Standard Practice for

Evaluating Faulting of Concrete Pavements

AASHTO Designation: R 36-21[1]

Technically Revised: 2021

Technical Subcommittee: 5a, Pavement Measurement

AASHTO

American Association of State Highway and Transportation Officials
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1. SCOPE

1.1. This standard describes a test method for evaluating faulting in jointed concrete pavement surfaces based on manual methods and automated methods.

1.2. Faulting is defined as the difference in elevation across a transverse joint or crack as illustrated in Figure 1.

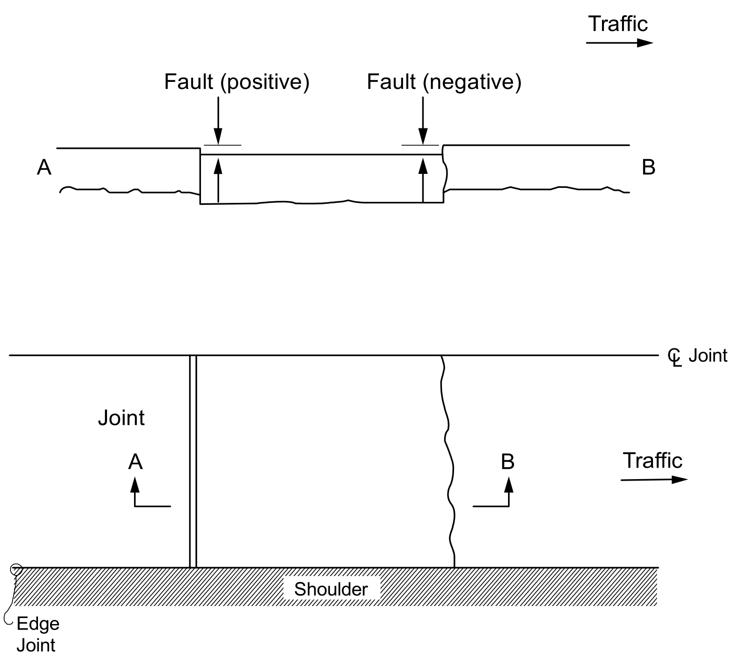

Figure 1—Faulting of Transverse Joints or Cracks (See Section 10.1)

1.3. Detailed specifications are not included for equipment or instruments used to make the measurements. Any equipment that can measure faulting with the accuracy stipulated herein and that can be adequately calibrated is considered acceptable.

1.4. *This standard practice may involve hazardous materials, operation, and equipment. The procedure 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 protocol to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 328, Inertial Profiler
- R 56, Certification of Inertial Profiling Systems
- R 57, Operating Inertial Profiling Systems

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *filtering*—filtering technique that excludes the wavelength contents other than those within the selected wave band.

3.1.2. *longitudinal profile*—the set of perpendicular deviations of the pavement surface from an established horizontal reference plane to the lane direction.

3.1.3. *outside wheel path*—a longitudinal strip of pavement 0.75 m (30 in.) wide and centered 0.875 m (35 in.) from centerline of the lane toward the shoulder.

3.1.4. *spalling*—breakdown or disintegration of slab edges at joints or cracks usually resulting in the loss of sound concrete.

3.2. *Definitions of Terms Specific to this Standard*:

3.2.1. *automated faulting measurement (AFM)*—a module in the Federal Highway Administration (FHWA) Profile Viewing and Analysis (ProVAL) software, used to automatically process longitudinal profiles for faulting computation and reporting based on Method A (see Section 6 this standard.

3.2.2. *automated faulting program (AFP)*—an Excel-based application developed by Florida Department of Transportation under the AASHTO Technology Implementation Group (TIG) program used to automatically process longitudinal profiles for faulting computation and joint detection reporting based on Method B (see Section 7) of this standard.

3.2.3. *faultmeters*—a type of device for manual fault measurement based on contact-type methodology.

3.2.4. *high-speed inertial profiler (HSIP)*—a vehicle equipped with laser height sensors and accelerometers to measure longitudinal profiles based on non-contact-type technology.

4. MANUAL FAULT MEASUREMENT

4.1. It is each agency's responsibility to designate the lane(s) and direction(s) of travel to be surveyed on the basis of sound engineering principles and pavement management needs within the agency.

4.2. Include the sampling rate level of at least 10 percent of all transverse joints or transverse cracks. The 10 percent sampling rate should be uniformly spaced (preferably every tenth joint or crack or more frequently) throughout the project to assess the condition. The location should be documented along with the measurement.

4.3. Record all faulting measured. It is recommended that a precision for faulting be established such that it is calculated to the nearest 1mm (0.04 in.).

Note 1—Care must be taken to not measure spalling and classify it as faulting.

4.4. Use a faultmeter to measure faulting across transverse joints and cracks in the outside wheel path of the survey lane at a sampling rate designated by the agency. The faultmeter should be a straightedge type of device as illustrated in Figure 2. An example of faultmeters and their operations are described in Appendix X2.

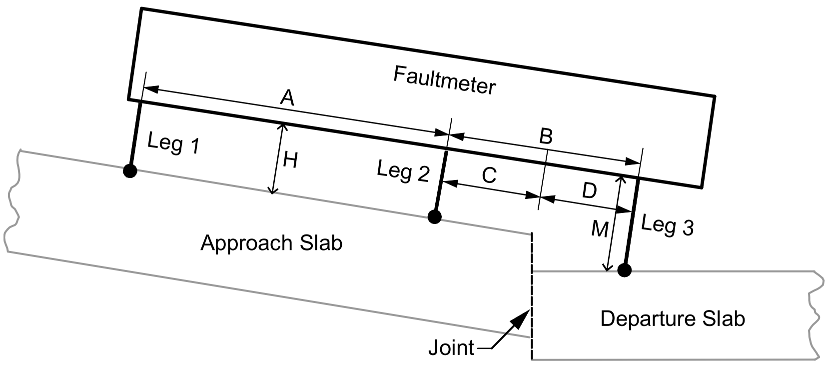

Figure 2—Manual Faulting Measurement with a Generic Faultmeter

4.5. Calculate faulting (F) using the following formula:

$$F = M - H \tag{1}$$

where:

F = faulting, mm (in.);

M = height for measurement Leg 3, mm (in.);

H = height for Leg 1 and Leg 2, mm (in.);

A = distance between Leg 1 and Leg 2, mm (in.);

B = $C + D$; B is recommended to be 300 mm (11.8 in.);

C = distance between Leg 2 and the joint location with a value between 76 mm and 226 mm (3 in. and 8.9 in.); and

D = distance between the joint location and Leg 3 with a value between 76 mm and 226 mm (3 in. and 8.9 in.).

4.6. See Appendix X2 for determining faulting at the joint using the concept of a faultmeter with an inclinometer.

5. AUTOMATED FAULT MEASUREMENT

5.1. It is each agency's responsibility to designate the lane(s) and direction(s) of travel to be surveyed on the basis of sound engineering principles and pavement management needs within the agency.

5.2. *The measurements should comply with the following best practices*:

5.2.1. The HSIP equipment should comply with M 328.

5.2.2. The operation of HSIP equipment should comply with R 57.

5.2.3. The repeatability and accuracy scores based on cross correlation under R 56 are recommended to be greater than or equal to 92 percent and 90 percent, respectively.

5.2.4. For project-level survey, the sampling interval needs to be 19 mm (0.75 in.) or less. No digital filtering during postprocessing of data shall be allowed. Automated triggering is recommended to locate the start and end of survey sections with high precision.

5.2.5. For network-level surveys, the sampling interval needs to be 38 mm (1.5 in.) or less. No digital filtering during postprocessing of data shall be allowed.

5.2.6. Profile data should be collected for both left and right wheel paths.

5.2.7. Observation should be recorded for profiler sensor footprint, aggressive surface textures, tining, slope/grade, spalling, curl/warp, skewed joints, and sealant-filled joints.

5.3. Users can elect either Method A (see Section 6) or Method B (see Section 7) or Method C (see Section 8) to process the HSIP data to compute faulting.

6. METHOD A—PROCESS OF AUTOMATED MEASUREMENTS

6.1. The data processing and reporting should comply with the following best practices for identifying locations of joints/cracks and computing faults. Method A consists of a two-step process. Firstly, joint/crack locations are identified, then an algorithm is used to compute faulting for each joint/crack location.

Note 2—The AFM module in the FHWA ProVAL software (www.RoadProfile.com) is recommended for data processing and reporting, to ensure consistent results based on Method A (see Section 11.2).

6.2. Identify joint/crack locations using an automated method: downward spike detection, step detection, and curled edge detection (see Figure 3).

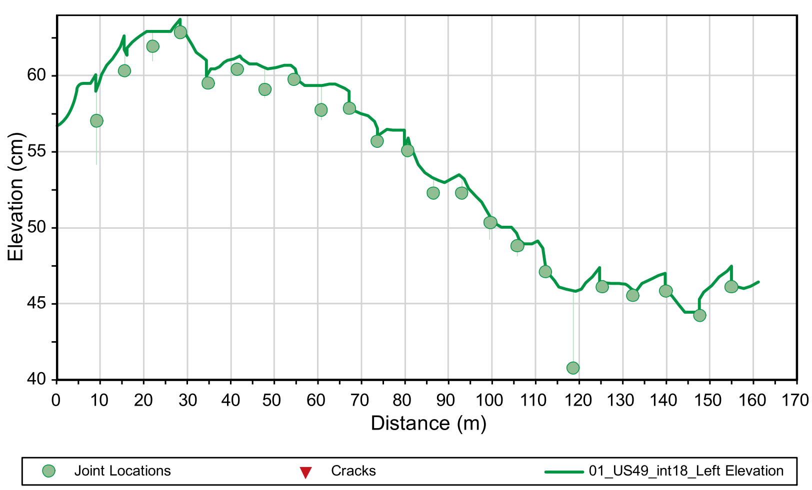

Figure 3—Identification of Joint and Crack Locations

6.2.1. Use the downward spike detection method when profiles consist of downward spikes at joint and crack locations. (See Section 11.3.)

6.2.1.1. Perform anti-smoothing filtering using a moving average filter at a cutoff of 250 mm (9.84 in.).

6.2.1.2. Normalize the filtered profile with its root mean squares (RMS) and produce the spike profile, i.e., making the spike profile unitless.

6.2.1.3. Detect the locations where the spike profile values exceed a threshold value (the starting threshold is –4.0), but avoid multiple hits within a clearance width, 0.5 m (1.64 ft).

6.2.1.4. Screen the above locations to differentiate joints from cracks.

6.2.2. Use the step detection method when faulting is noticeable on profiles. (See Section 11.4.)

6.2.2.1. Deduct profile elevations between consecutive data points resulting in elevation differences.

6.2.2.2. Detect the locations where the absolute values of the elevation differences exceed a threshold value (the starting threshold value is 2.032 mm or 0.08 in.) but avoid multiple hits within a clearance width of 0.91 m (3 ft).

6.2.2.3. Screen the above locations to differentiate joints from cracks.

6.2.3. Use the curled-edge detection method if slab curls are noticeable. (See Section 11.2.)

6.2.3.1. Perform bandpass filtering using a moving average filter with short cutoff at 250 mm (9.84 in.) and long cutoff wavelength at 50 m (150 ft).

6.2.3.2. Simulate a rolling straightedge response with base length of 3 m (9.8 ft).

6.2.3.3. Detect the locations where the simulated rolling straightedge responses exceed a threshold value (the starting threshold is 3 mm or 0.12 in.) but avoid multiple hits within a clearance width of 0.5 m (1.64 ft).

6.2.3.4. Screen the above locations to differentiate joints from cracks.

6.3. Compute faulting following the best practices:

6.3.1. Crop a profile segment that centers a joint with a length of 2.438 m (8 ft).

6.3.2. Separate the profile slices for the approach slab and departure slab (i.e., 1219 mm or 48 in. for each slice).

6.3.3. For the profile slice from the approach slab, mask the area close to the joint based on the joint window input and perform least squares fitting. The fitting would extend to the departure side of the joint for an offset between 76 mm and 226 mm (3 in. and 8.9 in.). Obtain the elevations at the downstream end of the fitted line for later fault computation as P_1^i corresponding to all data points within this offset.

6.3.4. For the profile slice from the departure slab, mask the area close to the joint based on the joint window input and perform least squares fitting. The fitting would be performed from the downstream end of the slice toward the joint location. Obtain the elevations at all data points with an offset between 76 mm and 226 mm (3 in. and 8.9 in.) from the joint location toward the downstream end of the fitted line (i.e., matching the exact horizontal locations of the elevation readout value from the above step) as P_2^i corresponding to all data points within this offset.

6.3.5. Take the differences in the elevations from the above two steps as individual elevation differences (f_i), then compute the faulting using the following formula:

$$F = \frac{\sum_{i=1}^{n} f_i}{n} = \frac{\sum_{i=1}^{n}\left(P_1^i - P_2^i\right)}{n} \qquad (2)$$

where:

F = calculated faulting, mm (in.);

f_i = elevation differences between P_1^i and P_2^i at locations of data points within the offset range, mm (in.);

n = number of data points within the offset range.

P_1^i = elevation at the fitted line for the profile slice on the approach slab at locations of data points within the offset range, mm (in.); and

P_2^i = elevation at the fitted line for the profile slice on the departure slab at locations of data points within the offset range, mm (in.).

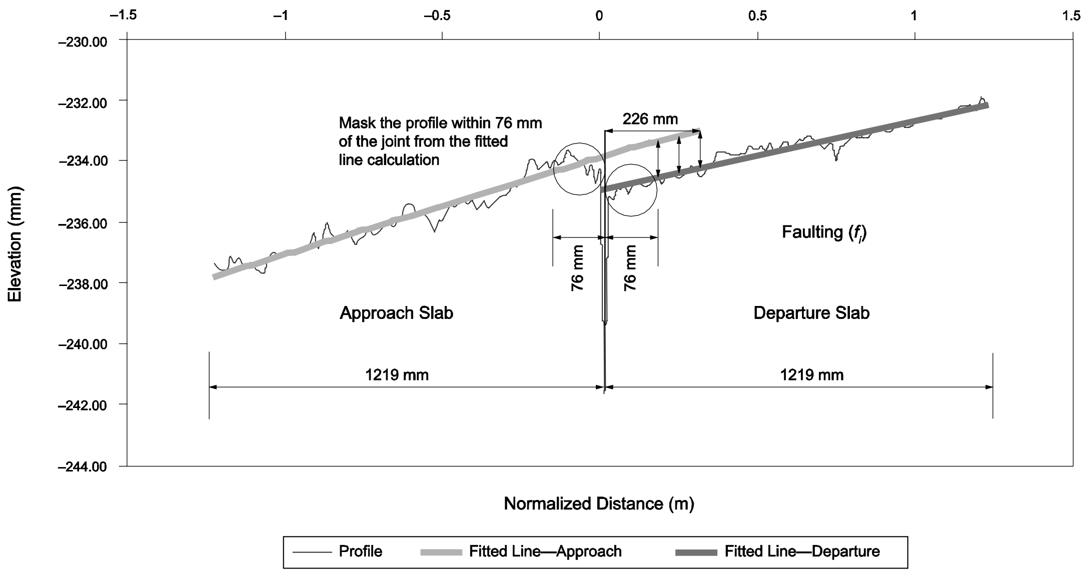

Figure 4—Curve-Fitting of Cropped Profile Slices and Computation of Faulting

7. METHOD B—PROCESS OF AUTOMATED MEASUREMENTS

7.1. The data processing and reporting should comply with the following best practices for identifying locations of joints/cracks and computing faults. Method B combines the joint/crack locations identification and fault computation in one process.

Note 3—The Automated Fault Program (AFP), an Excel-based application developed by Florida Department of Transportation under the AASHTO Technology Implementation Group (TIG) program, is recommended for the data processing and reporting to ensure consistent results based on Method B (see Sections 11.5, 11.6, and 11.7).

7.2. Follow these best practices to identify joint/crack locations and estimate faulting by setting the parameters in such a way that the AFP performs the following tasks:

7.2.1. Automatically sets a seed value for the sensitivity factor (SF) as:

$$SF = 0.01 \times SA \quad (3)$$

where:

SF = the slope between two consecutive profile points, unitless; and

SA = profile sampling interval, mm (in.);

7.2.2. Calculates the vertical grade between consecutive profile elevation points, mm/mm (in./in.);

7.2.3. Identifies a joint or crack location where the calculated grade is greater than the *SF*;

7.2.4. Calculates relative elevation change between sets of profile points P_1 and P_2 separated by a distance of 300 mm (11.8 in.);

7.2.5. Calculates faulting, F, as the average of all individual elevation changes (f_i) calculated in the previous step:

$$F = \frac{\sum_{i=1}^{n} f_i}{n} = \frac{\sum_{i=1}^{n} \left(P_1 - P_2\right)_i}{n} \qquad (4)$$

where:

F = calculated faulting, mm (in.);

f_i = individual elevation change, mm (in.); and

n = number of data sets, P_1 and P_2, within the 76.2-mm (3.0-in.) to 223.5-mm (8.8-in.) range from the center of a joint or crack;

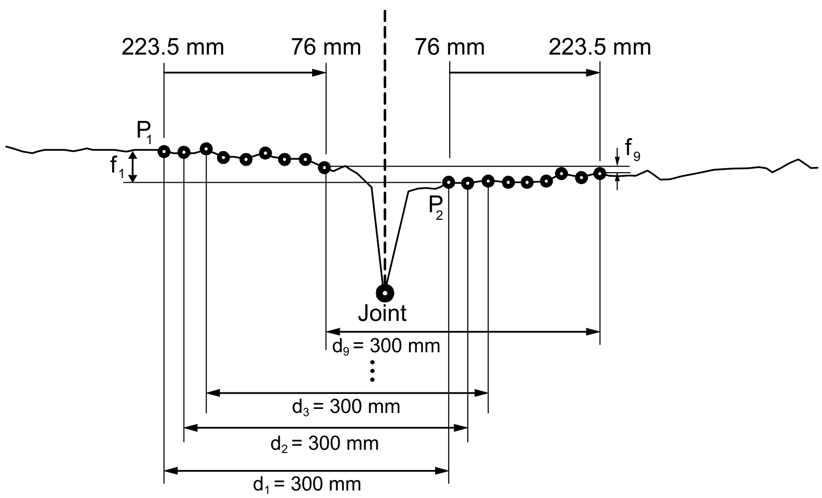

Figure 5—Profile Elevation Points P_1 and P_2 Are Used to Estimate Faulting

7.2.6. Calculates the theoretical joint count, JC_T calculated as:

$$JC_T = \frac{TL}{SL} \qquad (5)$$

where:

JC_T = theoretical joint count for the pavement section tested;

TL = total length of the tested pavement section, m (ft); and

SL = user input slab length, m (ft);

7.2.7. Performs up to nine additional iterations optimizing *SF* until the number of detected joints matches or is closest to JC_T;

7.2.8. Recalculates joint locations and faulting magnitudes;

7.2.9. Saves joint location and faulting magnitude for the optimum *SF*.

8. METHOD C—PROCESS OF AUTOMATED MEASUREMENTS

8.1. The data processing and reporting should comply with the following best practices for identifying locations of joints/cracks and computing faults. Method C consists of a two-step process. Firstly, joint/crack locations are identified and then an algorithm is used to compute faulting for each joint/crack location.

Note 4—This method is intended for 3D automated pavement data.

8.2. *Identify joint/crack locations using an automated method*:

8.2.1. Locate joints by manually digitizing or by using an automated algorithm provided by the 3D data provider.

8.3. *Use the sampling procedure described below to identify the two boxes around point A used to sample range values*:

8.3.1. Identify a point A 178 mm (7 in.) away from the right edge of the lane marking as shown in Figure 6.

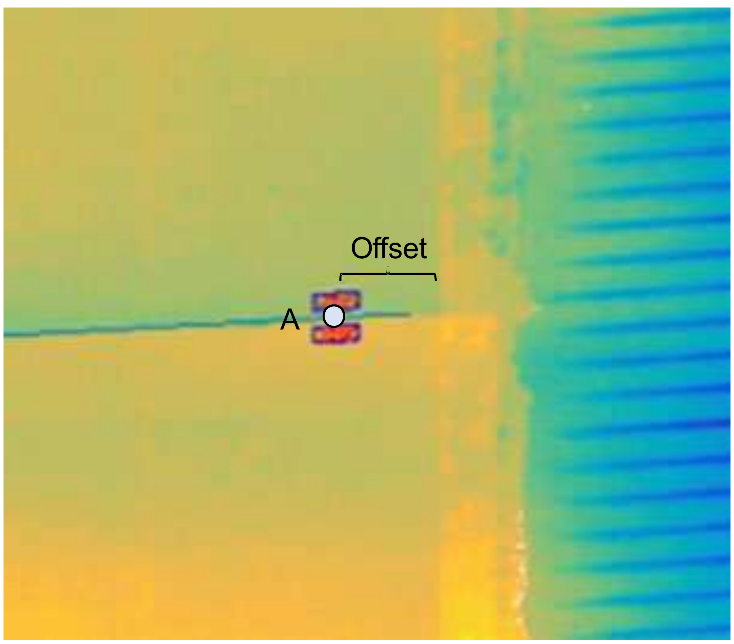

Figure 6—View of Joint Showing Offset to Point A

8.3.2. *Calculate the offset distance, o, as*:

$$o\ (\text{mm}) = 60 + \frac{w}{2}\tan\theta \qquad (6)$$

where:

w = width of the box (100 mm (4 in.)) and

θ = angle made by the joint with the transverse direction.

(This is for skewed joints, and so o (mm) = 60 for perpendicular joints.)

8.3.3. Locate the bottom center of box P at a point o distance away from A along the direction of travel and top center of box Q at a point o distance away from A along the opposite of the direction of travel. The width of the boxes is w = 100 mm (4 in.) and height is h = 50 mm (2 in.) (Figure 7).

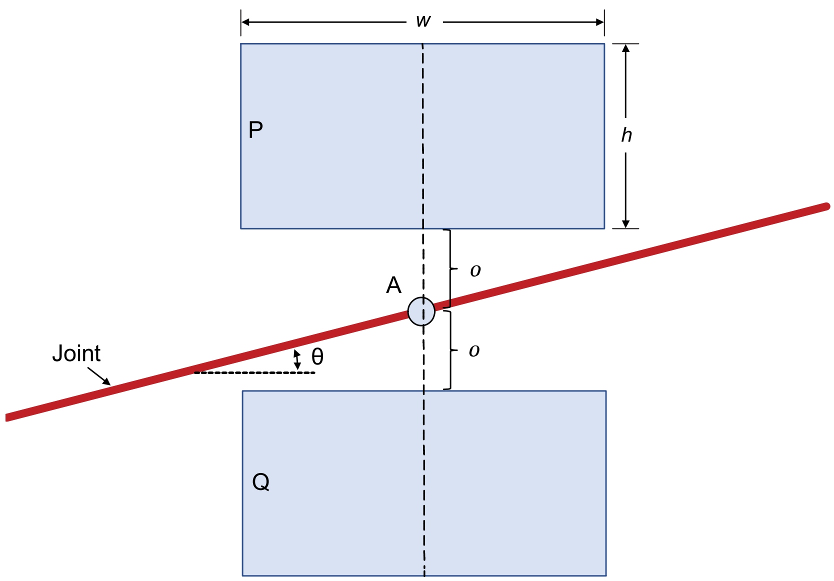

Figure 7—Offsetting Smoothing Boxes from Point A

8.4. Smoothen the pavement surface captured within boxes P and Q using the following steps:

8.4.1. Fit a plane to the points inside box P using ordinary least squares method. The location of the pixel provides the *x* and *y* coordinates while the height of the pavement surface at that point given by the range image provides the *z* coordinate. Let the equation of the fitted plane be:

$$a_P x + b_P y + c_P z + d_P = 0 \quad (7)$$

8.4.2. Repeat Section 8.4.1 for box Q. Let the equation of the fitted plane be:

$$a_Q x + b_Q y + c_Q z + d_Q = 0 \quad (8)$$

8.5. *Calculate the faulting across the joint using the following steps*:

8.5.1. Identify five collinear points inside box P (P1, P2, P3, P4, and P5) and box Q (Q1, Q2, Q3, Q4, and Q5) with P3/Q3 at the center of their respective boxes and the other points placed horizontally at 17-mm intervals (Figure 8).

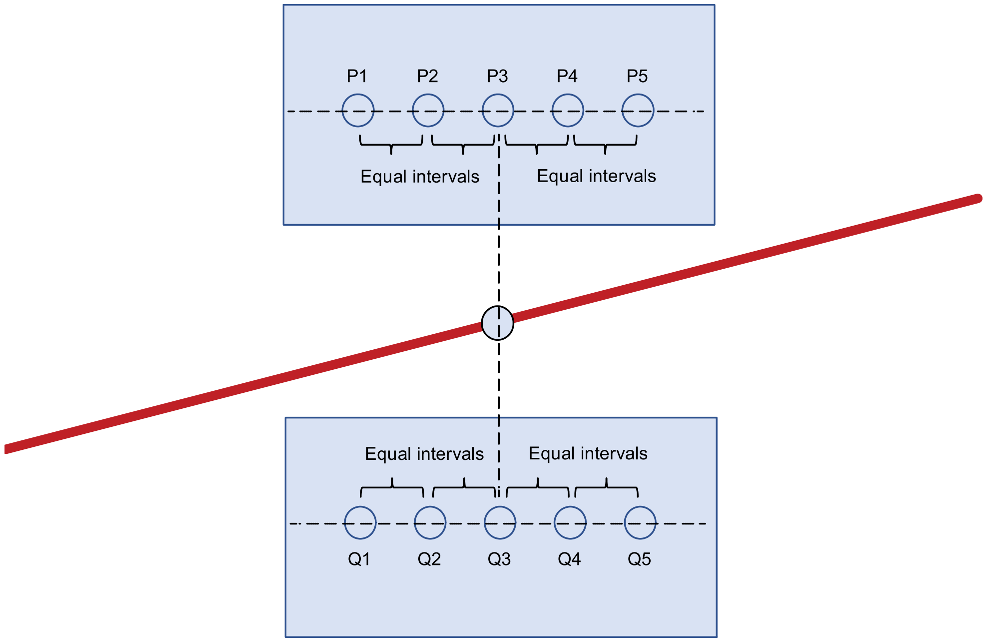

Figure 8—Location of Points P_i and Q_i

8.5.2. Use the equations of the fitted planes for box P and Q to find the height of the plane at these points. For example, for point *M* at (x_M,y_M) in box P:

$$z_M = \frac{-a_P x_M - b_P y_M - d_P}{c_P} \quad (9)$$

8.5.3. Calculate the faulting, *F*, as the average difference between the heights of the fitted planes at each point:

$$F = \frac{\sum_{i=1}^{5} z_{P_i} - z_{Q_i}}{5} \quad (10)$$

9. REPORT

9.1. *At a minimum, report the following items for each test section*:

9.1.1. Section identification;

9.1.2. Date and time of data collection;

9.1.3. Operator(s);

9.1.4. Device(s);

9.1.5. Total length of the data collection section, m (ft);

9.1.6. User inputs typical slab length, m (ft);

9.1.7. Joint/crack locations, m (ft);

9.1.8. Positive and negative faulting at all transverse joints and cracks;

9.1.9. Maximum value of faulting for all joints per 0.1 km (0.1 mi);

9.1.10. Average absolute faulting for the test section, mm (in.);

9.1.11. Total number of detected joints and transverse cracks with measurable faulting; and

9.1.12. Location and faulting magnitude of each detected joint, m (ft) and mm (in.).

10. KEYWORDS

10.1. Concrete pavement; fault measurement; faulting; jointed concrete pavement; joints.

11. REFERENCES

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11.7. Mraz, A., A. Nazef, H. Lee, C. Holzschuher, and B. Choubane. "Precision of FDOT Automated and Manual Faulting Measurement Methods." Transportation Research Board, Paper 12-1376, *91st Transportation Research Board Meeting*, Washington, DC, 2012.

11.8. *ASTM Standards*:

- E867, Standard Terminology Relating to Vehicle-Pavement Systems
- E950, Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference
- E1166, Standard Guide for Network Level Pavement Management
- E1170, Standard Practices for Simulating Vehicular Response to Longitudinal Profiles of Traveled Surfaces
- E1364, Standard Test Method for Measuring Road Roughness by Static Level Method

APPENDIXES

(Nonmandatory Information)

X1. GUIDELINES—QUALITY ASSURANCE PLAN

X1.1. *Quality Assurance Plan*—Each agency should develop a quality assurance plan. The plan should include survey personnel certification training records, accuracy of equipment, daily quality control procedures, and periodic and ongoing quality control. The following guidelines can be used for developing such a plan.

X1.2. *Certification and Training*—Agencies are individually responsible for training and/or certifying their data collection personnel and contractors for proficiency in using the manual faultmeter or the profile measuring equipment according to this standard practice and other applicable agency procedures.

X1.3. *Faultmeter and Inclinometer Calibration Check*—Any manual faultmeter should be verified for height and inclination repeatability and accuracy in accordance with the manufacturer's specifications at a frequency required by an agency. The following components should be calibrated:

X1.3.1. The faultmeter should be checked for transducer calibration by introducing accurately measured blocks of known height to verify the faultmeter's transducer measures accurately through its entire measuring range. If the measurements do not meet the manufacturer's device accuracy, the faultmeter should be calibrated or sent to the manufacturer for calibration;

X1.3.2. The inclinometer, if a faultmeter is so equipped, should be checked for calibration by placing the faultmeter on a flat, level surface and setting the inclinometer to zero. A manufactured wedge with known angle is placed under the faultmeter and the angle is measured. If the difference between the inclinometer measured angle and standard wedge angle exceeds the inclinometer's accuracy, the device should be calibrated per manufacturer's recommendations or sent to the manufacturer for calibration. This calibration procedure should be used only if faultmeter is equipped with an inclinometer.

X1.4. *High-Speed Inertial Profiler Calibration*—Any high-speed inertial profiler should be verified for profile and distance repeatability and accuracy in accordance with R 56 at a frequency required by an agency. The following components should be calibrated:

X1.4.1. The accelerometer should have an internal or external calibration feature that should display errors in calibration to the operator. As an alternative, the acceleration transducer may be calibrated separately in the laboratory and its errors should be reported to the operator;

X1.4.2. The height transducer should be statically calibrated by introducing accurately machined reference blocks 12.7 mm (0.50 in.), 25.4 mm (1.00 in.), and 50.8 mm (2.00 in.) in height which should be placed under the apparatus to verify that height measurements are performed accurately through the entire apparatus measuring range;

X1.4.3. The distance measurement instrument (DMI) should be calibrated by measuring a predetermined distance on a straight section. The measured distance should be at least 1.6 km (1.0 mile) long to determine any significant difference between measured and predetermined actual distance.

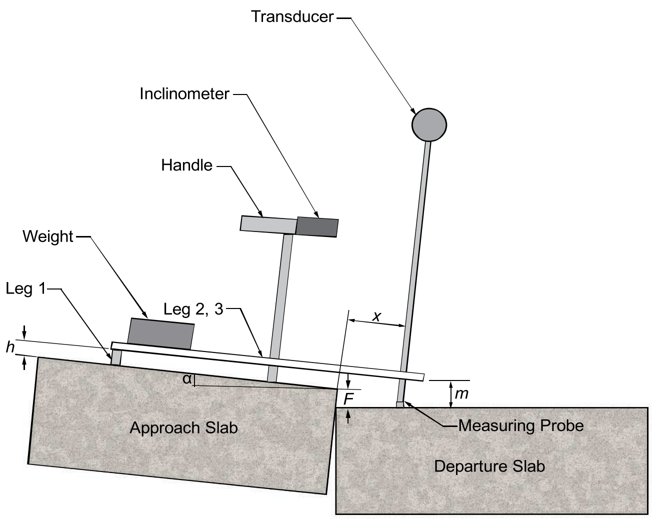
X1.5. *Verification Sections*—Verification sections are selected with known faulting. Faulting on these sections is measured by equipment operators on a regular basis. Evaluations of these measurements provide information about the accuracy of field measurements and give insight into needed equipment calibration. The repeatability precision requirement is recommended to be between and 0.7 mm (0.03 in.) and 2 mm (0.079 in.) at a 95 percent confidence level at a single joint. Verification sections are rotated on a regular basis in order to assure that the operators are not repeating previously known faulting values during the verification. As an alternate to verification sections, remeasure and compare up to 5 percent of the data as a daily or weekly quality check.

X1.6. *Repeatability, Reproducibility, and Bias for the Automated Methods*—The fault magnitudes from two profiling runs on the same joint should not differ more than 0.6 mm (0.02 in.), when collected by the same HSIP, at a 95 percent confidence level. The fault magnitude from two profiling runs on the same joint should not differ more than 0.9 mm (0.04 in.), when collected by two different HSIPs, at a 95 percent confidence level. The bias of the automated fault measurements should not exceed 0.7 mm (0.03 in.) at a 95 percent confidence level.

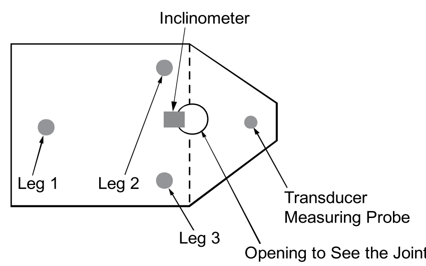
X1.7. *Quality Checks*—Additional quality checks can be made by comparing the previous year's faulting statistics with current measurements. At locations where large changes occur, the pavement manager can require additional checks of the data.

X2. AN EXAMPLE OF FAULTMETERS

X2.1. Example of a faultmeter with optional inclinometer for measuring tilt angle between approach slab and departure slab is shown in Figure X2.1.



(a) Side View



(b) Top View

Figure X2.1—Concept of Faultmeter with Inclinometer

X2.2. *The procedure using the above example faultmeter is as follows*:

X2.2.1. Place the faultmeter on the approach slab and zero the digital inclinometer, if equipped.

X2.2.2. Record the fault value, *m*, measured with transducer.

X2.2.3. If the faultmeter contains an inclinometer, place the faultmeter on the departure slab and record the grade correction angle, α, from the inclinometer, noting the sign as positive (upgrade) or a negative (downgrade).

X2.2.4. Calculate faulting from measured data using the following equation:

$$F = m \text{ (if tilt angle between approach slab and departure slab is not measured),} \tag{X2.1}$$

or

$$F = m \times \cos(\alpha) - x \times \sin(\alpha) \text{ (if tilt angle between approach slab and departure slab is measured)}$$

where:

F = faulting at the joint, mm (in.);
m = faulting measured at a distance x from the joint, mm (in.);
α = measured inclination angle between approach and departure slab in degrees;
x = distance offset between center of measuring probe and center of joint or crack, mm (in.);
$x \times \sin(\alpha)$ = slab angle correction factor, mm (in.).

X2.2.5. Record all calculated faulting and offset distances, m (ft).

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[1] Formerly AASHTO Provisional Standard PP 39. First published as a full standard in 2004. New Section 8, Method C added in 2021.