Nondestructive Testing Device for Tie Bar Placement Accuracy

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ABSTRACT

The Kansas Department of Transportation (KDOT) in cooperation with Kansas State University (KSU) and the American Concrete Pavers Association (ACPA) is developing an instrument capable of assessing tie bar placement accuracy suitable for use in a paving environment. The instrument is now in its fourth prototype. The third-generation prototype used a single magnetic sensor and was capable of assessing depth accuracy at a rate of approximately two miles of construction joint per hour on projects during the 2004 construction season. KDOT is developing a new placement specification appropriate for this type of sensing technology. The fourth-generation prototype will possess multi-sensor capability to assess lateral placement as well as depth accuracy. Due to cooperation with the ACPA, this instrument is targeted to be integrated into paving equipment for real-time quality control. This paper reviews the basic sensing principles of magnetic tomography and how it can be successfully integrated with microprocessors and communications into a nondestructive instrument for use in a concrete construction environment.

Key words: magnetic tomography—nondestructive testing—tie bar

PROBLEM STATEMENT

The Kansas Department of Transportation (KDOT), in cooperation with Kansas State University (KSU) and Koss Construction via the American Concrete Pavers Association (ACPA), has been developing an instrument capable of assessing tie bar and dowel bar placement accuracy for use in a paving environment. KDOT demonstrated a single-sensor prototype in 2004 that was capable of assessing tie bar depth at a rate of approximately two miles of construction joint per hour. In 2005, KDOT is moving forward with a revision of the tie bar placement specification appropriate for use with this type of sensing technology. KDOT is also pursuing a multi-sensor prototype in order to assess lateral placement accuracy and depth accuracy. In 2004, Koss Construction committed extra manpower to their paving operation that was dedicated to monitoring tie bar placement depth. The project sponsors intend to integrate the multi-sensor instrument directly into the paving equipment later this year to facilitate real-time quality control.

BACKGROUND

In 2001, KDOT began investigating the feasibility of developing an instrument capable of nondestructively assessing the depth and orientation of steel reinforcement, namely dowel bars and tie bars, in concrete pavements. After surveying possible techniques, magnetic tomography emerged as the most promising technology. Magnetic detection relies on magnetic permeability differences between the target (in this case, steel bars) and its surroundings (such as concrete). It is the same basic principle used in concrete cover meters. Tomography simply refers to the mapping of these magnetic properties to form a curve, contour, or image that represents the target. Although nondestructive electromagnetic techniques such as ground penetrating radar continue to be refined, magnetic tomography has the additional advantage of being unaffected by moisture, which allows it to be used on plastic concrete.

An experimental x-y scanning table was constructed at the KDOT Materials and Research (M and R) in 2001. The scanning table coupled electronic signals from two optical encoders, one for each axis, with the audio feedback from a Kolectric MicroCovermeter and stored the data electronically in a PC. A sample of the data obtained from this device is shown in Figure 1. The picture depicts the placement of dowels in a dowel basket array (note that the vertical units are in error in the diagram).

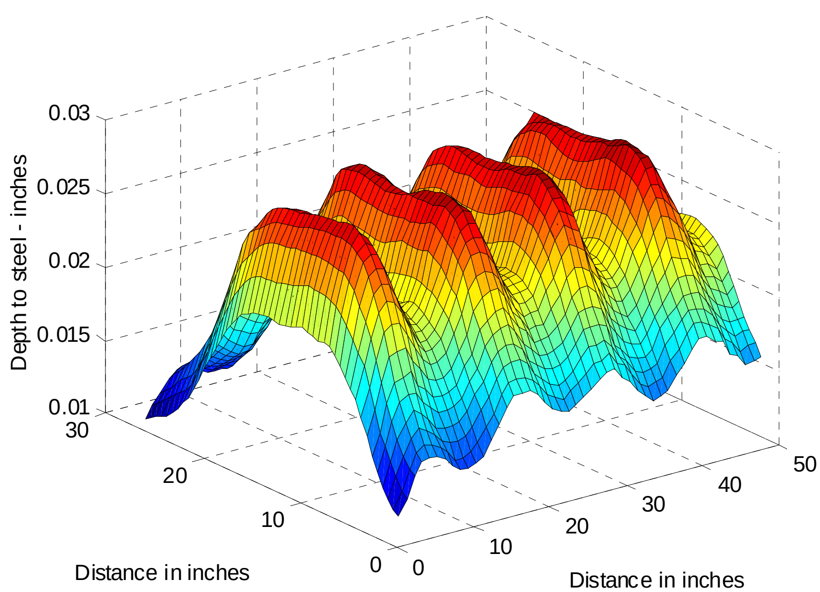

Figure 1. Two-dimensional magnetic scan of a dowel array

Although cover meters are routinely used to investigate suspected misplaced steel and to locate reinforcement steel prior to drilling core samples, the use of a cover meter to systematically assess placement accuracy is far too manpower-intensive to be feasible. The data provided by the experimental 2D scanner indicated that the sensing technology within the cover meter was capable of yielding accurate depth and orientation when coupled with an electronic positioning device. The concept came to be known as a cover meter on wheels.

In the fall of 2001, KSU Electrical and Computer Engineering proposed to KDOT the development of a cart-type device that incorporated this principle and could be used during construction behind a concrete paver. The proposal was accepted and work commenced in the summer of 2002. The resulting prototype is shown in Figure 2. Working with Kolectric, a custom cover meter was produced that directly outputs signal strength in real-time via an RS-232 serial connection. Distance was logged through use of an optical encoder wheel. The device demonstrated that depth and orientation of tie bars and dowel bars could be obtained with multiple passes over the joint. Rectangular slots cut in the transparent tray that carried the detection coil provided known distance left and right of the joint, which allowed the generation of multiple traces and the development of a 3D perspective of the steel's orientation.

Figure 2. Prototype instrument developed at KSU in 2003

The device demonstrated its potential in the laboratory, but practical concerns of field operation prohibited multiple passes and prevented rapid data collection. The basic operational principles were valid, but the design of the cart went through two more iterations at the M and R laboratory in 2003 and 2004 before a functional prototype was produced. The current prototype, shown in Figure 3, was successfully demonstrated in field tests during the 2004 construction season.

Figure 3. M and R prototype built and field tested in 2004

The current three-wheeled device works in a similar fashion to the KSU prototype, but alterations in the chassis allow for rapid data collection. The acrylic sled for the sensor coil maintains an offset of approximately 1/4 of an inch from the concrete. The sled is fastened by two nylon bolts toward the front of the prototype. This allows the sled to rise whenever debris or excessive crown interferes with available clearance. These and other innovations allowed the prototype to demonstrate rapid data collection in 2004 in varying construction environments, including rain, mud, and heavy dust. Over four miles worth of data were collected in less than two hours on the last project. Table 1 lists the projects in 2004 where the current prototype was used to collect data.

Table 1. Data collection activities in 2004

Date	Description
April 2004	Data samples on I-35 and I-70 following the MIT-SCAN
July 2004	Wichita, sections of I135 North of Wichita ~3,000 feet of centerline longitudinal joint during rain
August 2004	Kansas City, sections of 635 ~1,200 feet of longitudinal joint, extremely dusty environment
August 2004	Wichita, ~6,000 feet of I-135 to confirm correction of tie bar placement process
August 2005	Wellington Airport, ~1,000 feet of shoulder longitudinal joint to confirm suspected tie bar problem
October 2004	I-35 near BETO junction, ~4 miles of data along center and shoulder longitudinal joint confirmed correct placement of tie bars

DATA ANALYSIS

Presentation and analysis of data was performed using a customized program that displayed the one-dimensional trace and estimated the depth to the tie bar. Examples of this are shown in Figures 4 and 5. Figure 4 depicts the location of tie bars along a shoulder joint on I-135 North of Wichita, Kansas. An exposed shoulder joint provides a convenient source for validating the instrument. The exposed steel tie bars allow for visual inspection and direct comparison with the results from the prototype instrument. Notice the irregularity at ~17 feet in Figure 4. This phenomenon is caused by the proximity of the steel dowel baskets at a transverse joint.

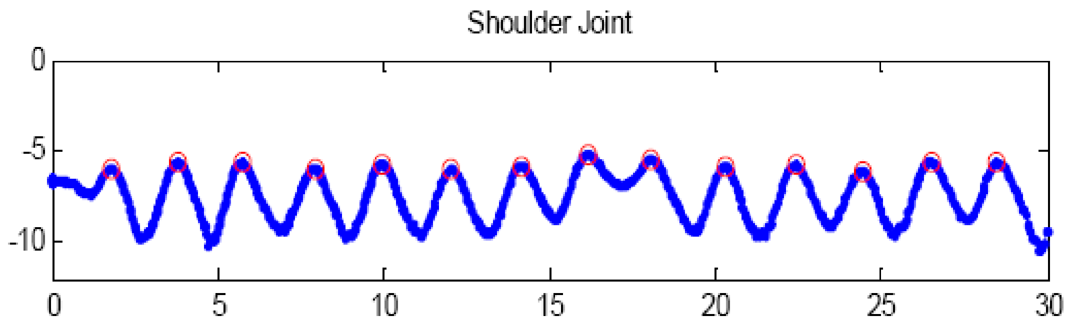

Figure 4. Tie bar depth (in inches) along a 30-foot section

Figure 5 depicts the depth of tie bars along the centerline joint on the same section of roadway. Note that in the first 30 feet, the tie bars are discernable, with one tie bar near the surface at 15 feet, probably at a transverse joint location. From 30 to 60 feet, most of the bars are near the bottom of the pavement. The data collected on this project confirmed a suspected tie bar inserter problem.

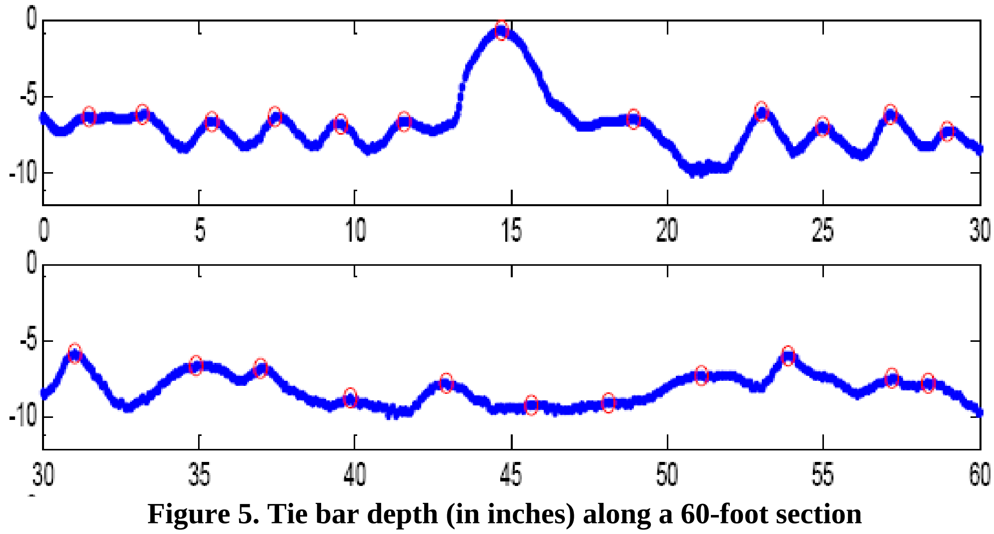

Figure 5. Tie bar depth (in inches) along a 60-foot section

The current prototype has been ruggedized for field work, but provides only depth to steel at the construction joint. Theoretically, multiple passes of the instrument at known lateral offsets from a construction joint could be combined to obtain orientation as well as depth, as was demonstrated in the laboratory at KSU. However, multiple passes are not practical in the field. Even if manpower were not an issue, debris on the road causes slight deviations in measured distance. These errors in turn cause inaccurate orientation calculations. An instrument that could take two or more depth measurements simultaneously would be more practical. This is the goal of the next prototype.

COMPLIMENTARY WORK

In 2003, a German company began marketing a product in the United States called MIT-SCAN. MIT-SCAN is similar in concept to the current prototype, but it specifically targets the automated dowel bar inserter market. The MIT-SCAN instrument requires that a track be placed on the pavement prior to collecting data. MIT-SCAN contains five sensors and can assess the orientation of a dowel array in a single pass. However, several factors inhibit it from being used in the field on an ongoing basis. The dependence on a customized track limits its data collection speed. In April 2004, the M and R prototype was tested alongside the MIT-SCAN. The M and R prototype collected data at approximately twice the speed of the MIT-SCAN device, and this was prior to improvements in the prototype software that allowed for more rapid data collection. This combined with its high cost and other factors led KDOT to continue with its independent development.

During the 2004 construction season, Koss Construction hired an additional worker on its concrete paving jobs to monitor tie steel placement. The sensing coil of a cover meter was placed on the burlap drag directly behind the paver. The worker was responsible for monitoring the cover meter, continuously checking for appropriate depth of tie steel. Normal paving consists of placement of two lanes of traffic and a shoulder in one pass. The meter was rotated between and centerline and shoulder joint throughout the day. Of the data collection activities in 2004, the I-35 project near BETO junction, constructed by Koss, was the only job in which the prototype confirmed correct placement of tie steel rather than confirming misplaced steel.

FUTURE DEVELOPMENT

Moving forward, KDOT has committed to revisit the specification that governs the accuracy of tie bar placement, assuming that an instrument is available, similar to the current prototype, suitable for field operation and capable of assessing both depth and lateral position with respect to the construction joint. The development of an appropriate specification is being led by Andrew Gisi from the KDOT Geotechnical Unit.

Assessing lateral placement accuracy requires multi-sensor capability. The periodic send signal creates an exponentially decaying magnetic field which generates eddy currents in the tie bar. The eddy currents in turn induce magnetic fields about the tie bar. A receive coil detects the disturbance in the exponentially decaying magnetic field as a result of the presence of the tie steel. Synchronization of the send signals from multiple sensors is necessary if two or more cover meters operate within several meters of one another. If the meters are not synchronized, the timing circuitry of the receive coil will be foiled by the presence of an out-of-phase decaying magnetic field emanating from a different cover meter. The interference due to non-synchronized meters is analogous to the operation of multiple radars in close proximity. Send signals from one radar can interfere with receive signals in a second radar, causing erroneous readings.

The prototype currently under development will be capable of simultaneously collecting three traces. Figure 6 depicts the control circuitry provided by Kolectric that allows for three sensors to operate synchronously. The cart to house the three-sensor version is being designed similarly to the cart shown in Figure 3. At the time of this writing, the multi-sensor prototype is under construction. Although synchronized operation of the three magnetic sensors has been demonstrated in the lab, the effects of proximity on detection range have yet to be assessed.

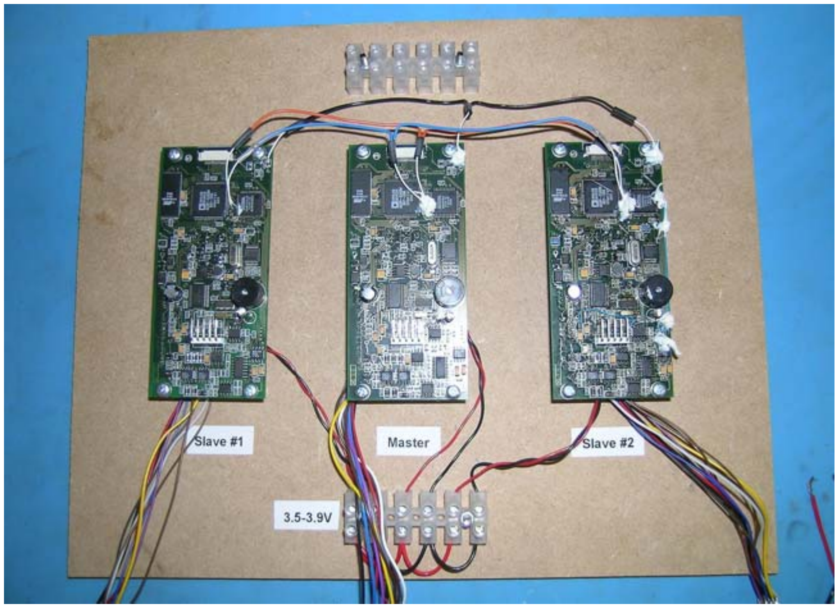

Figure 6. Control circuitry of three synchronized cover meters provided by Kolectric

Figure 7 plots the sensor data from the three synchronized meters during a preliminary laboratory test. In the test, the sensor coils are positioned parallel to one another approximately six inches apart in the following order: Slave1, Master, Slave2. A steel dowel was passed over the array of sensor coils at a constant height (by hand). In the results graphed in Figure 7, Slave1 detects the bar first, then the Master, and then Slave2. On the return trip, the order is reversed, with Slave2 detecting the bar first, then the Master sensor in the middle, and finally Slave1 detects it again. The results in Figure 7 simply demonstrate that multiple sensors can operate in close proximity as long as the control circuitry is synchronized. It is unknown whether the detection range of each individual sensor is diminished due to the proximity of the other sensor coils.

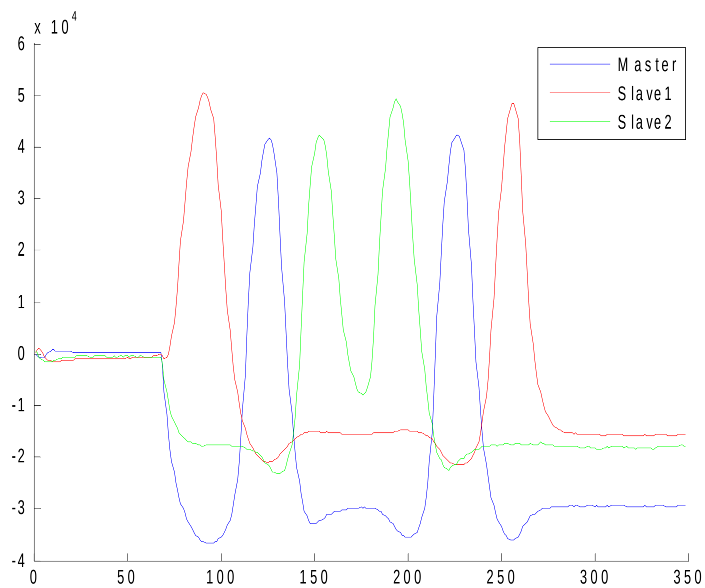

Figure 7. Results of preliminary laboratory test with synchronized meters

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Jim Devault and Ruth Miller, professors in the Department of Electrical and Computer Engineering at Kansas State University, for their collaboration and support in the project. Primary funding for this project was provided by the Kansas Department of Transportation through a grant to Kansas State University. Koss Construction Company and the American Concrete Pavers Association provided funding for the purchase of materials and equipment. All statements and opinions presented in this paper are the sole responsibility of the authors, and may not necessarily reflect those of the Kansas Department of Transportation.

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