Use of Magnetic Tomography Technology to Evaluate Dowel Placement

DESCRIPTION OF MIT SCAN-2

MIT Scan-2 consists of three main components, as shown in Figure 1:

- Sensor unit (the rectangular box shown in Figure 1) that emits electromagnetic pulses and detects the induced magnetic field - The sensor unit contains five sensors: one at the center and two each to either side. The sensors are evenly spaced and are centered (approximately) along the line directly below the white line of the MIT logo on the box (Figure 1).
- Onboard computer that runs the test, collects and stores the test data, and performs the preliminary evaluation.
- Glass-fiber-reinforced plastic rail system that guides the sensor unit along the joint, parallel to the pavement surface, and at a constant elevation.

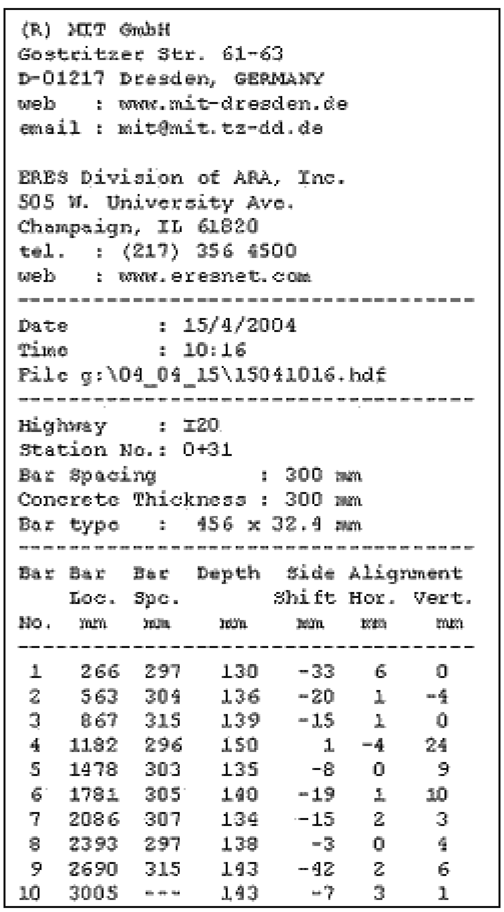
Figure 1. MIT Scan-2, consisting of the sensor unit (a rectangular, green box), onboard computer, and glass-fiber-reinforced plastic rail system.

MIT Scan-2 is designed for use on construction sites without requiring any special precautions. Both the sensor unit and the onboard computer are adequately protected against dust, and they can be used in adverse weather conditions, including rain and low temperatures. The operating temperature range is from 23 °F to 122 °F (-5 °C to 50 °C). The test results are not influenced by weather conditions.

Figure 2 shows a joint being scanned using MIT Scan-2. Scanning a joint takes less than a minute. The field data analysis is fully automated, and results are produced in less than a minute after scanning. The onboard computer is equipped with a printer to provide a printed output in the field. Example field results are shown in Figure 3. The test data are stored in a PCMCIA flash memory card. Data for up to 600 joints (single lane) can be stored in the 32-megabyte (MB) memory card provided with the device. This is typically more than adequate storage, and the data can be transferred easily to a laptop computer by simply removing the PCMCIA card from the onboard computer and plugging it into the PCMCIA card slot of a laptop computer.

Figure 2. Scanning a joint using MIT Scan-2.

Figure 3. Example field output of MIT Scan-2.



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Date : 15/4/2004
Time : 10:16
File g:\04_04_15\15041016.hdf

Highway : I20
Station No.: 0+31
Bar Spacing : 300 mm
Concrete Thickness : 300 mm
Bar type : 456 x 32.4 mm

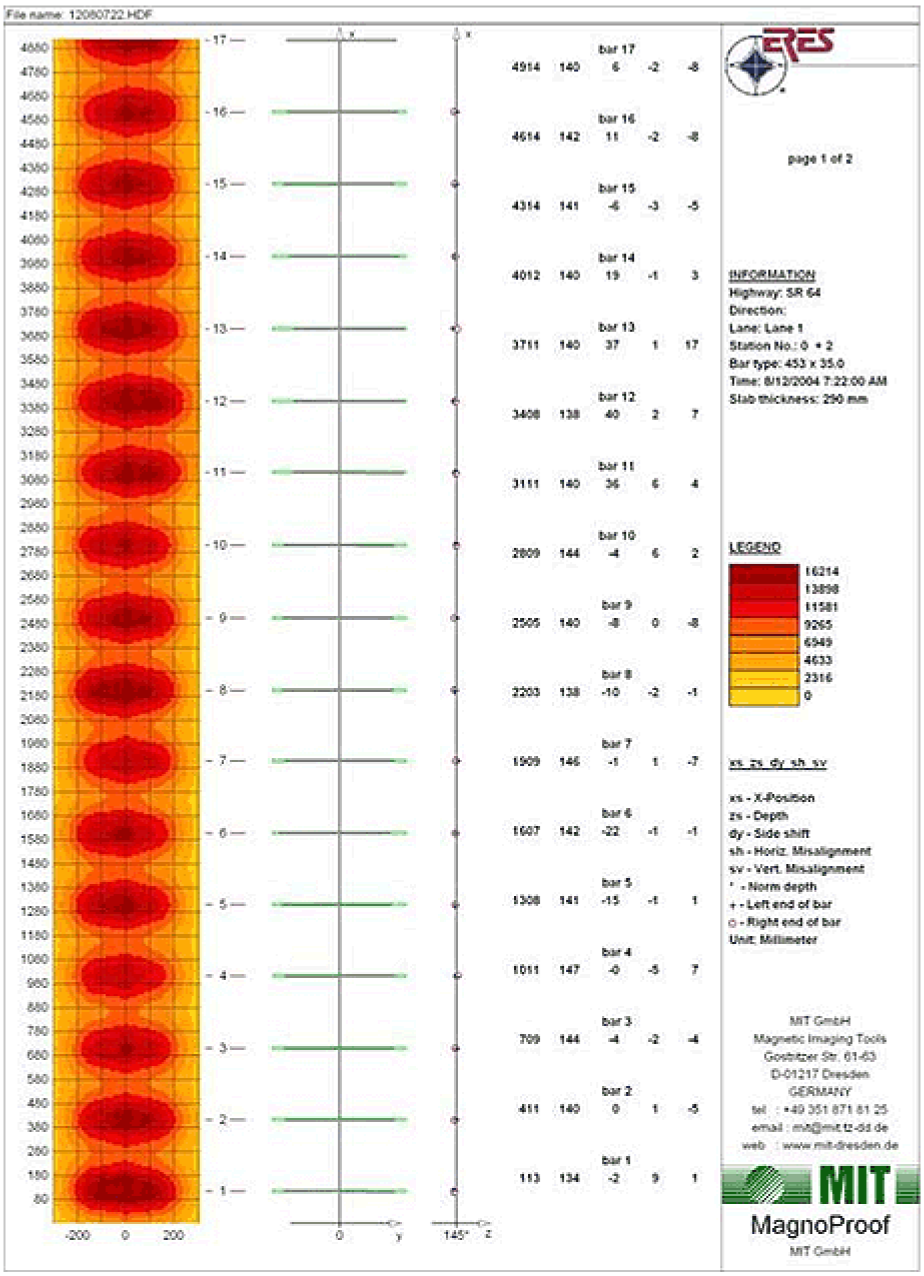
Bar No.	Bar Loc. mm	Bar Spc. mm	Depth mm	Side Shift mm	Alignment Hor. mm	Alignment Vert. mm
1	266	297	130	-33	6	0
2	563	304	136	-20	1	-4
3	867	315	139	-15	1	0
4	1182	296	150	1	-4	24
5	1478	303	135	-8	0	9
6	1781	305	140	-19	1	10
7	2086	307	134	-15	2	3
8	2393	297	138	-3	0	4
9	2690	315	143	-42	2	6
10	3005	---	143	-7	3	1

MIT Scan-2 allows the entire joint to be scanned in one pass, providing results for all dowel bars in the joint. The field results (produced by MagnoNorm software) are accurate for the following conditions:

Mean dowel depth 150 + 40 mm (4.3 to 7.5 in.)
- Maximum vertical misalignment + 20 mm (0.8 in.)
- Maximum horizontal misalignment + 20 mm (0.8 in.)
- Maximum lateral position error (side shift) < 50 mm (2 in.)

For other conditions, the accompanying PC software (MagnoProof) can be used to conduct a more comprehensive analysis. MagnoProof is also highly automated and easy to use, but it allows more manual control of the analysis process. For example, the automatic process for detecting the bar locations may not pick up a bar that is placed much deeper than the others because of the weaker signal. MagnoProof allows the users to insert or delete bars based on the observation of signal-intensity plot, which is shown on the screen. The user may also restrict the analysis region to cut out the part containing strong influence of foreign objects, which cannot be analyzed. The output options include a signal-intensity contour map and an illustration of the analysis results that shows the specified bar locations and the actual bar positions (Figure 4).

Figure 4. Example graphical output of MagnoProof.



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The fundamental operating principle behind MIT Scan-2 is pulse-induction (MIT 2002). The device emits a weak, pulsating magnetic signal and detects the transient magnetic response signal induced in metal bars. The weak magnetic field emitted by MIT Scan-2 is harmless to the surrounding area and does not affect the physical properties of the dowels or of the concrete. The response signals are measured with high precision using special receivers in the testing device. The detected signal values are recorded at a relatively high sampling rate to assure large quantities of data for mathematical evaluation. The data redundancy enables evaluation of measurements taken under less than ideal circumstances (e.g., the presence of foreign metal or magnetic aggregates).

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The basis of the solution technique employed in MIT Scan-2 is magnetic tomography. In magnetic tomography the response of the investigated objects to external fields is measured in both space and time. These signals contain information on the distribution of electrical conductivity and magnetic properties, which permits the determination of position, size, shape, orientation, and type of metallic bodies in the investigated region and the indication of defects in those objects. However, when multiple objects are present, only the overall effects of all objects within the detection range can be measured. The inability to detect the response signal of individual objects separately greatly complicates data analysis. The true value of MIT Scan-2 is in the innovative techniques employed to determine the position and orientation of individual objects from the integrated signal. The innovations include the application of an array of sensors and novel filter techniques, the usage of the redundant data recorded from different positions from multiple sensors, and the use of all existing additional physical knowledge about the object in determining the position and orientation of the object scanned (Lehmann 2001).

Calibration and Validation

Each MIT Scan-2 unit is individually calibrated to each type of bar that will be detected using the device to provide very accurate results. During calibration, measurements are taken over the entire range of bar positions and orientations to correlate the response signals to the known bar positions and orientations. The testing results are used to develop a device-specific parameter file for each type of bar. The bar type is defined by the bar dimensions (diameter and length) and metal composition (e.g., steel, solid stainless steel, or stainless steel clad).

Figure 5 shows the calibration measurements being taken at the MIT GmbH laboratory. The test bench is completely free of all metal objects. The wooden vise that holds the test sample is attached to a jig that allows the bar to be positioned at any depth and lateral position (side shift) within the evaluation range, and the bar can be rotated up or down. A full factorial of readings is taken during calibration testing, except for the rotation in the horizontal direction. Horizontal alignment is determined based on the locations where the maximum signal intensity was recorded at each end of the bar as the sensor unit is pulled along the joint. The calibration results are field verified at the MIT GmbH testing facility by comparing MIT Scan-2 results to manual measurements (Figure 6) to ensure that the interaction of neighboring dowel bars does not produce additional measurement errors.

Figure 5. Calibration measurements being taken at MIT GmbH laboratory.

Figure 6. Test track at MIT GmbH for validation of calibration results.

The bar type is a required input during testing, and it is important to specify the correct bar type to obtain meaningful results. However, the field data and calibration data are kept separately in the MIT Scan-2 data files, and the calibration information is applied at data analysis time. If an incorrect bar type is specified during testing, the correct bar type can be substituted during data analysis using MagnoProof. However, it is important to note that the correct bar type must be specified to obtain accurate results. The accuracy of the results obtained using an incorrect bar type is unpredictable.

Operation

MIT Scan-2 is easy to operate and requires minimal maintenance. Only two preparations are required prior to field testing:

- Charging batteries - The sensor unit contains a maintenance-free, lead-acid battery, which takes about 4 hours to fully charge. The battery in the onboard computer takes about 10 hours to fully charge using the charger supplied with the computer. Alternatively, an external charger may be used to charge the battery in about 2 hours.
- Ensuring that the flash memory has enough room for new data - The memory card can be removed and plugged into any compatible laptop computer for managing data files. The data should be downloaded onto a laptop computer or other permanent storage device after each day of testing, and the flash memory card kept clear to provide room for future test data.

In the field, the setup process consists of assembling the rail system and connecting the onboard computer to the sensor unit. The sensor unit takes 5 min to warm up. If measurements are taken while the unit is not warmed up, additional errors may be introduced.

The measuring process involves setting the rails on the joint to be scanned, entering the pavement information into the onboard computer, and then pulling the unit along the joint. The details of operating MIT Scan-2 are provided in Appendix A: MIT Scan-2 Operations Guide.

MIT Scan-2 keeps track of both joint number and station. Both numbers are automatically incremented or decreased (the joint number by 1, and the station number by the joint spacing) after testing each joint according to the user settings. Prior to testing, it is highly recommended to number the joints in the test section to ensure that the recorded joint numbers correspond to the correct joints. Marking every 5th joint is adequate for this purpose.

Productivity

After the initial setup, testing takes 1 to 2 min per joint, depending on the number of lanes being tested. The setup process, including assembling the rail system and marking the joints to be scanned, takes about 30 min. Up to three lanes can be scanned together in a single pass, and testing multiple lanes together does not drastically slow the rate of testing (in terms of number of joints tested, counting one pass as one joint). However, longer rails are more cumbersome to move and slow the rate of testing (again, counting one pass as one joint). To prevent damage to the rail system, one person per lane-width is needed to move the rail. For example, one person can move the rail for a single lane. When testing two lanes at a time, two people are needed to move the rail without causing damage.

The maximum rate of testing is also limited by the file naming convention used by MIT Scan-2, which uses the minute during which the test is conducted as a part of the file name. MIT Scan-2 produces two files for each joint scanned: a binary file (*.hdf) containing the raw data and a text file (*.txt) containing the field data analysis results. The file names are generated based on the date and time as follows:

ddMMhhmm. - dd* is the date, *MM* the month, *hh* the hour, and *mm* the minute.

Because the minute of the testing time is used in the file name, no more than one test can be conducted per minute. Therefore, the maximum productivity is 60 joints per hour. In general, this restriction is not a limiting factor when testing multiple lanes, but it does affect productivity when testing a single lane. Although up to 60 joints can be tested in an hour, this rate of testing cannot be sustained throughout a work day, even when testing a single lane. Field experience shows that a good average daily productivity is about 200 joints for two lanes and moderately more (e.g., 250 joints) for a single lane.