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Standard Test Methods for Measurement of Skid Resistance on Paved Surfaces Using a Passenger Vehicle Diagonal Braking Technique[1]

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1. Scope

1.1 These test methods cover the measurement of skid resistance on paved surfaces with a passenger vehicle equipped with specified full-scale vehicle tires and using the diagonal braking mode. These test methods include the following:

1.1.1 *Full-Stop Method*—This represents the nonsteady-state skid resistance on two diagonally locked wheels, as the vehicle decelerates over a wetted pavement surface under specified limits of static wheel load and from a desired speed. The vehicle shall remain essentially parallel to its original direction of motion.

1.1.2 *Pulse-Braking Method*—The deceleration resulting from momentary diagonal wheel lockup (pulse braking) is measured. The vehicle decelerates over a wetted pavement surface under specified limits of static wheel load and at a desired speed. The vehicle shall remain essentially parallel to its original direction of motion.

1.2 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents: therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *ASTM Standards:*

E 178 Practice for Dealing with Outlying Observations[2]

E 274 Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire[3]

E 501 Specification for Standard Rib Tire for Pavement Skid-Resistance Tests[3]

E 524 Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests[3]

F 403 Test Method for Tires for Wet Traction in Straight-Ahead Braking, Using Highway Vehicles[4]

F 457 Method for Speed and Distance Calibration of a Fifth Wheel Equipped with Either Analog or Digital Instrumentation[4]

3. Summary of Test Methods

3.1 The test apparatus for both test methods consists of a passenger vehicle with four wheels, of which two are used for test purposes. The apparatus contains transducers, instrumentation, and a selected brake system for the test wheels. The test wheels are to be equipped with the Standard Pavement Test Tires described in Specification E 501 or E 524.

3.2 For both test methods, the pavement in the test lane is wetted with two applications from a water wagon equipped with a spray bar or other means of distributing water evenly and rapidly. The test vehicle is brought above the desired test speed and permitted to coast onto the wetted section until proper speed is attained. The brakes are then promptly and forcefully applied to cause quick lock-up of the test wheels.

3.3 For the full-stop method, the vehicle operator maintains brake application until a complete stop is obtained. The resulting distance required to stop is recorded with the aid of suitable instrumentation, and the velocity at the moment of brake application is noted. The skid resistance of the paved surface is determined from the resulting stopping distance measurement and test speed as stopping distance number, SDN, as determined from the equations given in Section 10, or as stopping distance, SD.

3.4 For the momentary deceleration (pulse-braking) method, the vehicle operator maintains the locked wheel condition for approximately 1 s, and then releases the brakes. The resulting deceleration during braking is recorded with the aid of suitable instrumentation, and the velocity during brake application is noted. The skid resistance of the paved surface is determined from the resulting deceleration measurement and test speed as diagonal braking number, DBN, as determined from the equation given in Section 10.

NOTE 1—Since tire-tread design has a significant effect on pavement surface skid-resistance measurements, ranking and comparison of pavement surfaces using the Specification E 501 test tire might be considerably different from that using the Specification E 524 test tire.

NOTE 2—Since speed has a significant effect on pavement surface skid-resistance measurements, ranking and comparison of pavement surfaces at higher speeds might be considerably different from that at lower speeds.

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 09.02.

4. Significance and Use

4.1 The knowledge of vehicle stopping distance or deceleration serves as an additional tool in characterizing the pavement surface skid resistance. When used in conjunction-with other physical and chemical tests, the skid resistance values derived from these test methods may determine the suitability and adequacy of paving materials or finishing techniques. Improvements in pavement maintenance practices and schedules may result from use of these test methods.

4.2 The stopping distance or deceleration values measured by these two test methods with the equipment and procedures stated herein do not necessarily agree or correlate directly with other methods of skid-resistance measurements. These test methods are suitable where direct comparison between pavement surfaces are to be made within the same test program.

5. Apparatus

5.1 *Vehicle*—The vehicle shall be a four-wheel passenger car or a light truck, preferably equipped with a heavy-duty suspension system.

5.1.1 *Rear Axle*—Posi-traction or other limited-slip differentials must not be used.

5.1.2 *Braking System*—The brake system shall be capable of rapidly locking the diagonal test wheels and maintaining a locked-wheel condition throughout the test. The test vehicle shall be equipped with appropriate brake system cut-off valves, either manual or electric to prevent brake actuation on the diagonal wheel pair not equipped with test tires.

5.1.3 *Wheel Load*—The static wheel load of the vehicle shall not exceed the rated load of the Standard Tire for Pavement Tests in accordance with Specification E 501 or E 524 and shall be as close to the stipulated load as possible. The vehicle gross weight shall not be less than 3200 lb [1.45 mg].

5.1.4 *Steering System*—Power steering is recommended to minimize control requirements that might result from brake application.

5.1.5 *Tire and Rim*—The test tires shall be the Standard Tire for Pavement Tests of Specification E 501 or E 524 mounted on a 15 by 6 JJ rim. Unbraked wheels of the test vehicle shall be equipped with standard production tread designs, and shall be maintained to provide at least 80 % of "new" tread depth.

5.1.6 *Safety Equipment*—Vehicle lighting and signing shall conform to local requirements.

5.2 *Instrumentation*:

5.2.1 *Vehicle Speed-Measuring Transducer and Indicator*—The transducer shall be a "fifth-wheel"-mounted tachometer generator or pulse transducer and speed-indicating meters shall provide speed resolution and accuracy of ±1.0 mph [±1.5 km/h]. Output shall be directly viewed by the operator and recorded if desired. The slewing rate of the fifth wheel shall be within the limits described in Test Method F 403.

5.2.2 *Distance-Measuring Transducer and Counter*—For the full-stop method, a "fifth-wheel"-mounted transducer, producing at least 1 count per foot [3 counts per metre] shall actuate a high-speed distance counter, visible to the operator, and capable of accepting a count rate equivalent to the number of counts produced at the test speed, or the transducer output shall be recorded.

NOTE 3—The fifth wheel assembly with speed and distance readouts should meet requirements specified in Method F 457.

5.2.3 *Vehicle Test Wheel Revolutions*—Pulse transducers, capable of providing at least 1 count per revolution, or tachometer generators, meeting specifications given in Test Method F 403, shall be mounted on each diagonal-braked wheel to provide indication of wheel lockup. Output shall be directly viewed by operator, recorded, or both.

5.2.4 *Pressure-Sensitive Switch*—A pressure-sensitive switch, such as a hydraulic brake-light switch, requiring 70 to 90 psi [480 to 620 kPa] pressure to close, shall be installed in the wheel hydraulic brake system to actuate the stopping-distance counter.

5.2.5 *Acceleration-Measuring Transducer or Meter*—For the momentary deceleration (pulse-braking) method, an accelerometer, ranged to ±1 g full scale and mounted near the vehicle center of gravity to measure longitudinal deceleration of the vehicle, shall provide deceleration resolution and accuracy of ±0.01 g. The accelerometer frequency response: direct current to minimum 10 Hz (flat ±1.0 %). Transducer output shall be recorded; meter readings shall be monitored by test observer in vehicle.

5.2.6 *Low-Pass Filter*—To minimize vehicle and roadway related vibrations from effecting the deceleration data, a low-pass filter shall be connected to the signal output of the accelerometer. The filter shall be flat ±2 % from direct current to 5 Hz, −3 dB at 9 ± 1 Hz and rolloff at between 12 and 24 dB per octave.

5.2.7 *Multichannel Recorder*—If a multichannel recorder is used during tests with either method, the recorder should meet the requirements specified in Test Method F 403.

5.2.8 *Power Supply*—The power supply for transducers and recorder (optional) should meet requirements specified by transducer and recorder manufacturers.

6. Calibration

6.1 *Speed*—Calibrate the speed indicator of the test vehicle at the test speed by determining the time for traversing, at constant speed, a reasonably level, straight, and accurately measured pavement at least 0.5 mile (0.8 km) in length. Make a minimum of two speed determinations at the test speed. The speed shall be accurate to within ±1 mph [±1.5 km/h] and repeatable to within± 2 mph [±3.0 km/h] when calibrated at 40 mph [65 km/h].

6.2 *Distance*—Calibrate the distance transducer and counter by traversing, at the approximate test speed, a reasonably level, straight, and accurately measured pavement at least 0.5 mile [0.8 km] in length. Initiate the calibration from a complete stop at the beginning of the test course and terminate by stopping at the end of the test course. Distance counter over a 0.5-mile [0.8-km] test course shall be within ±3.0 ft [±1.0 m] and repeatable to within a range of ±4 ft [±1.2 m] when calibrated at 40 mph [65 km/h]. Perform a minimum of two distance calibrations.

6.3 *Vehicle Test Wheel Revolutions*—If pulse transducers are used, verify proper output during the vehicle speed calibration procedure described in 6.1. If tachometer generators are used, calibrate in accordance with the manufacturer's specifications.

6.4 *Pressure-Sensitive Switch*—Select a pressure-sensitive switch responding to the specified pressure by testing it in a hydraulic system equipped with a calibrated pressure transducer or gage having an accuracy of ±3 % of the applied pressure.

6.5 *Accelerometer*—The accelerometer shall be accurate to within ±0.01 g and repeatable to within ±0.02 g when statically calibrated as specified below.

6.5.1 *Electronic Transducer Type*—Conduct calibration of transducer-type accelerometer statically by tilting the accelerometer on a rotary table or another test fixture to incrementally increased or decreased angles with respect to a true horizontal plane and record the accelerometer output values for each angle by observing the chart trace deflections on the recorder used in testing. Follow accelerometer calibration steps specified in Test Method F 403.

6.5.2 *Pendulum Type*—By using a known accurate inclinometer, rotate the pendulum-type accelerometer in 5° increments up to 30 ± 0.2°, recording the accelerometer output at each increment. The accelerometer output in *g*s should agree with the tangent of the angle within ±0.01 g at each increment.

7. Preparation

7.1 *Test Vehicle*—Install test tires on one front and one rear wheel diagonally. Use a similar pair of test tires with the same tread type and condition. Condition new tires by running them at their rated inflation pressure on the test vehicle (or a similar vehicle) at a maximum of 50 mph (80 km/h) for a distance not less than 200 miles [320 km] before using them for test purposes. Dynamically balance all tire and wheel assemblies. Prior to each series of tests, inspect the tires for flat spots, damage, or other irregularities that may affect the results, and reject tires which have been damaged or worn beyond the wear line. The tire inflation pressure shall be 24 ± 0.5 psi [165 ± 3.5 kPa] at ambient temperature (cold). Warm up the tires by traveling for at least 5 miles [8 km] at normal traffic speeds. Adjust vehicle brake system cut-off valves to brake only diagonal test tires, while allowing the other tires to remain free rolling.

7.2 *Test Sections*—Test sections shall be defined as segments of the highway or runway having a pavement of uniform age and uniform composition that has been subjected to essentially uniform wear along its length. For instance, do not include sharp curves and steep tangent sections in the same segment with level tangent sections, and do not include passing lanes with traffic lanes.

7.3 *Test Sites*—Test sites shall be defined as segments of test sections selected for stopping distance or deceleration measurement, and shall include highway traffic lanes, or passing lanes, runway touchdown areas and taxi areas, in both directions of travel.

7.4 *Pavement Wetting*—Wet the test lane at the test site just prior to skid testing using a water wagon equipped with a spray bar or other means of distributing water evenly and rapidly. Make two or more applications of water with a minimum coverage of 0.015 gal/ft^2 [0.6 L/m^2] ±15% per application until the surface is well-saturated (surface cavities are filled with water and runoff results). Wet a sufficiently long segment of the test lane to permit the test vehicle to skid on wet surface and to allow the driver to adjust speed before brake application. Conduct the test immediately after the water truck clears the test area. Rewet the test lane between tests as required to maintain similar wetness conditions.

NOTE 4—Marking and comparing pavement surfaces at different water depths may vary considerably since surface water depth has a significant effect on pavement skid-resistance measurements.

8. Test Speed

8.1 The standard test speed for both the full-stop and pulse-braking methods shall be 40 mph [65 km/h]. Tests may be made at other speeds but not less than 20 mph (32 km/h). Initiate tests within ±1.0 mph [±1.5 km/h] of the desired speed. When the test speed is 40 mph, it is desirable, but not necessary, to cite the speed when quoting test data. For all other speeds, the test speed must be stated. This may be done by adding to the symbol as a subscript, the numerals of the test speed in mph; that is SDN_{30}, SD_{30}, or DBN_{30} indicates stopping distance number, stopping distance, or diagonal braking number at a test speed of 30 mph [48 km/h].

9. Procedure

9.1 *Full-Stop Test Method*:

9.1.1 *Distance Counter Reading*—Set the distance counter to zero prior to testing and record the total counts accumulated during the skid. If a strip-chart recorder is used for the purpose of measuring stopping distance, the recorder pulses may be counted later, but properly mark the chart or have the brake switch apply a mark to the chart when the switch closes.

9.1.2 *Lateral Position of Test Vehicle on Highway*—Normally, test in the center of the wheel tracks of a traffic lane of a highway. A stopping distance number, or stopping distance, may be quoted without qualification only if the test vehicle was so positioned during the test. If, during the test, the vehicle moves outside the wheel tracks for more than 20 % of the stopping distance, or terminates skidding off the test lane, void the test. If testing cannot be conducted in the prescribed manner, identify the test data accordingly.

9.1.3 Wet the pavement in the test lane at the test site as outlined in 7.4. Bring the vehicle above the desired test speed and permit it to coast (transmission gear in neutral) onto the wetted section until proper speed is attained. Then apply the brakes promptly and forcefully to cause quick lock-up of the wheels and to maintain the locked-wheel condition until the vehicle comes to a stop. Note the speed at the moment the brake is applied.

9.2 *Pulse Braking Test Method*:

9.2.1 *Accelerometer Reading*—If a pendulum-type accelerometer is used, set the accelerometer to zero prior to testing and record the deceleration level measured during the pulse braking skid. If an electronic transducer-type accelerometer is used, the recorded deceleration output may be determined later, but properly identify the records.

9.2.2 If a recorder is used, turn it on prior to the start and turn it off after completing the vehicle test run.

9.2.3 Wet the pavement in the test lane at the test site as outlined in 7.4. Bring the vehicle above the desired test speed and permit it to coast (transmission gear in neutral) onto the wetted section until proper speed is attained. Then apply the brakes promptly and forcefully to cause quick lockup of the wheels, maintain locked wheel condition for approximately 1 s, release the brakes and convert to four-wheel braking to bring the vehicle into position for the next test. Note the speed at the moment the brakes are applied and released and the deceleration level measured if a pendulum-type accelerometer is used.

10. Calculation

10.1 *Full-Stop Test Method*:

10.1.1 *Calculation of Stopping Distance Number*—Calculate the stopping distance number, SDN, for each test as follows:

$$SDN = (V^2/15\ SD) \times 100 \tag{1}$$

where:

V = speed of test vehicle at the moment of brake application, mph, and

SD = stopping distance, ft (total count × feet per count)

or

$$SDN = (V^2/127.5\ SD) \times 100 \tag{2}$$

where:

V = speed of test vehicle at the moment of brake application, [km/h], and

SD = stopping distance, [m] (total count × metres per count).

The test results may also be expressed in terms of stopping distance, SD, measured in units of feet [metres]. Stopping distance obtained within the permissible speed deviation may be corrected to the desired test speed by the equation:

$$\text{Corrected } SD = (\text{desired speed})^2/(\text{actual speed})^2 \times \text{actual } SD \tag{3}$$

10.2 *Pulse-Braking Test Method*:

10.2.1 *Calculation of Diagonal Braking Number*—Pavement diagonal braking number, DBN, as measured by an accelerometer is determined from the equation:

$$DBN = 2a \times 100 \tag{4}$$

where:

a = average locked-wheel deceleration corrected for the vehicle free-rolling drag acceleration.

NOTE 5—If an electronic transducer-type accelerometer is used, the values of free-rolling deceleration before and after the locked-wheel portion of the test run are available for correcting locked-wheel deceleration values as denoted by the typical oscillograph-record accelerometer trace shown in Fig. 1. If a pendulum-type accelerometer is used, determination of the average differential deceleration between free-rolling and locked-wheel test conditions requires a separate test run to obtain the average free-rolling deceleration level through the same speed range and with similar surface conditions as measured during the locked-wheel test run.

FIG. 1 Pulse-Braking Deceleration

11. Number of Tests and Retests

11.1 *Skid Resistance of a Test Section*—Perform at least three measurements of skid resistance using either method in each test lane at a given test site and at each selected test speed. Test no less than two sites in a test section. The arithmetic average of either the stopping distance numbers or diagonal braking numbers shall be considered to be the skid resistance of the test section. If statistical or other criteria applied to the stopping distance numbers or diagonal braking numbers for a long test section indicate that it cannot be considered to be uniform, the section shall be treated as two or more sections. For treatment of the results of faulty tests see 11.3.

11.2 *Skid Resistance of a Single Lane*—If the skid resistance of a single lane at a given test site must be known, perform at least six measurements of stopping distance or deceleration at each test speed.

11.3 *Faulty Tests*—Tests that are manifestly faulty or that give stopping distance numbers or diagonal braking numbers differing by more than 5 SDN or DBN from the average of all tests in the same test section shall be treated in accordance with Recommended Practice E 178.

12. Report

12.1 *Field Report*—The field report for each test section shall contain data on the following items:

12.1.1 Location and identification of test sections,

12.1.2 Date and time of day,

12.1.3 Weather conditions (principally temperature, cloud cover, and wind),

12.1.4 Location of each test site and lanes tested,

12.1.5 Test speed (for each test),

12.1.6 Tire type (for each test),

12.1.7 Accelerometer type (for each test), and

12.1.8 Stopping distance number, stopping distance, or diagonal braking number (for each test).

12.2 *Summary Report*—The summary report shall include for each test section data on the following items as far as they are available and pertinent to the variables or combination of variables under investigation:

12.2.1 Location and identification of test section,

12.2.2 Number of lanes and presence of lane separators,

12.2.3 Grade and alignment,

12.2.4 Pavement type, mix design of surface course, condition and aggregate type (specify source if available),

12.2.5 Age of pavement,

12.2.6 Average daily traffic for each year since pavement construction,

12.2.7 Average traffic speed (or speed mix as in the case of grade with heavy truck traffic),

12.2.8 Date and time of day,

12.2.9 Weather conditions,

12.2.10 Lane tested, and

12.2.11 Average stopping distance number(s), stopping distance(s), or diagonal braking number(s) for test section, tire and speed(s) at which reported average was obtained (highest and lowest average values for test sites may be reported); if values are reported that were not used in computing the test section average, this fact shall be so stated.

13. Precision and Bias

13.1 The relationship of observed SDN and DBN units to some "true" value of locked-wheel sliding friction has not been established at this time. As a result, only repeatability is given for these test methods.

13.2 The analysis of available data obtained with an experienced operator indicates that repeated tests using both the full-stop and the pulse-braking test methods show repeatability or agreement within ± 5 % of the average value. Stopping number data obtained with the same operator and under identical test conditions should not be considered suspect unless they differ by more than 5 %.