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Standard Test Method for Evaluating Concrete Pavement Dowel Bar Alignment Using Magnetic Pulse Induction[1]

This standard is issued under the fixed designation E3013/E3013M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the equipment, field procedures, and interpretation methods for the assessment of Portland cement concrete pavement dowel bar alignment using magnetic pulse induction (MPI), also referred to as magnetic imaging tomography or eddy current tomography. Magnetic pulse induction (MPI) devices induce a weak-pulsed magnetic field that causes the induction of eddy currents in metal objects disturbing the field. When metal (dowel bar) enters into the field, an electrical signal is produced and processed through algorithms to detect and produce quantitative values for the depth, alignment, and side shift locations of each dowel and tie bar present in the pavement joint.

1.2 MPI equipment includes the following: systems scanning device that induces the magnetic field and collects the electrical signal; orientation system such as a rail system; field data collection device that collects the signal data from the scanner, performs field analysis, and stores data; analysis software package that calculates the dowel bar positions, allows data adjustments to account for detected anomalies, and produces reports.

1.3 MPI field procedures describe the steps and processes required to collect reliable, repeatable, and accurate results from the scanner operation and orientation system. Critical to the accuracy is the absence of any metal items except for the dowel bars in the vicinity of the joints being tested. Metal in the scanner and orientation system should be minimized. The scanner operation procedures cover the collecting of the data, reviewing the results on the field data collector, and determining if the data collection test was successful.

1.4 MPI interpretation methods describe how to analyze data collected in the field procedure, steps taken to address interferences, and anomalies discovered during the data analysis to provide accurate results for the dowel bar positions. Also, minimum report content is prescribed for the production of meaningful test information substantiating the results.

1.5 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

A1078/A1078M Specification for Epoxy-Coated Steel Dowels for Concrete Pavement

3. Terminology

3.1 *Definitions:*

3.1.1 *composite misalignment, n*—the composite misalignment using the horizontal and vertical misalignments as components in calculating a total spatial deviation of the dowel axis from design orientation.

3.1.1.1 *Discussion*—Horizontal and vertical misalignment are the legs of a right-angle triangle, and the composite misalignment is the hypotenuse.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.2 *depth, n*—the measured position of the centroid of the dowel bar from the surface of the concrete pavement in the *z*-axis.

3.1.3 *depth deviation, n*—the difference in specified or design depth of the dowel bar versus the measured depth at the centroid of the dowel bar.

3.1.3.1 *Discussion*—Values are expressed as either positive for additional depth or negative for less depth.

3.1.4 *horizontal misalignment, n—also referred to as horizontal skew*, the amount of horizontal rotation in a dowel bar about its center point when viewed from above the pavement or lane where the test was initiated.

3.1.4.1 *Discussion*—Rotation in a clockwise direction is reflected as a positive value. Rotation in a counter-clockwise direction is reflected as a negative value. The value is the distance from specified or design orientation to the as-measured location on the end of the dowel bar. See Fig. 1.

3.1.5 *horizontal translation, n—also referred to as dowel position (x-position)*, the movement of the dowel bar laterally along the centerline of the sawed joint in the concrete pavement.

3.1.5.1 *Discussion*—Positive values are expressed for movement away from the starting point of the test.

3.1.6 *side shift, n*—the movement of the dowel bar longitudinally from the centerline of the transverse joint (*y*-axis) in the concrete pavement.

3.1.6.1 *Discussion*—Values are expressed as either positive for movement to the right of the joint or negative to the left of the joint. This term can be used interchangeably with *longitudinal translation*. See Fig. 1.

3.1.7 *testing coordinate system, n*—spatial location reference methodology for establishing baselines to measure from in three dimensions.

3.1.7.1 *Discussion*—The *x*-axis lies along the transverse joint line, the *y*-axis lies along the pavement or lane edge, and the *z*-axis is down from the surface of the concrete pavement. Its origin point (0, 0, 0) begins with the intersection of the transverse joint line (*x*-axis), the longitudinal edge of the pavement (*y*-axis), and the surface of the concrete pavement (*z*-axis). Positive values represent points away from the edge of pavement for the *x*-axis, to the right of the joint for the *y*-axis. (Note that it can be the inside or outside edge pavement depending upon the direction the test is performed, and down from the surface of the concrete pavement for the *z*-axis.)

3.1.8 *vertical misalignment, n—also known as vertical tilt*, the amount of vertical rotation in a dowel bar about its center point when viewed from the edge of pavement or lane where the test was initiated.

3.1.8.1 *Discussion*—Rotation in a clockwise direction is reflected as a positive value. Rotation in a counter-clockwise direction is reflected as a negative value. The value is the

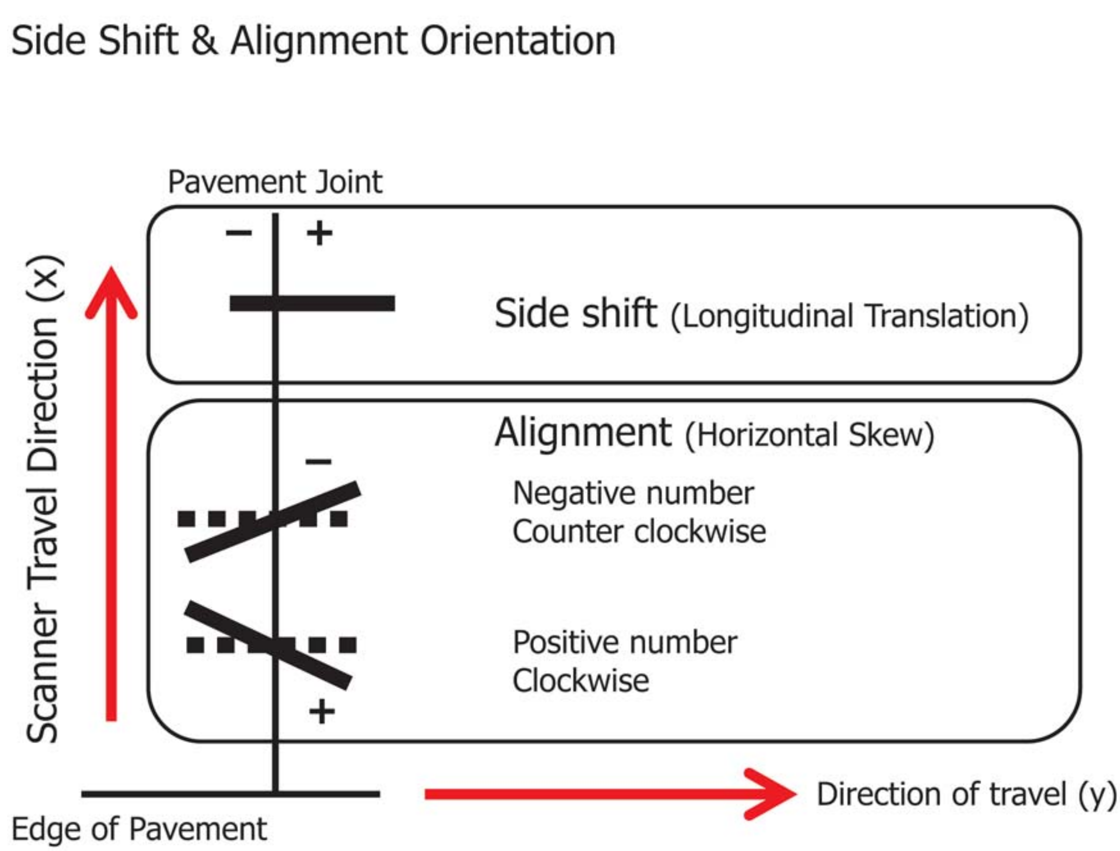

FIG. 1 Side Shift and Alignment Orientation

distance from specified or design orientation to the as measured location on the end of the dowel bar.

4. Summary of Test Method

4.1 Set-up for a test in the field requires assembling and setting the fiberglass rail (orienting) system that the scanning device travels on parallel to the joint that contains dowel bars across the joint. See Fig. 2 for orientation on the joint. Care should be taken to ensure that the *x*- and *y*-coordinate starting points are correctly established. The *x*-coordinate orientation is referenced to the edge of pavement or lane. The *y*-coordinate is referenced to joint centerline. The rail (orienting) system should be clearly marked to aid in locating these critical references. The data collection device input should also be performed during the set-up phase where the location of the test is identified by highway number, cardinal direction (north, south, east, or west), lane number, project stationing, and joint number. It is important to check the dowel bar size selected in the data collector software since it contains the scanner-specific calibration file for the dowel bar size selected and is used by the measurement algorithms. In addition, the operator should input project specification requirements of design depth of dowel bars, tolerances for bar misalignment, and side shift. The operator should check the communication connection between the data collector and scanner prior to starting the data collection.

4.2 Prior to starting the test, the operator should inspect the adjacent area within 10 ft [3 m] of the rail (orienting) system for any metallic objects that could interfere with the quality of data taken. Metallic interferences can be vehicles, equipment, tools, underground duct banks, pipes, direct buried cables, and safety shoes with metal. Metal objects such as reinforcing structural steel in barriers or guardrail systems near the end of the rail (orienting) system can affect the edge-of-pavement results. Metallic items that cannot be removed from the test area should be noted for inclusion in the report during the analysis period.

4.3 The scanner should be inspected daily prior to the start of testing to make sure that its wheels roll freely, its battery is fully charged, and that there is less than ⅛ in. (approximately 3 mm) of lateral movement on the rail (orienting) system.

4.4 The test begins with the operator pulling or pushing the scanning device along the rail (orienting) system at walking speed. The scanner movement should be smooth and constant to avoid causing the scanner to jump or lurch forward on the rail system. The operator should stand to one side of the rail (orienting) system to avoid the tripping hazard from the crossties. After the scanner travels the length of the joint or the test area, the operator should review the results shown on the data collector. Field results should display as a minimum a color map showing each dowel bar, and the following quantitative data *x*-coordinate location, depth of dowel bar.

4.5 The data should be transferred from the field data collector to the user's personal computer that contains the manufacturer's proprietary software used to further refine the results. The software allows interpretation and adjustment analysis to produce accurate results. The software should produce reports and summaries that are suitable for quality control records.

4.6 The PC software performs data management for the test data files and reports, and produces maps and summary output files. After selecting a data file for analysis, the measurement algorithm is initiated to calculate the dowel bar *x*-coordinate, depth from surface of the concrete, horizontal misalignment, vertical misalignment, and minimum concrete coverage at the dowel bar end closest to the top of concrete. From the measurement data deviation from design depth, deviation from the *y*-coordinate (side-shift), and composite misalignment (a calculation of combining *x*-coordinate and *y*-coordinate misalignments) are calculated. The software should be able to compare the project specification limits inputted by the operator to the calculated measurements, and highlights deviations outside of the limits. The software should allow the operator to block out strongly deviating values due to the physical location of the bar being outside of the operating limits for achieving the stated accuracy tolerances.

4.7 The PC software provides signal results quality indicators for the three interior sensors collecting the electrical signal. These indicators, used in conjunction with the signal curves, allow the operator to detect interferences in the test area. Once a disturbance is detected then the operator should evaluate the cause of the disturbance, such as a tie or thin bar in the longitudinal joint, and decide whether to do one of the following: *(1)* insert a value for a dowel bar, *(2)* delete a value for a dowel bar, or *(3)* do nothing and just note the interference. Insertion or deletion of dowel bars does not alter the original

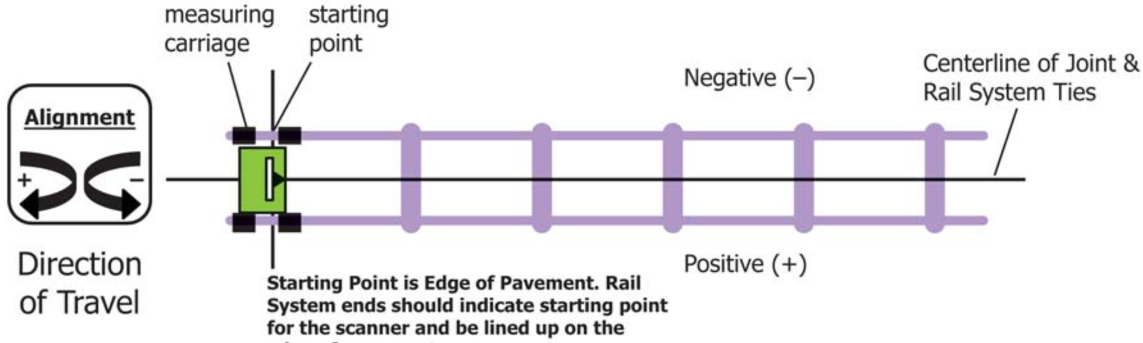

FIG. 2 Rail (Orienting) System

data file nor the original results. It does allow for compensation within the algorithms to more accurately reflect the true position of the bars in the joint. The quality indicators should guide the operator in this process; with each successive insertion or deletion the quality values should improve.

4.8 The PC software should produce output files capable of being printed as a colored map showing the dowel bars in the joint, a plan and section view with project specification tolerance limits, values for *x*-coordinates, depth, *y*-coordinate deviation (side shift), horizontal and vertical misalignments. A project information box with location and joint number should also be included. The section view of the map should also show the location of both ends of the bar (left and right) versus the tolerance limits.

4.9 The PC software should produce a data file that is compatible with commercially available spreadsheet software such as Microsoft Excel that shows project information and measurements and calculations listed above in 4.5.

5. Significance and Use

5.1 Joints in concrete pavements of highways, airfields, and other facilities are exposed to stresses and strains due to traffic and temperature variation. Examining concrete pavement dowel bars (see Specifications A615/A615M and A1078/A1078M) in joints is important to ensure that load transfer at joints between concrete slabs occurs efficiently in order to prevent damage to the pavement and thus shortening its service life. Using magnetic pulse induction (MPI) to examine dowel bars provides owners and contractors a nondestructive testing method to determine that the bars are installed correctly. MPI examination can be performed on existing joints and can support forensic investigations into pavement failures.

5.2 The use of MPI methods and equipment provides a quality control process for installers to use to document that dowel bars are installed correctly in new pavements. Owners use the same device to perform quality assurance activities and accept installed facilities from contractors.

5.3 MPI devices provide reliable quantitative results that are repeatable with not only the same device but also with other calibrated MPI devices.

6. Interferences

6.1 MPI testing relies upon plain concrete pavement where dowel bars are the only metal in and under the pavement in the evaluation area. Adjacent metal objects such as equipment or vehicles, if large enough and within 10 ft [3 m], can influence the test results. Underground utilities can also influence the signal if they contain an electrical current or metal. If the test requires the scanner to start or end with guardrails or barrier wall reinforcing steel within 3 ft [1 m] of it, the test results are affected only locally (that is, the nearest bars to the metal object).

6.2 It should be noted that metal interferences do not affect the entire test run, only the area closest to the metal, and to a reducing effect as the distance from the metal object increases. The MPI PC software should be able to identify metal anomalies that are detected during the scanning, and at minimum show the anomalies in the map reports.

6.3 Ties or thin bars in longitudinal joints that are within 24 in. [0.61 m] to dowel bars can affect up to three dowel bars on each side of the longitudinal joint, depending upon the distance from the tie or thin bar. In most cases, only the closest dowel bars are influenced.

6.4 The MPI systems were developed to examine dowel bars inserted into the pavement during the paving process. It has been successfully used in dowel bars installed using baskets. The shipping or tie wire of the basket frame must be cut in order to obtain meaningful results from MPI methods. The cutting of the wires forces the electrical signal produced and measured through the dowel bars. The MPI system can identify baskets without cut shipping or tie wires in the map report, however, the tabular results will not be meaningful. When measuring dowel bars in baskets, the basket anchors, typically metal rods, should be attached to the bottom continuous transverse wires of the basket frame to minimize the added metal from the anchor influencing the results.

6.5 In the PC software, the interpretation of interferences requires the operator to insert or delete values for dowel bars to allow the algorithms to accurately calculate the position of the dowel bars. In some cases, the interference cannot be compensated for and results in the operator making a note in the reports of the dowel bars that are affected.

6.6 The system calibration limits the dowel bar depth that accurate results can be calculated.

6.7 The physical configuration of the scanner limits the ability to collect accurate data on alignment of the dowel bars.

7. Apparatus

7.1 The magnetic pulse induction system consists of the following components: rail (orienting) system, scanner, field data collection device, and PC software.

7.2 The rail (orienting) system must be constructed out of nonmetallic materials such as fiberglass, except for the rail connectors which may contain a small amount of metal in the form of screws and threaded sockets required for making tight and smooth connections. The crossties must have centerline markings for aligning the rail (orienting) system along the joint centerline. The crossties connect the rail segments and maintain the gauge to ensure that the scanner maintains a straight path during the test. The rail segments connect to the ties with connectors, and must form a smooth joint to avoid causing the scanner to stop or jump when crossing the joints during the test. The end rail segments must have a starting point indication to establish the test starting point for the scanner.

7.3 The scanner is a self-contained unit that induces a pulsed magnetic field under the scanner. The strength of the field can be adjusted depending on the thickness of the concrete. Sensors in the scanner measure the electrical current produced when metallic objects enter into and disturb the magnetic field. Each sensor must collect signal data every 20 milliseconds. The maximum rate of speed for the scanner along the joint is 1.5 ft/s. A lateral resolution of 6 in. or less and a longitudinal resolution of 0.4 in. or less is required from the sensor array in the scanner. The longitudinal position of the sensor array along the joint must have a resolution of 0.5 mm or less. The scanner should have a rechargeable battery sufficient to allow a minimum of 8 h of testing time.

7.4 The field data collector is small enough for the operator to carry while performing the test. It includes an LCD color screen to display maps and data results of recently scanned dowel bar tests. An alphanumeric keypad, either hard-button or virtually displayed on the LCD screen, is required for inputting test information and selecting scanner settings. The field data collector should have a rechargeable battery sufficient to allow a minimum of 8 h of testing time.

7.5 The PC software must be capable of processing the data collected in the field to provide accurate results within the stated precision in Section 14. The results must be repeatable when the same data file is processed multiple times by the same PC or by other PCs running the same software. The data results are presented in tabular form, providing quantitative results for each dowel bar and joints. A color map visually showing the data results for the dowel bars in the joint is required. The software will produce reports for both the map and the tabular results; in both cases the software will save the reports in common electronic file formats of Microsoft Excel for the tabular data and JPEG file format for the maps that allow use by computers without the MPI system software.

8. Hazards

8.1 Be sure to keep back straight and use proper lifting techniques when moving MPI system transport and storage cases. Use two people to lift transport boxes into vehicles for transport. Use transport box wheels when moving them by hand.

8.2 The scanner device may contain a lead acid gel battery. The field data collector may contain a lithium battery. Proper recycling or disposal of the batteries is recommended.

9. Preparation of Apparatus

9.1 Charge batteries in scanner and field data collector.

9.2 Prepare the field data collector by inputting project information including highway or runway number and direction, path or lane number, and width. Select dowel bar size from list of calibrated dowel bars for the scanner. Input project station numbering location and joint number. Input project design parameters for depth and spacing of dowel bars, as well as the offset distance from edge of concrete to first dowel bar centerline. Set the evaluation area to be measured by inputting the length of joint that data collection is needed.

9.3 Assemble rail (orienting) system by connecting the crossties and rail sections together long enough to allow continuous pulling or pushing of the scanner over the test area. End-rail sections should be used to ensure proper alignment to the edge of pavement or lane and scanner starting point so that the *x*-coordinate values are accurate. The rail (orienting) system must be aligned to the centerline of the joint so that the *y*-coordinate values are accurate. See Fig. 2 for orientation of rail system. If the joint being tested is uneven across the joint, then shimming with nonmetallic materials is acceptable to level the rail (orienting) system.

9.4 The test area should be inspected for metallic objects that could influence the data results. If possible, remove the metallic objects from the area. If the objects cannot be moved then the operator should record the description of the metallic items and the distance from the evaluation area. Small metallic items such as nails, dowel bars, steel rods, or hand tools should be a minimum of 3 ft [1 m] from the evaluation area. Large metallic objects such as vehicles, construction equipment, and structural steel should be a minimum of 10 ft [3 m] from the evaluation area.

9.5 Turn on the field data collector and scanner after setting the scanning device on the rails at the starting point.

10. Calibration and Standardization

10.1 Each MPI system is calibrated to specific dowel bar sizes, material type, and lengths. A calibration data file is developed by the manufacturer for each device and bar type. The calibration process involves using the specific dowel bars to develop a software file that adjusts the signal measurement received to provide accurate results for the specific bar type, as well as a correction factor for the metal content in the specific scanner being used. Unless the device is damaged, no periodic calibration is required. Additional dowel bar type calibrations may be added to an existing device. The calibration data file is also used in the evaluation software in the field data collector and the PC. Scanners and software are not interchangeable between MPI systems due to the device-specific calibration files.

11. Procedure

11.1 The test begins by initiating the START TEST command on the field data collector, which activates the magnetic field induction and sensor data collection operations in the scanner. The operator then begins pulling or pushing the scanner along the rail (orienting) system in a smooth, continuous motion until reaching the end of the rail (orienting) system. The speed of the device should be less than 1.5 ft/s [0.5 m/s].

11.2 Once data collection is completed, the field data collector automatically begins calculating results which are displayed on the screen. The operator checks the results to see if they are as expected or if any metallic interferences are present. If the results and the map do not indicate any problems, then the operator should save the results and proceed to the next joint to be tested. If the results indicate anomalies, the operator must accept the test and store the data, or re-perform the test by selecting the REPEAT command on the field data collector. The REPEAT command will discard the previous data and allow the operator to re-run the test. If the scanner jumps the rails or is inadvertently lifted off the rails, then a new test is required. If underground interferences are discovered in the results, then this item would be noted and a re-test is not required.

11.3 Once the field testing activities are completed, the operator connects the field data collector to the PC that contains the MPI system software for transferring the field measurement data files and begins the analysis that will produce the final results.

11.4 After moving and saving the field data measurement files on the PC, the operator can open a single file or select a set of field data measurement files for batch processing. Upon opening a field data measurement, the operator should review the project data for accuracy. If the project data is not correct, the operator should correct it and save the data measurement file. In addition, prior to processing the data measurement files, the operator can correct the dowel bar size selected and used during the test; this will allow accurate results using the corrected dowel bar calibration file. Again, the file should be saved after making this change.

12. Calculation or Interpretation of Results

12.1 After checking the project information, the operator is ready to perform the calculations to provide position data of the dowel bars in the joint. This is initiated by the LOAD DATA command in the software. After the field data measurement information is loaded, then the operator initiates the COMPUTE POSITION command that will provide the values for dowel bar depth, depth deviation from plan depth, side shift, total misalignment, horizontal misalignment, vertical misalignment, and minimum concrete cover from end of dowel bar to top of concrete. Additional interpretation aids may be provided to assist in identifying interferences and anomalies that were detected during the calculations.

12.2 Once the results are initially calculated, the operator should review the values looking for instances where interferences have influenced the results, such as a tie or thin bar in a longitudinal joint may have caused the calculation to not identify a dowel bar. In this case the operator should insert a dowel bar and rerun the calculation. This iteration is repeated or reversed depending upon the results generated until the calculations address the interferences.

12.3 The operator may need to delete a nonexisting dowel bar that the calculation added inadvertently due to an adjacent metallic object. The same steps are followed in an iterative manner until the results are considered reliable.

13. Report

13.1 The MPI system software should be capable of producing a single joint report and multiple joint reports called batch or project reports.

13.2 A report at minimum shall provide the following information. A picture or diagram of the dowel bar as measured configuration which can include a comparison of the design location in the plan and section views where translations, skews, and tilts are visible. Joint identification information is provided on the report which can include stationing, joint numbering, lane information, highway, runway, or taxiway numbering and direction. The report should also have the dowel bar size and length used in the calculations. A tabular section or additional report identifying each dowel bar and showing the values for depth, horizontal location, depth deviation, side shift, cumulative misalignment, horizontal misalignment, vertical misalignment, and minimum concrete coverage. In addition, an editable comment section and the ability for the user to customize additional columns for project specific requirements.

13.3 The project or batch report shall have the same attributes displayed as the individual joint report.

14. Precision and Bias

14.1 Precision and bias of this test method is influenced by the quality of the dowel bar installation. The MPI system will measure with the following precision. Horizontal location will be ±0.15 in. + 3 % [±3 mm + 3 %] of the distance travelled. Bar spacing precision will be ±0.2 in. [4 mm]. Horizontal skew (misalignment) will be ±0.2 in. [4 mm]. Vertical tilt (misalignment) will be ±0.2 in. [4 mm]. Side shift will be ±0.3 in. [8 mm]. Dowel bar depth will be ±0.2 in. [4 mm].

14.2 Repeatability bias is 0.1 in. [2 mm] when the dowel bar installation precision is met.

15. Keywords

15.1 concrete pavement; concrete pavement joint NDT; depth of dowel bars; dowel bar alignment; dowel bar baskets; dowel bar insertion (DBI); dowel bar NDT; dowel bar spacing; eddy current tomography; electromagnetic tomography; magnetic pulse induction tomography; NDT dowel bar examination; pulse induction method; QA/QC dowel bar joints