Florida Method of Test for Automated Measurement of Pavement Cross-Slope and Grade

Designation: FM5-611

1. SCOPE

1.1 This test method covers the automated measurement of pavement transverse cross-slope (CS), longitudinal grade (G), and Drainage Path (DP) using a multi-purpose survey vehicle (MPSV).

1.2 The MPSV is an automated data collection system which consists of a host vehicle equipped with a Global Positioning System (GPS) aided by a tightly coupled Inertial navigation System (INS) and a laser based inertial profiler system. A distance measuring instrument (DMI) is also used as a linear referencing system.

1.3 A minimum of three sensors are mounted in the front bumper and one in the rear bumper. The front bumper laser sensors are required for CS measurement and the rear bumper laser sensor is required for G measurement.

2. APPLICABLE DOCUMENTS

AASHTO PP 69 – Standard Practice for Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profiles

AASHTO M 328 Standard Specification for Inertial Profiler

ASTM E 1656, Standard Guide for Classification of Automated Pavement Condition Survey Equipment

ASTM E 1778, Terminology Relating to Pavement Distress

ASTM E 867, Standard Terminology Relating to Vehicle-Pavement Systems

ASTM C 670 – Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

FM 5-549 – Measuring Pavement Longitudinal Profiles Using a High-Speed Inertial Profiler

FDOT Standard Specifications for Road and Bridge Construction (2014)

3. METHOD SUMMARY

3.1 This method is for automated measurement of CS and G with a MPSV on all pavement types.

3.2 The MPSV and inertial profiler subsystem shall conform to FM 5-549. It shall consist of a minimum of four (4) laser height sensors. Six (6) laser height sensors are recommended, five of which are mounted in the front of the host vehicle and the sixth on the rear bumper. The GPS must be capable of sub-meter positional accuracy, with capability to be integrated with the collected data.

3.3 CS and G measurements must meet the FDOT tolerance of ±0.2% or 0.002 ft/ft (0.002 m/m). The laser height sensors shall operate at a minimum sampling rate as specified in FM 5-549 Section 3.3.

3.4 The MPSV shall be driven along the wheel paths or as determined by the Engineer. While the MPSV is driven at highway speed, the laser sensors shall measure the vertical distance between the vehicle bumper and the pavement surface while the DMI measures the longitudinal distance traveled as specified in AASHTO M 328. The sensors' data shall be combined with vehicle roll, pitch, and yaw data captured by the Inertial Measurement Unit (IMU) through a computerized process to generate CS and G of the pavement surface traveled.

Note 1: Left and right wheelpaths are defined as longitudinal strips of pavement 3 ft. (0.91 m) wide in the direction of travel, centered 3 feet (0.91 m) from the lane centerline toward the adjacent lane or shoulder, respectively. In the absence of markings, an equivalent portion of the pavement surface shall be used.

4. SIGNIFICANCE AND USE

4.1 This method provides an automated means for evaluating the CS and G of a new, rehabilitated, or in-service pavement directly from measured roadway geometry using the MPSV.

4.2 One of the primary functions of the roadway CS is to provide positive surface drainage and to reduce the potential of hydroplaning.

5. APPARATUS

5.1 The MPSV shall consist of a host vehicle and electronic components that conforms to FM 5-549 Section 5 and AASHTO M 328. It shall be equipped with a GPS/INS consisting of 1) IMU, 2) GPS receiver with positional correction capability 3) DMI, and 4) two additional GPS antennas and receivers for precise heading using a GPS Azimuth Measurement System (GAMS).

Note 2: GPS data correction must be achieved in real-time using technologies such as OmniSTAR or U.S. Coast Guard DGPS beacon corrections to enable sub-meter positional accuracy.

5.2 The MPSV shall be equipped with an inertial profiler system consisting of a minimum of four (4) laser sensors, three mounted in the front of the host vehicle for CS measurement correction and the fourth laser located on the rear bumper for G measurement correction. A six (6) laser height sensors configuration is recommended for higher accuracy and for lanes that are 12 feet wide or greater. Two front laser sensors shall be mounted 34.5 inches (87.6 cm) ±0.5 inch (±1.3 cm) to the left and to the right of the bumper midpoint, respectively to measure the pavement longitudinal profiles in the left and right wheel paths of the traveled lane. The third laser sensor shall be mounted in the center of the front bumper and the fourth laser sensor shall be mounted in the center of the rear bumper. The two remaining front laser sensors shall be mounted no less than 58.0 inches (147.3 cm) ±0.5 inch (±1.3 cm) to the left and right of the bumper centerline, respectively. Single-point laser height sensors must meet requirements in FM 5-549 Section 5 and 7. An example of a five-laser MPSV is shown in Figure 1.

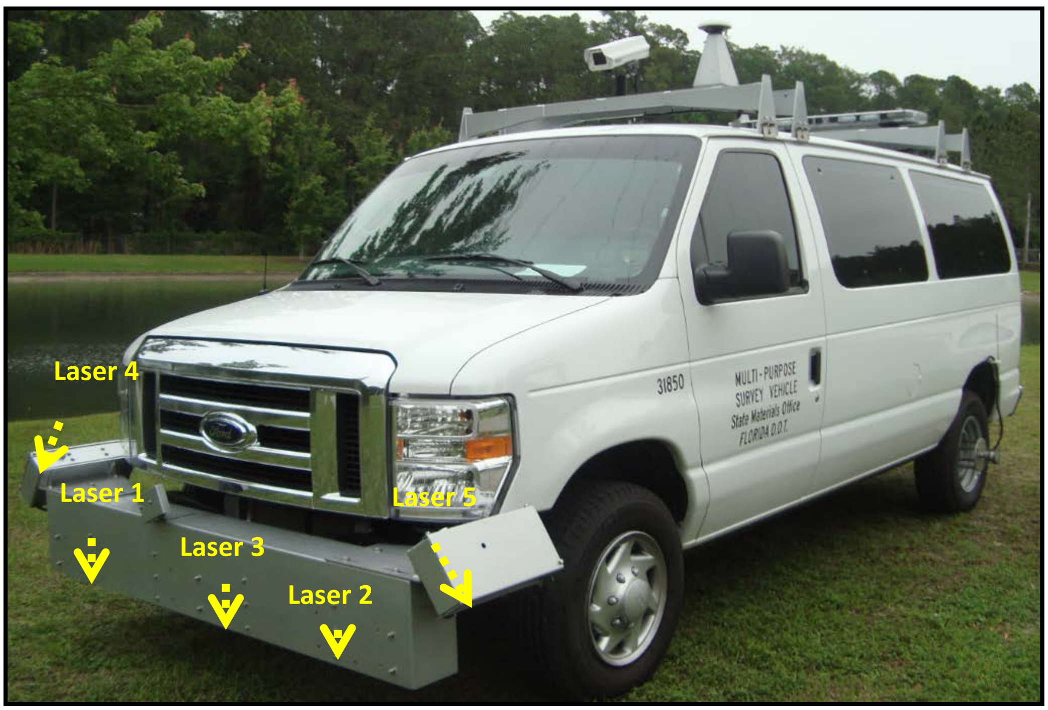

Figure 1. FDOT MPSV with 5 Laser Height Sensors Mounted in the Front Bumper

Note 3: Three laser sensors configuration shall be used when collecting data on narrow pavements, typically with travel lanes less than 12 ft. (3.66 m) wide, and/or on pavements with features such as curb and gutter that would otherwise affect data collected using outward angled laser sensors.

5.3 The GPS/INS shall be capable to collect, process, and store vehicle orientation measurements (i.e., roll, pitch, and yaw), the longitudinally traveled distance, and corrected geographic coordinates (latitude and longitude). The system shall be also capable of processing the raw data and to output CS, G, distance traveled, and geographic location.

5.4 The inertially-aided GPS shall produce CS and G with 0.01 decimal degree resolution and geographic coordinates (latitude and longitude) with minimum resolution of 0.000001 decimal degrees.

5.5 The inertial profiling system shall comply with FM5-549.

5.6 The MPSV shall be equipped with an automated triggering system capable of detecting a reference mark to start, stop, and identify events during the data collection process.

5.7 The DMI shall produce a sufficient series of pulses as specified in FM5-549, Section 5.3. At minimum, the DMI shall produce 1,024 pulses but, preferably, the DMI with 5,000 pulses shall be used.

5.8 The data acquisition system shall have capacity to output, display, and store sensors' data in real time.

5.9 The MPSV shall be capable of data collection at a minimum and maximum speed of 15 mph (24.1 kph) and 60 mph (96.6 kph), respectively. The CS and G data is analyzed to determine roadway DP.

5.10 The host vehicle shall not exceed the axle loads specified by the vehicle manufacturer.

6. SAFETY PRECAUTIONS

6.1 The host vehicle, as well as all accessories, shall comply with all applicable State and Federal laws. Precautions shall be taken beyond those imposed by law to ensure the safety of all personnel and the general public. No testing shall be conducted when dangerous conditions exist.

7. CALIBRATIONS AND VERIFICATIONS

7.1 Verification Section Requirements

7.1.1 Distance Calibration – See FM5-549, Section 7.1.1.

7.1.2 Transverse Cross-Slope – The verification section shall be uniform in roughness and contain at least one horizontal curvature with super-elevation with at least 0.1-mile (0.16 km) long tangent sections at each end. In addition, the verification section shall contain lead-in and lead-out sections of at least 0.1-mile (0.16 km). The triggering mechanism shall be placed at the beginning and end of the test section to accurately capture the location of the section limits. Reference (ground truth) CS data with accuracy better than 0.02% shall be measured at the edge of the lane to minimize the effect of rut and other pavement deficiencies. The left wheelpath shall be painted with white dots spaced approximately 50 ft (15.24 m) apart to aid tracking and reduce vehicle wander. A minimum of 20 control points each representing the average of 3 repeat measurements with ± 0.02% or 0.0002 ft/ft (0.0002 m/m) accuracy shall be used as a ground truth.

7.1.3 Longitudinal Grade – The verification section shall consist of a minimum of three test locations with uniform roughness not exceeding IRI of 95 inch/mile throughout and long enough to contain varying grade and at least 0.1-mile (0.16 km) lead-in and lead-out segments. Each test location will have different G magnitude and have a minimum of three discrete test sites evenly spaced 12 ft. (3.66 m) apart as seen in Figure 2. Reference G measurement shall be performed in the left wheelpath located 9 ft. from edge of pavement. Left wheelpath markers shall be painted white to aid with wheelpath tracking and reducing vehicle wander. The average of the three ground truth measurements for each location shall be reported with ± 0.02% or 0.0002 ft/ft (0.0002 m/m) accuracy. The triggering mechanism shall be placed at the beginning of each test site to accurately capture the location of the section limits.

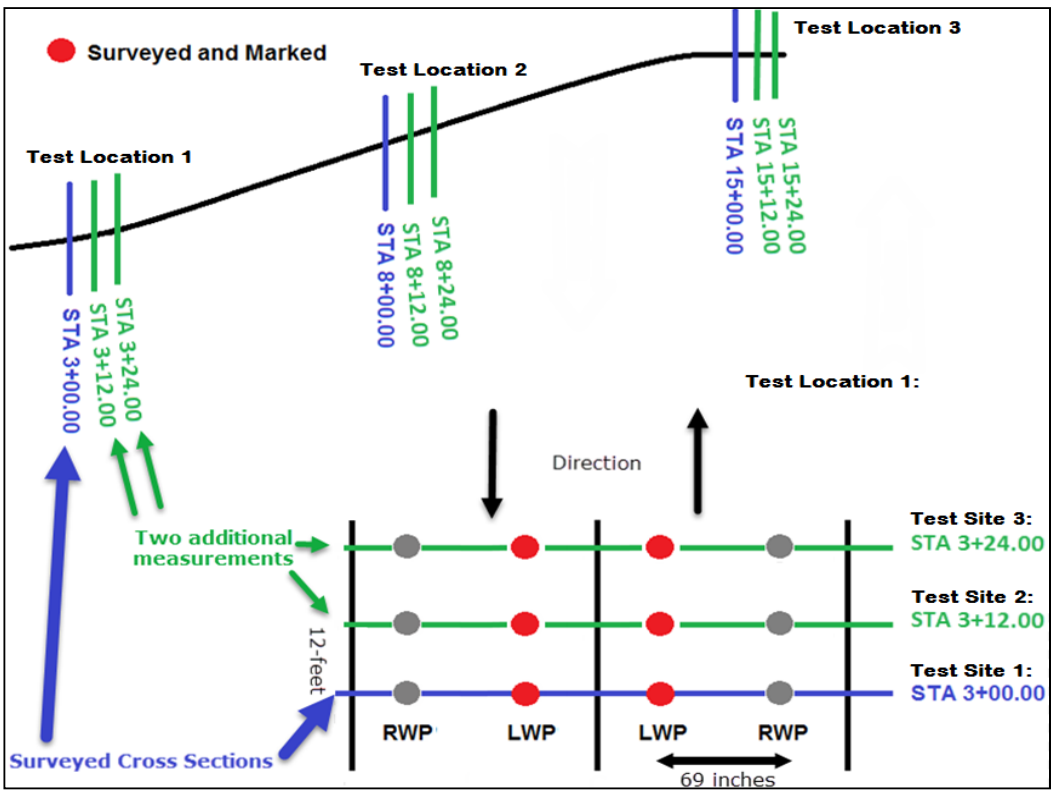

Figure 2. Example Layout of Longitudinal Grade Test Section

Note 4: The 12 ft. spacing between test sites is based on the vehicle wheelbase. If a different vehicle configuration is used, the test site interval may need to be adjusted accordingly.

Note 5: CS and G test sections may be combined into one test section.

7.2 Calibration and Verification Procedures

Prior to calibration, caution shall be exercised to ensure proper operation of all electronic and mechanical equipment. The pavement shall be free of standing water or debris during testing. All calibrations and verifications shall be performed as specified in FM5-549 in addition to the following requirements:

7.2.1 CS and G calibration shall be performed per manufacturer's recommendations to ensure the MPSV and all its components are level. In absence of manufacturer's recommendations, perform calibration as follows:

7.2.1.1 Park the MPSV on a flat surface and carefully level the MPSV using hand jacks until the inertially-aided GPS reads zero degree roll and pitch.

7.2.1.2 Place a flat aluminum calibration bar under the laser sensors to align them. The calibration bar must be in level using a digital level. Similarly, a calibration plate shall be placed under the rear laser sensor. The calibration plate must also be in level and at the same elevation as the calibration bar or calibration blocks used for the front laser sensors. This can be achieve by placing an electronic level with a laser pointed in front of the calibration bar so that the laser projects a beam at the height of the calibration bar to the back of the vehicle, where calibration plate is placed (Figure 3 and 4). Raise or lower the rear calibration plate so the top surface is aligned with the projected laser beam. After that, the calibration plate shall be leveled using a digital level (Figure 5).

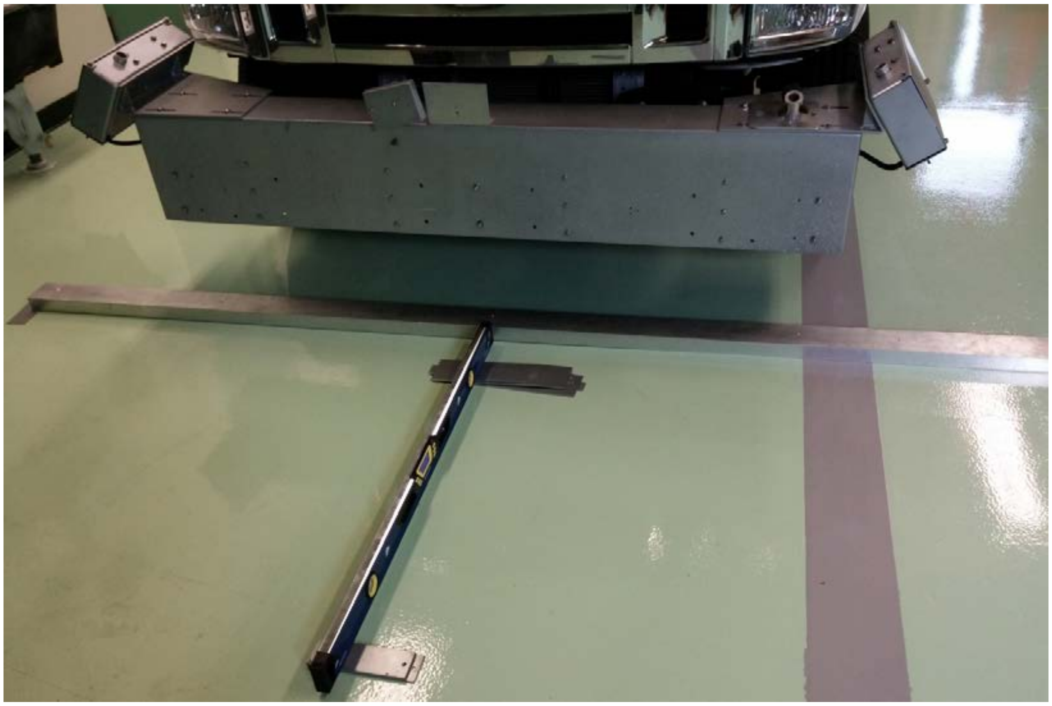

Figure 3. MPSV Calibration for CS and G (Front-View)

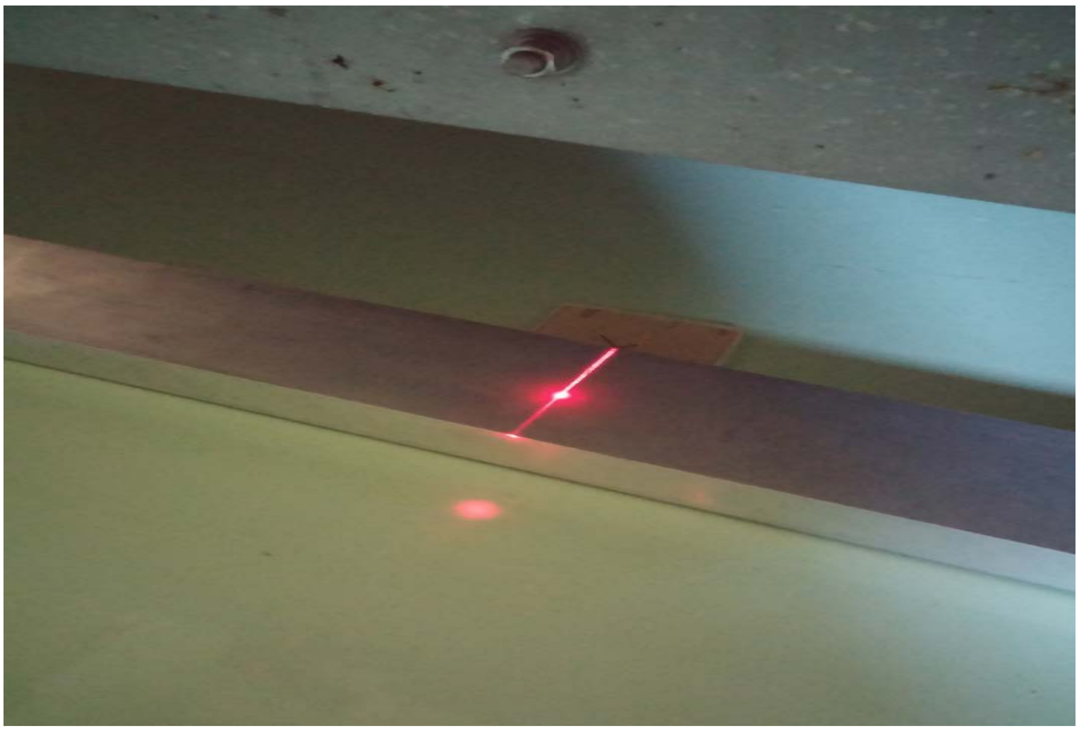

Figure 4. MPSV Calibration for CS and G (Detail of Laser Beam Projected from Digital Level to Calibration Plate Placed Under Rear Laser Sensor)

Figure 5. MPSV Calibration for CS and G (Detail of Calibration Plate Placed Under Rear Laser Sensor)

7.2.1.3 The equipment shall have features to display and report calibration status for the operator’s acceptance.

Note 6: If calibration blocks are used, the floor must be level, otherwise a calibration bar must be used. The calibration bar must be leveled with digital level with minimum resolution of 0.05 degree.

Note 7: If the MPSV is not equipped with the rear laser sensor, the equipment does not have to be calibrated for G.

7.2.2 Transverse CS and G verification shall be performed by collecting data from CS and G verification sections (Section 6.1.2 and 6.1.3). Prior to data collection, the MPSV shall pass a C and G calibration (Section 6.2.1), a distance calibration (FM5-549, Section 7.2.2), a block check (FM5-549, Section 7.2.5), and a bounce check (FM5-549, Section 7.2.6). CS data shall be collected using a sampling interval of 1.0 in (25.4 mm) or less. The CS and G check shall be based on the schedule in Section 6.3. The collected data shall be processed and evaluated against survey-grade CS and G data for the entire test section length. On average, CS and G measurement error shall not exceed the threshold of ±0.2% or 0.002 ft/ft (0. 002 m/m) when compared to ground truth measurement. In addition, no more than 15% of the test locations may exceed the CS threshold and none of them may exceed an error of 0.5% or 0.005 ft/ft (0.005 m/m). Any measurement with error exceeding the threshold shall be considered suspect and shall be investigated.

7.3 Frequency

The distance and CS verification test sections shall be verified every five years or as deemed necessary by the Engineer. The minimum frequency of calibration and verification procedures described in Section 6.2 shall be performed in accordance with Table 1. The calibrations and checks shall be performed every time repair or upgrade of the MPSV components is performed.

Table 1. Frequency of Check and Calibration Procedures

Type of Check or Calibration Procedure	**Minimum Frequency**		
	Daily	Within 7 Days	Within 30 Days
Tire Pressure Check (FM5-549, Section 7.2.1)	N, P, R		
Distance Check and Calibration (FM5-549, Section7.2.2)		P, R	N
CS Check and Calibration (Section 6.2.2)			N, P, R
G Check and Calibration (Section 6.2.2)			N, P, R
Accelerometer Calibration (FM5-549, Section 7.2.4)	N, P, R		
Block Test (Section 7.2.5)			N, P, R
Bounce Test – Network and Project Level (FM5-549, Section 7.2.6.1)		P	N
Bounce Test – Research Level (FM5-549, Section 7.2.6.2)		R	

N – Network Level, P – Project Level, and R – Research Level

8. GENERAL REQUIREMENTS

8.1 Equipment relative to CS, G, and recording systems shall be inspected prior to initiating any test.

8.2 Constant speed shall be maintained throughout the test. Use of cruise control is highly recommended. The test speed shall be within the posted speed limits. In all instances, the maximum test speed shall not exceed 60 mph (96.6 km/h).

8.3 Data collection shall be conducted when the ambient air temperature and humidity are within the ranges described in AASHTO M 328.

9. PROCEDURE

9.1 Before testing, turn on electronic equipment and drive MPSV for at least 25 minutes to warm up the tires and electronic components.

9.2 During the warm up, get familiar with the test section, including the beginning and end of the test locations and wheel tracks.

9.3 Input any system parameters, if needed.

9.4 Bring the MPSV to the desired test speed and align left wheelpath during the approach to the test section. Maintain a constant speed throughout the test section.

9.5 Turn the data collection system on prior reaching the lead-in.

9.6 Start data collection upon reaching the beginning of test section. The beginning of the test section shall be identified as a part of the recorded data.

9.7 Collect data as close to the LWP as possible.

9.8 Avoid data collection at speeds below 15 mph (25 km/h).

9.9 Avoid sudden speed changes to minimize unwanted accelerometer input.

9.10 Collect data using all laser sensors. Note roadway configuration, such as pavement width and other obstacles that could prevent the use of outward angled laser sensors during data processing.

9.11 Observe and check the recorded data for reasonableness.

9.12 At the end of the project limits, end the data collection. The end of the test section shall be identified as a part of the recorded data.

9.13 Continue driving in the lane that is being tested for additional 0.1 mile (0.16 km) and then turn the data collection system off. This establishes lead-out.

9.14 Discard test results that are manifestly faulty according to ASTM Recommended Practice E 178.

9.15 Do not test pavement if debris or standing water is present.

9.16 Perform testing per manufacturer’s operation procedure.

9.17 Raw data, equipment maintenance, and calibration records shall be maintained in a log book located within the host vehicle and made available upon request.

9.18 Prior to leaving the test site, verify that GPS signal outage is shorter than 2 minutes. Also, plot CS, G, rut, and ride data for visual inspection and quality control of collected data.

10. CALCULATIONS

10.1 Process the raw CS, G, and any other required data using the appropriate analysis program.

10.2 If required, calculate the drainage path (DP) using the following equation:

$$DP^2 = W_C^2\left[1 + \left(\frac{G}{CS}\right)^2\right]$$

where:
DP = drainage path length, ft (m)
W_C = pavement drainage width, ft (m)
CS = transverse cross-slope, ft/ft (m/m)
G = longitudinal grade, ft/ft (m/m)

Note 7: Drainage path length increases with steeper G and with shallower CS. It is also influenced by pavement width.

10.3 Determine test section location, length, and limits.

11. REPORTS

11.1 Field Report – The field report for each section shall include, as a minimum, the following items:

11.1.1 Location and identification of test section(s).

11.1.2 Date and time of day.

11.1.3 Weather conditions as necessary (temperature, wind).

11.1.4 Type of pavement.

11.1.5 Lane tested.

11.1.6 Speed of test vehicle.

11.1.7 Test results.

11.1.8 Operator name.

11.2 Summary Report – As a minimum, the summary report for each test section shall include following items:

11.2.1 Location and identification of test section(s).

11.2.2 Lane tested.

11.2.3 Date of test.

11.2.4 Pavement type.

11.2.5 Test results.