediately after opening to traffic but they are still tight and stable after 1.5 years of traffic." ❖