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Where the Dowel Bars Are

by Shreenath Rao

A new quality-assurance tool could help engineers improve the performance of concrete pavements.

Due to daily and seasonal fluctuations in temperatures, concrete slabs contract and expand, but the joints in the pavements serve to absorb these movements. The dowel bars embedded in concrete pavements transfer the load across the construction joints. When aligned properly, they help reduce faulting and improve the pavement's performance.

For more than 30 years, the Federal Highway Administration (FHWA) has recommended using large-diameter dowel bars for all jointed concrete pavements subjected to high volumes of heavy truck traffic to help avoid roughness caused by faulting. Implicit in this recommendation, however, is the assumption that the dowel bars will be placed in proper three-dimensional alignment.

A worker is pulling the MIT Scan-2 scanning device across a joint in a new pavement to measure the alignment of the dowel bars in the concrete.

Misplaced or misaligned dowel bars can adversely affect the performance of concrete pavements. Misaligned dowel bars can lock up the joints and prevent them from opening and closing freely, which may result in the opening and deterioration of midslab cracks, as well as spalling (chipping) and cracking near the joints. Because of the difficulties in determining the position of dowel bars in hardened concrete, misplaced dowel bars went largely undetected in the past, until it was too late and problems started to develop.

Until recently, engineers had few practical options for verifying the position and orientation of dowel bars. Probing manually or taking core samples is invasive and can be time consuming. Ground-penetrating radar is another option, but analyzing the data can be difficult, and the variations in material properties along sections of pavement can introduce significant errors in results. A new state-of-the-art, nondestructive testing device known as MIT Scan-2 offers a faster, easier, and more accurate means for measuring the three-dimensional position of dowel bars embedded in concrete.

MIT Scan-2 is the first device of its kind created specifically for measuring the alignment of dowel bars. Developed by Magnetic Imaging Tools (MIT) of Dresden, Germany, MIT Scan-2 was designed to be simple to operate and to provide accurate, real-time results in the field.

“MIT Scan-2 holds the promise of greatly improving the quality of concrete pavement construction, as well as providing significant cost savings by preventing costly errors in dowel placement,” says Sam Tyson, FHWA’s technical representative for a project to evaluate the device. “Evaluating dowel positions in real time will afford the opportunity to identify problems during construction when onsite corrections can be made.”

How the Device Works

The MIT Scan-2 system consists of a sensor unit encased in a green box, an onboard computer that controls the testing process and records data, and a special plastic rail system that guides the unit along the joint to be scanned. During testing, the device emits a weak, pulsating magnetic signal and detects a transient magnetic response signal induced in the metal dowel bars. Employing the methods of tomography, the user is able to determine the position of a bar by taking a cross section mathematically to obtain useful information such as the bar’s orientation in the vertical and horizontal planes.

To use the device, an engineer enters pavement information, such as the type of dowel, slab thickness, and other data, into the onboard computer. The engineer then places the rails along the joint and slowly pulls the unit by hand over the length of the joint. The testing takes about 1 minute per joint, and up to three lanes can be tested at a time. In an 8-hour day, a two-person crew can test 200 or more joints. In addition, the tool can run continuously for up to 8 hours on one battery charge.

MIT Scan-2 tests the entire joint in one pass, providing results for all dowel bars placed in the joint. The field data analysis is fully automated, and the results can be printed using the onboard computer.

“This device shows promise because of its built-in software, its portability, and the speed with which it can be used on hardened concrete,” says Tyson.

The field results are accurate for the following dowel placement conditions:

- Mean dowel depth of 150 +/- 40 millimeters (6 +/- 1.5 inches)
- Maximum vertical misalignment +/- 20 millimeters (0.79 inch)
- Maximum horizontal misalignment +/- 20 millimeters (0.79 inch)
- Maximum lateral position error (side shift) <50 millimeters (2 inches)

For other conditions, engineers can use the accompanying PC-based software to conduct a more comprehensive analysis. The results include a graphical output that shows a contour map of the induced magnetic field, which is the response signal to the active, pulsating, electromagnetic signal. A darker red color indicates a stronger signal, meaning that the object is closer to the surface. A graphical illustration of the results shows the specified bar location and the placement tolerance, represented by rectangles with the actual bar positions shown as gray bars.

The accuracy of the results depends on the position and orientation of the bars. The device provides the most accurate results when the bars are placed within typical placement tolerances. For bars within the dowel placement conditions listed above, the overall standard deviation of measurement error is about 2 millimeters (0.08 inch) for horizontal and vertical misalignments (maximum error of about 4 millimeters or 0.16 inch).

The results obtained are precise because of the meticulous calibration of MIT Scan-2 to each type of bar to be detected using the device. During calibration, measurements are taken over the entire range of bar positions and orientations to correlate the response signals to known bar positions and orientations. As the final step in calibration, the results are verified at the testing facility at the manufacturer's lab by comparing the MIT Scan-2 results to manual measurements.

Because MIT Scan-2 operates on an electromagnetic field, the presence or absence of nonconducting material does not affect the results. Thus, the results for tests conducted in the open air are the same as those conducted with concrete or any other cover material. Nor will the presence of water on the pavement surface or changing moisture content in the concrete as it cures affect the results. In fact, the testing can be conducted in the rain, if necessary.

A closeup of the MIT Scan-2 resting on a new concrete pavement.

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(R) MIT GmbH
Gostritzer Str. 61-63
D-01217 Dresden, GERMANY
web   : www.mit-dresden.de
email : mit@mit.tz-dd.de

ERES Division of ARA, Inc.
505 W. University Ave.
Champaign, IL 61820
tel.  : (217) 356 4500
web   : www.eresnet.com
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Date       : 15/4/2004
Time       : 10:16
File g:\04_04_15\15041016.hdf
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Highway    : I20
Station No.: 0+31
Bar Spacing         : 300 mm
Concrete Thickness : 300 mm
Bar type   :  456 x 32.4 mm
-----------------------------------
Bar Bar  Bar  Depth  Side Alignment
    Loc. Spc.        Shift Hor. Vert.
No.  mm   mm    mm     mm   mm    mm
-----------------------------------
 1   266  297   130   -33   6     0
 2   563  304   136   -20   1    -4
 3   867  315   139   -15   1     0
 4  1182  296   150     1  -4    24
 5  1478  303   135    -8   0     9
 6  1781  305   140   -19   1    10
 7  2086  307   134   -15   2     3
 8  2393  297   138    -3   0     4
 9  2690  315   143   -42   2     6
10  3005  ---   143    -7   3     1
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The field output shown here summarizes the essential information about the joint being analyzed, including the location, date and time measured, concrete thickness, and the type, spacing, and orientation of the bars. "Bar Loc." refers to the offset of the individual bar from the edge of the pavement. "Bar Spc." indicates the spacing between individual bars. "Depth" indicates the depth of the center of the bar from the top of the pavement. "Side shift" refers to the shift of the bar to the right (positive) or left (negative) of the middle of the bar over the joint. Alignment (horizontal or vertical) indicates the deviation of one end of the bar from the other end in plan view of the pavement (horizontal) or side view of the pavement (vertical).

Field Trials in California

Since December 2002, the California Department of Transportation (Caltrans) has been conducting trial tests using MIT Scan-2. Instrumental in bringing the technology to the United States, Caltrans has used MIT Scan-2 to detect numerous problems associated with dowel bar and tie bar placement on existing pavements. The agency has found the tool valuable for quality assurance and quality control tests during construction of concrete pavements.

Examples of problems that Caltrans identified using MIT Scan-2 include the following:

- On one project using a dowel bar inserter (DBI), MIT Scan-2 results showed that the dowel alignment on the project was so poor that the joints were practically cross-stitched.
- On another DBI project, the MIT Scan-2 results showed that the dowel bars were dropped to the bottom of the slab over the 2.4 kilometers (1.5 miles) of the project.
- On another project, an equipment problem caused tie bars across the centerline joint to be placed too shallowly. MIT Scan-2 successfully identified the fact that the majority of the bars were cut when workers sawed the longitudinal joint.
- And on a project using dowel basket construction, MIT Scan-2 results showed that the majority of dowel baskets were either shoved or had burst open. As a result, construction stopped while the contractor used additional pins to secure the dowel baskets. Comparing the concrete placed before and after this adjustment showed a striking improvement. Before the adjustment, nearly 100 percent of the joints had at least one severely misaligned dowel bar. After the fix, 100 percent of the bars satisfied the specification requirement.

According to Tom Pyle, chief engineer of rigid (concrete) pavement materials and structural concrete with Caltrans, the device holds promise for allowing early detection of these types of problems and helping agencies avoid compounding costly errors. “MIT Scan-2 is the only machine that we have found that provides information on the location of every dowel bar with such accuracy,” he says. “One of the biggest challenges we have now is to figure out how to manage the large amount of data it produces.”

An engineer calibrates measurements at the MIT GmbH laboratory.

Pyle adds, “The next big step for us is to determine how we will roll the information into a useful test method for dowel bars. With coring, we can only check a few slabs and have to wait until the concrete can support a drill rig. With MIT Scan-2, we can scan about one joint per lane every minute and do so after only a modest strength gain since we carry [and then drag] the device. Therefore, we will be able to check trial slabs quickly and thus help contractors get off to a good start in terms of the accuracy of their dowel bar placement.”

DBI Versus Dowel Baskets

Researchers recently used MIT Scan-2 to study the relative effectiveness of using dowel baskets versus DBI systems during construction. Dowel bars are either placed manually before concrete placement using dowel baskets or during construction using automatic DBI equipment. Concerns about possible problems with dowel bar misalignments are one of the reasons why DBIs are not widely used in the United States, even though they can expedite construction and reduce costs.

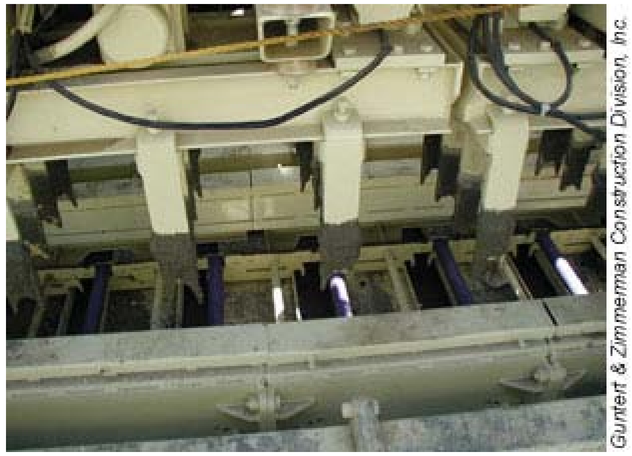
Experience using MIT Scan-2, however, shows that using dowel baskets does not guarantee good dowel alignment. Testing conducted by FHWA and several State departments of transportation (DOTs) using MIT Scan-2 showed that excellent results can be obtained by using a dowel bar inserter.

A dowel bar alignment is set up for a field validation at the testing facility.

The study compared dowel alignments for five DBI projects and seven basket projects located in six States across the United States. The findings showed that comparable results can be obtained using either method of construction, as long as care and attention are given to the many details required to achieve accurate dowel bar alignment.

For dowel baskets, the most critical factor appears to be the manner in which the baskets are secured on the subbase prior to paving. If the baskets are not adequately pinned down, they may be shoved, rotated, or pulled apart during paving, resulting in extreme misalignments. The baskets also may bend during handling or concrete placement if walked on.

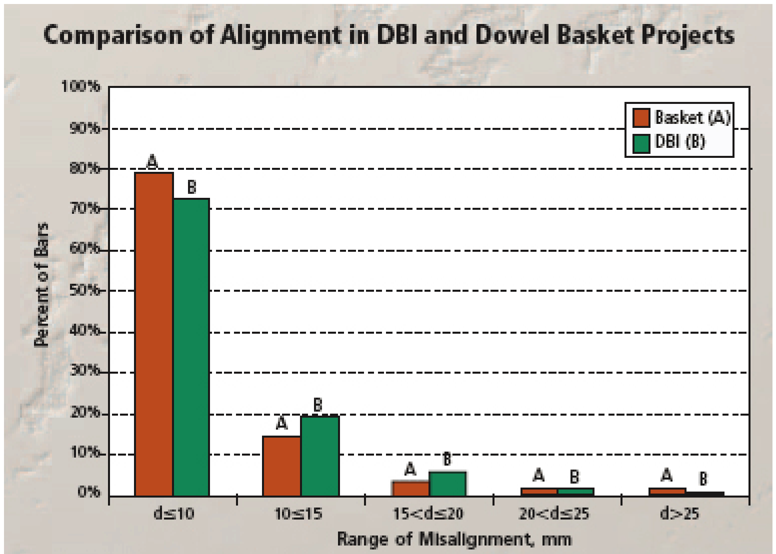
Because MIT Scan-2 is essentially a metal detector, the presence of any metallic objects within about 1 meter (3 feet) of the bars being scanned interferes with the measurements. Therefore, dowel baskets could interfere with the measurement results. Regardless, reasonably accurate results can be obtained for dowel baskets if the following conditions are met: (1) the dowel bars used with the baskets are epoxy coated, and (2) the transport ties on the basket are either cut or removed. If these conditions are met, the results for horizontal and vertical alignments are typically within +/- 5 millimeters (0.2 inch) of their true alignment. In addition the manufacturer recently developed analysis software to improve on the accuracy. With careful construction practices and inspection, testing is needed only to verify that the basket has not moved or burst open during paving. With specific calibration for the type of basket used, the accuracy can be improved further.



This closeup shows a dowel bar inserter. (Above) A construction crew is using a dowel bar inserter on this highway paving project.

Even without specific calibration, however, MIT Scan-2 is still a useful screening tool for identifying problem areas because it can easily detect the results of displaced or burst baskets. For example, engineers can easily identify problems in the bar placement or sawcut locations visually by looking at the images generated by MIT Scan-2. In a signal intensity plot generated by the device, areas with severe vertical misalignments will show up in an asymmetrical alignment rather than a parallel configuration.

For DBI construction, the critical factors are the proper adjustment of the equipment and concrete mix design. When using a DBI, the portland cement concrete (PCC) mix must be stable enough to hold the bars in place without displacing them during the paving operation.



The bar chart compares the dowel alignments in projects featuring (A) dowel baskets and (B) dowel bar inserters (DBI). The comparison is based on the MIT Scan-2 results of five DBI projects and eight dowel basket projects located in seven States across the United States. The results demonstrate that with careful attention to paving details, comparable results can be obtained using either method of construction. *Source: Yu, Thomas,* Dowel Bar Alignments of Typical In-Service Pavements, *American Concrete Pavement Association, Skokie, IL, 2005.*

Field Trials in the Carolinas

On a reconstruction project on I-95 in South Carolina, the contractor elected to use the DBI construction method, which posed a significant concern for the State because it had no prior experience with this paving system. However, using MIT Scan-2, engineers from the South Carolina Department of Transportation (SCDOT) were able to monitor the dowel bar alignment to their satisfaction.

"MIT Scan-2 provided us with considerable peace of mind that the insertion process was working properly on I-95," says Andrew Johnson, State pavement design engineer with SCDOT. "Although more research is necessary to understand exactly what tolerances are acceptable, we feel like the vast majority of inserted dowels were appropriately located. We would not have had this assurance without MIT Scan-2."

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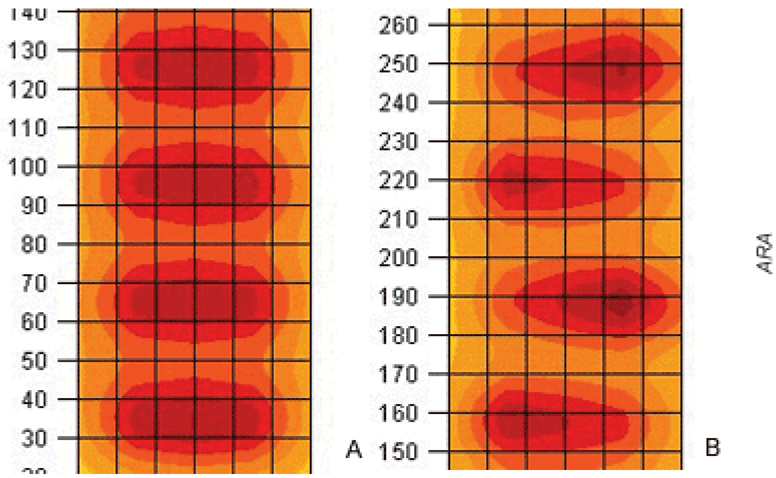
Workers prepare to use MIT Scan-2 to evaluate the dowel alignment in a new pavement joint.

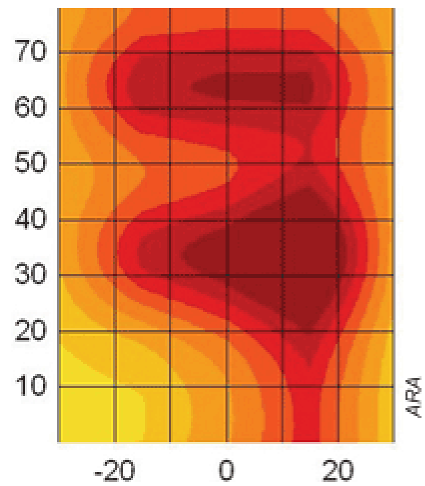
Three workers are using MIT Scan-2 on a U.S. 64 bypass construction project in Knightdale, NC.

Johnson adds that the scanning data led to the replacement of several defective joints that would not have been caught otherwise. One joint problem the State encountered was that tie bars were being placed at dowel locations. Although this in itself is not a major problem, tie bars can displace the dowel bars as they are inserted. MIT Scan-2, however, can easily detect problems like this. “I am certain that the use of the device led to higher quality on our project,” Johnson adds.

In North Carolina, a contractor performing work on a U.S. 64 bypass project used MIT Scan-2 to gain approval to use the DBI construction method for a substantial savings in construction costs. On that project, the North Carolina Department of Transportation (NCDOT) used the device to monitor the dowel alignments to optimize the concrete mix design. When the PCC mix was optimized with assistance from the DBI manufacturer, an FHWA study showed that the resulting dowel bar alignment is among the best observed on any project, whether using a DBI or a dowel basket.



These two signal intensity plots illustrate how easily an engineer can use MIT Scan-2 to see the difference between properly aligned dowel bars (A) and severely misaligned bars (B). A good alignment is characterized by uniformity and symmetry in the intensity of the magnetic signal. A poor alignment shows an asymmetrical magnetic signal, which is a telltale sign that the dowel basket was pulled apart and the alternating ends of successive bars were dropped. *Source: ARA.*

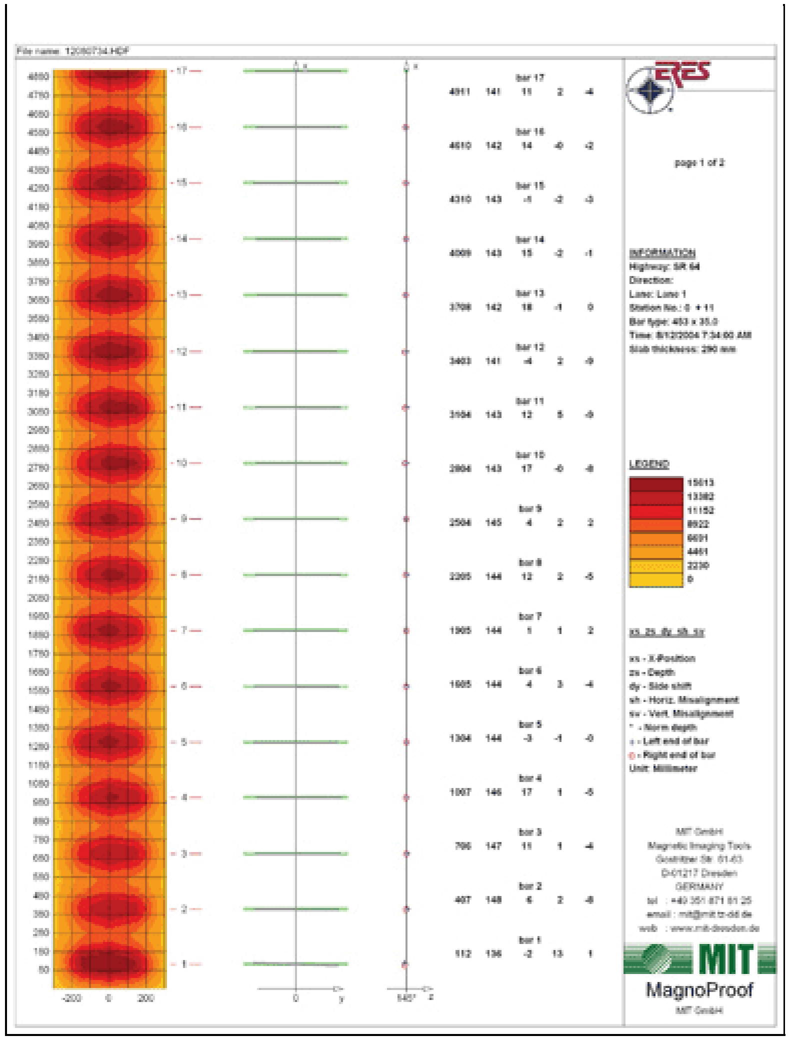


This signal intensity plot shows that a tie bar was placed too close to a dowel location. The dowel bars are indicated by the red elliptical regions oriented horizontally. The presence of the tie bar is indicated by the vertical dark red region near the right end of the bars. *Source: ARA.*

Further Testing

For both dowel basket and DBI methods of construction, MIT Scan-2 can be instrumental in fine-tuning the construction process. For baskets, MIT Scan-2 can be used to determine whether the planned method of securing the dowel basket is adequate. For DBIs, MIT Scan-2 can help optimize the PCC mix design and detect any equipment adjustment needs. By providing a practical means of verifying dowel alignment, MIT Scan-2 already has enabled contractors to use DBIs in States that had no previous experience with them. The ability to quantify and document quality also sets the stage for the development and implementation of performance-related specifications regarding dowel alignments.

Results of the MIT Scan-2 testing indicate that many inservice pavements may contain at least a few bars that do not satisfy the current specification requirements, even on well-performing pavements with no signs of any distresses. One consequence of not having had a practical means of measuring dowel alignment in the past is that the existing specifications on dowel placement tolerances are largely untested. As a result, no clear consensus exists on what specifications would lead to the most durable pavements. In addition, the actual field performance data that could be used to determine what is needed do not exist.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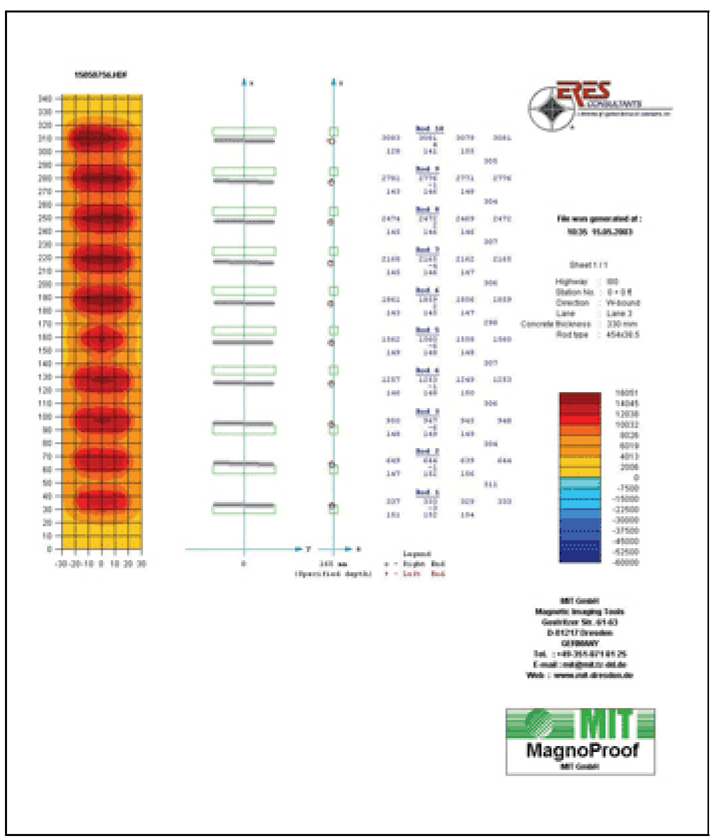
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Magnetic Imaging Tools
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These readouts show the typical graphical output from the scanning device. The plots consist of three types of information: (1) signal intensity plot (on the left); (2) a schematic illustration of the analysis results (center), which shows the specified dowel location with placement tolerance and the actual measured dowel position; and (3) numerical results (right) that show the bar location, depth, lateral placement error, horizontal misalignment, and vertical misalignment. The readout on the left shows an example of very good dowel bar alignment, while the one on the right shows poor alignment. *Source: MIT GmbH.*

A comprehensive review of the existing specifications is critical, and the National Cooperative Highway Research Program (NCHRP) recently launched a study for a review. NCHRP Project 10-69—"Guidelines for Dowel Alignment in Concrete Pavements" kicked off in March 2005.

FHWA recently acquired an MIT Scan-2 device for its Mobile Concrete Laboratory. "The measurement of dowel locations in existing concrete will enable FHWA to review current guidelines and specifications for dowel placement tolerances and recommend best practices for construction," says FHWA's Tyson. "Equally important is the ability to use the device to measure dowel positions in newly placed concrete a short distance behind the paving train. These measurements, in three dimensions with a printout for immediate review and electronic storage of all data, make this one of the more useful devices to be added in recent years to the toolbox for constructing high-performance concrete pavements."

Shreenath Rao, Ph.D., is a senior engineer with Applied Research Associates, Inc. (ARA). Rao received his M.S. degree in transportation engineering at the University of Arkansas and his doctorate in civil engineering at the University of Illinois, specializing in transportation structures and pavement engineering. Since joining ARA in 1997, Rao has been active in pavement evaluation and design and in numerous areas of pavement research and technology transfer, including pavement performance, design, and rehabilitation.

For more information, contact Shreenath Rao at 217-356-4500 or srao@ara.com.

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