SAE International™

SURFACE VEHICLE RECOMMENDED PRACTICE

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Light Vehicle Dry Stopping Distance

RATIONALE

Not applicable.

1. SCOPE

This document establishes best practices to measure vehicle stopping distance on dry asphalt in a straight path of travel intended for the purpose of publishing stopping distance by manufacturers and media organizations. It is recommended that the test method within be adopted for all vehicles less than 10 000 lb (4536 kg) GVWR. This procedure is typically used with initial speeds of 100 km/h and 60 mph, but other speeds may be used.

1.1 Purpose

This vehicle stopping distance procedure outlines methodology to provide consistent results within a test facility or test site, using best known practices including standards for test equipment, vehicle and tire guideline preparation, and dry asphalt surface friction compensation.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J299 Stopping Distance Test Procedure

2.1.2 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO21994 2007 Passenger Cars – Stopping Distance at Straight Line Braking with ABS – Open Loop Test Method

TO PLACE A DOCUMENT ORDER:
Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
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http://www.sae.org/technical/standards/J2909_201005

2.1.3 ATSM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org

E445 Standard Test method for Stopping Distance on Paved Surfaces Using a Passenger Vehicle Equipped with Full-Scale Tires

E1136 Standard Specification for a Radial Standard Reference Test Tire

E1337 Standard Test Method for Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using a Standard Reference Test Tire

F2493 Standard Specification for P225/60R16 97S Radial Standard Reference Test Tire

2.1.4 United States Government Federal Safety Standards

Available from U.S. Superintendent of Documents, Washington, DC 20402-0001, Tel: 866-512-1800, http://bookstore.gpo.gov.

Motor Vehicle Safety Standard No. 105 (FMVSS105); Hydraulic and Electric Brake Systems

Motor Vehicle Safety Standard No. 135 (FMVSS135); Passenger Car Brake Systems

3. DEFINITIONS

3.1 Asphalt Surface

Known as asphalt concrete, it is a composite of asphalt binder and aggregate, mixed and compacted to form a road bed.

3.2 ABS

Anti Lock Brake System - a collection of sensing and control hardware installed on a vehicle to prevent wheel lockup during brake application. (ASTM F 1649)

3.3 GVWR

Gross Vehicle Weight Rating - the maximum amount allowable total weight of a vehicle.

3.4 Tire Burnishing

A break-in condition of the tire's tread surface completed under braking and/or miles driven prior to testing.

3.5 OEM-Original Equipment Manufacture

Reference to OEM applies to vehicle manufacturer's specifications.

3.6 Surface Temperature

The temperature of the test surface at the time of the test.

3.7 Adjusted Stopping Distance

The corrected stopping distance adjusted for actual initial speed, surface friction and temperature.

3.8 Tanh

The mathematical hyperbolic tangent function.

4. INSTRUMENTATION AND RECORDING

4.1 Vehicle Parameters

The minimum vehicle data channels required to conduct stopping distance testing are listed in the first column of Table 1 accompanied by suggested full scale ranges and sensor accuracy.

TABLE 1 - VEHICLE PARAMETERS

Variable	Sensor Range	Sensor Accuracy
Longitudinal Velocity	0 to 150 km/h	±0.5 km/h
Longitudinal Distance	0 to 100 m	±0.2%
Brake Pedal Force Trigger	0 to 700 N	±5 N

It shall be ensured that transient vehicle pitch angle changes during braking do not affect the measurement of the velocity and distance variables for the chosen transducer system.

All transducers shall be calibrated according to the manufacturer's instructions. The transducer manufacturer's recommended application software and firmware version shall be used. If parts of the measuring system used can be adjusted, such calibration shall be performed immediately before the beginning of the tests.

4.1.1 Optional Vehicle Parameters

Optional vehicle parameters and their corresponding full scale range and sensor accuracy are given in Table 2. These parameters may be useful for further understanding of results and associated variation in results.

TABLE 2 - OPTIONAL VEHICLE PARAMETERS

Vehicle Data Channel	Sensor Range	Sensor Accuracy
Brake Lining Temperatures	0 to 200 °C	1.0 °C
Brake Master Cylinder Pressure	0 to 20 000 kPa	100 kPa
Brake Caliper Pressures	0 to 20 000 kPa	100 kPa
Road Surface Temperature	0 to 75 °C	0.5 °C
Ambient Temperature	0 to 50 °C	0.5 °C
Longitudinal Accelerometer	0 to 1.2 G	0.01 G
Brake Pedal Force	0 to 1000 N (1500 N max)	±5 N

4.2 Data Recording

Recommend use of digital data acquisition system with the capability to scan all data channels at a minimum sample rate of 100 Hz with the same time reference.

5. TEST CONDITIONS

5.1 Test Vehicle Preparation

5.1.1 Brake Burnish

Condition new brake hardware with 200 stop FMVSS135 brake burnish (see Appendix C). Mileage accumulation, typically in the range of 2500 miles (not to exceed 50% highway), is another method to burnish new brake hardware equivalent to FMVSS135 brake burnish for the purpose of stopping distance testing. Vehicles with regenerative braking technology may require more mileage accumulation. Mileage accumulation up to 5000 miles of normal city/highway driving has typically not resulted in excessive wear of the brakes provided that the brakes have not been overheated.

5.1.2 Tire Burnish

Condition new tires by performing ten 100 km/h ABS stops on dry asphalt. Mileage accumulation exceeding 2500 miles (±500 miles) (not to exceed 50% highway) plus three 100 km/h ABS stops on dry asphalt is another method to burnish new tires. The tire parameters and tread widths should show a steady wear condition with a tread depth of at least 90% of the original value across the whole breadth of the tread and around the whole circumference of that of the new tire. Tire burnish is a critical factor in determining vehicle stopping distance and when comparing stopping distance between vehicles. See Appendix A for examples of tire burnish effects on stopping distance due to mileage accumulation or consecutive ABS stops.

5.1.3 Brake Lining Temperature

Install thermocouples at each corner of the vehicles at the center of the most heavily loaded brake lining shoe or pad following instructions in FMVSS135. The purpose of measuring brake lining temperatures is to establish initial brake lining temperatures between 80 and 120 °C before each ABS brake stop. This can be accomplished by using brake snubs from 80 to 30 km/h at 0.2 G deceleration. For cases where measuring brake lining temperatures is not practical, special attention will be required to ensure that the brake linings are not overheated and that identical brake cooling procedures are used when comparing stopping distances between vehicles.

5.1.4 Tire Inflation Pressure

Tire inflation pressure shall be set to OEM specifications or placard pressure to within 3.5 kPa (0.5 psi). Inflation pressures shall be set to the OEM placard with the tires in their cold state at approximately test ambient temperature. The inflation pressure will then change as the vehicle is driven. Do not adjust the inflation pressure of a warm tire.

5.1.5 Vehicle Test Weight

Vehicle weight shall be set at curb weight with the fuel level set between ¾ and full capacity. Stopping distance testing shall occur with driver and test instrumentation only. The total load of the driver plus instrumentation should not exceed 150 kg. If the vehicle is to be tested in any other load condition (e.g., GVWR), then the additional payload shall be evenly distributed such that cross-axle variations do not exceed 50 kg.

5.1.6 Vehicle Operational Test Conditions

Vehicles with an automatic transmission should have the gear selector in highest forward gear during stopping distance testing. Vehicles with manual transmissions should disengage the clutch or shift into neutral before applying brake pedal during stop. All vehicle openings (windows, hood, trunk, etc.) should be closed. All vehicle accessories should be turned off, except for headlights if required for test track operation.

On vehicles equipped with a vacuum booster, the brake force depends on the vacuum level of the vacuum brake booster. Therefore, a sufficient vacuum shall be ensured at the beginning of braking. To achieve a sufficient vacuum level, it is recommended to move the vehicle in a drag operation for a short time during the cooling phases between individual braking events. When doing so, the accelerator pedal can be released for at least 10 s at high engine speed (e.g., by engaging a suitable gear). Afterwards, the brake shall not be operated before the next measurement because this will reduce the vacuum level that was established before.

5.2 Test Track Conditions

5.2.1 Test Track Ambient and Surface Temperature

The surface temperature of the test track shall be between 5 and 55 °C and its variation during a sequence of measurements shall not exceed 10 °C. Ambient temperature should be between 5 and 40 °C and its variation during a sequence of measurements should not exceed 10 °C. Surface friction is normalized by the test surface temperature outlined in 5.2.2. Record the ambient and road surface temperatures at time of test. For tires intended for summer only use, ambient temperature shall be between 10 and 55 °C and surface temperature of the test track shall be between 10 and 55 °C.

5.2.2 Test Track Road Surface Friction

The road surface friction coefficient should be measured with an ASTM E 1136 standard reference tire in accordance with ASTM E 1337 method, at a speed of 64 km/h (40 mph) at the time of the test. The purpose of this measurement is to compensate for changes in road surface friction due to changes in environmental conditions such as ambient temperature and road surface temperature. Examples of dry asphalt surface friction variation are shown in Appendix B for both old (>10 years) and new (<1 year) asphalt surfaces. An example regression of road surface friction based on road surface temperature is shown in Figure 1. Road surface friction can be predicted as a function of road surface temperature by using the polynomial equation shown in Figure 1. Note that a surface friction and a temperature will have to be selected as a reference point and surface friction corrections will then be made to this reference point. See Appendix E for an example.

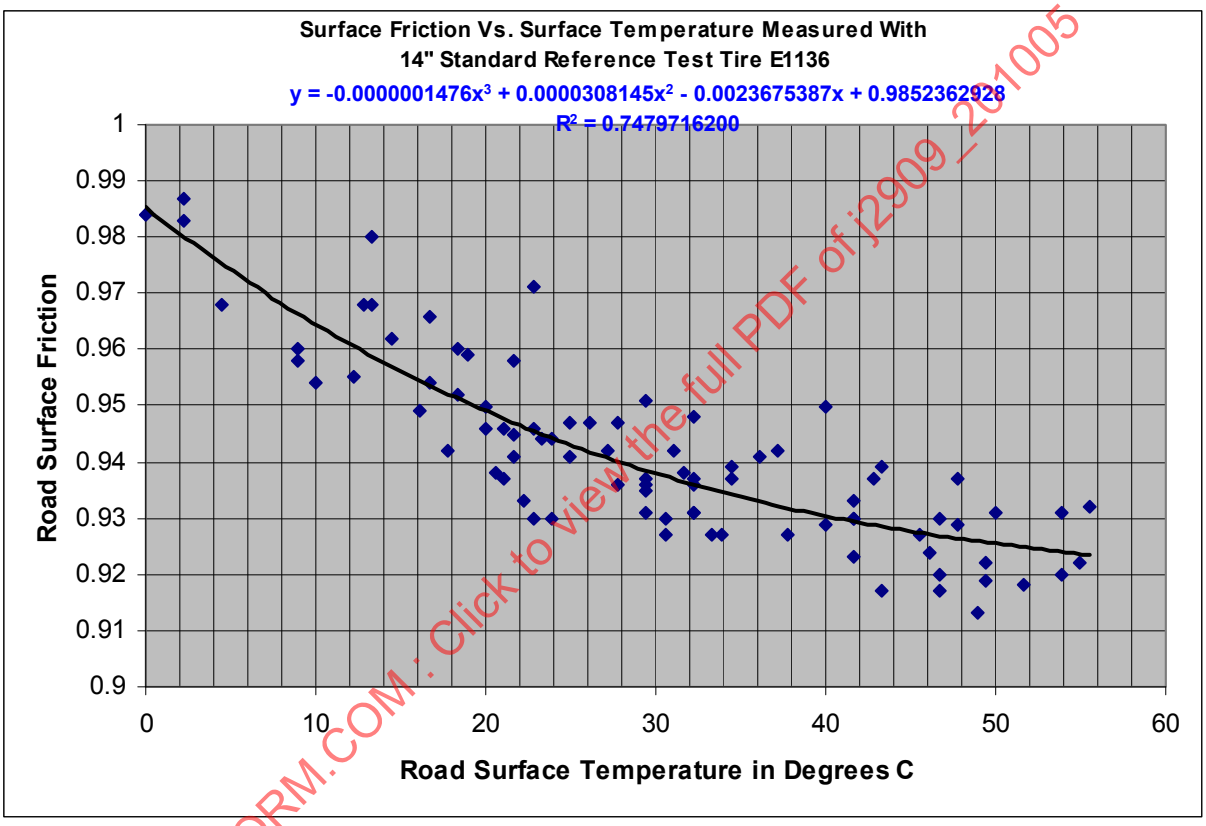

FIGURE 1 - SURFACE FRICTION VERSUS SURFACE TEMPERATURE EXAMPLE

The purpose of measuring road surface friction is to be able to provide a common reference point for comparing stopping distances between vehicles tested at different times. Alternative methods may be considered to establish this common reference point such as using a common reference vehicle with an accompanying reference tire that has had the same brake burnish and tire burnish described in this procedure. Special attention will be required to ensure the tires used for this purpose are equivalent, similar to methods used for the industry standard reference test tire.

5.2.3 Test Track Road Grade

The gradient of the test surface to be used shall not exceed 1% longitudinal inclination and 2% transversal inclination when measured over any distance interval between that corresponding to the vehicle track and 25 m. Special attention will be required to ensure each test vehicle was measured with same road grade when comparing stopping distances between vehicles.

5.2.4 Other Test Track Conditions

The ambient wind velocity in the direction of travel shall not exceed 10 km/h or, if the wind velocity ranges between 10 km/h and 18 km/h maximum, alternate runs in both driving directions. Special attention will be required to ensure that each test vehicle was measured with same wind speed and direction when comparing stopping distances between vehicles.

6. STOPPING DISTANCE TEST PROCEDURE

6.1 Verify all instrumentation is functioning properly.

6.2 Drive to the test track.

6.3 Establish initial brake temperatures between 80 and 120 °C using brake snubs from 80 to 30 km/h at 0.2 G deceleration.

6.4 Accelerate vehicle 5 to 8 km/h above target test speed. Maintain this speed and prepare instrumentation for test. Suggested range of target test speed is 80 to 120 km/h.

6.5 Release accelerator pedal and coast in gear to the target test speed. If the vehicle has a manual transmission, disengage clutch or shift into neutral to avoid stalling vehicle at low vehicle speed.

6.6 For vehicles equipped with ABS, activate ABS by using a spike brake pedal apply. The brake pedal force must be high enough to guarantee ABS control throughout the entire stop after the initial ABS activation. The spike brake pedal apply rate should be a minimum of 6000 N per second and shall not exceed 12 000 N per second within the first 0.1 s after exceeding a force of 20 N. The minimum brake pedal force of 667 N shall be achieved within 0.2 s. After initial brake pedal application, the pedal force is held at a level greater than 667 N.

6.7 For vehicles not equipped with ABS, a best effort stop is performed. Apply a spike brake apply to reach the maximum traction limit within 0.2 s. Then modulate the brake pedal force to maintain the highest deceleration without wheel lockup for longer than 0.1 s at speeds greater than 15 km/h.

6.8 Record initial vehicle speed at start of stop and vehicle stopping distance. Initial speed should not deviate more than 3 km/h from the requested target speed.

6.9 Repeat steps 6.1 through 6.8 for the requested number of stops. For tires with mileage accumulation, a total of 13 stops (3 tire burnish stops plus 10 additional stops – see 5.1.2) are recommended to be performed. For new tires, a total of 20 stops (10 tire burnish stops plus 10 additional stops) are recommended to be performed. Stopping distance measurements shall be made for all the stops including those classified as tire burnish stops. Use cooling laps of at least 1 mile and/or brake snubs from 80 to 30 km/h at 0.2 G deceleration to establish brake temperature of between 80 and 120 °C and brake booster vacuum level (see 5.1.6) before each stop.

7. DATA ANALYSIS

7.1 Calculations

7.1.1 Stopping Distance

Stopping distance shall be measured from the time brake pedal force rises through 60 N until the vehicles comes to a complete stop. Alternate brake pedal transducers such as pressure contact switches that typically activate in the range of 60 N brake pedal force may also be used. See Appendix G for an example of brake switch activation as a function of brake pedal force.

7.1.2 Initial Vehicle Speed Correction

Stopping distance reported shall be corrected for initial stopping speed using the following equation, provided that the actual initial speed deviated from the target test speed by no more than 3 km/h:

$$S_c = (S_m - (A * V_a)) * (V_r^2 / V_a^2) + (A * V_r)$$

where:

- S_c = Corrected stopping distance, m
- S_m = Measured stopping distance, m
- V_r = Requested initial speed, km/h
- V_a = Actual initial speed, km/h
- A = Brake response time factor (0.025 m/km/h) – See Appendix D

See Appendix F for an example.

7.2 Determine Stopping Distance Using Tanh Curve Fit

Use Microsoft Excel, MatLab, or comparable data analysis program to curve fit stopping distance results. For tires with mileage accumulation, curve fit the speed corrected stopping distances using the results from all 13 stops. For new tires, curve fit the speed corrected stopping distances using the results from all 20 stops. Use the Tanh curve fit equation to plot speed corrected stopping distance as a function of the number of stops. For mileage tires, the speed corrected stopping distance will be the result of the 6th stop using the Tanh curve fit equation. For new tires, the speed corrected stopping distance will be the result of the 13th stop using the Tanh curve fit equation. See Appendix F for an example.

7.3 Surface Friction Correction

For dry asphalt stopping distance, the speed corrected stopping distances shall be corrected to the peak friction coefficient for the test surface using the following formula:

$$S_f = (S_c - (A * V)) * (PFC_{act} / PFC_{spec}) + (A * V)$$

where:

S_f = Surface corrected distance
PFC_{act} = Actual Peak Friction Coefficient of test road measured at the time of the test or derived by the adjusted surface temperature referenced in Figure 1 of 5.2.2 (see Appendix E for determining the equation offset corresponding to the facility tested at) or similar adjusted surface temperature curve derived from actual road surface.
PFC_{spec} = Standard Surface Peak Friction Coefficient defined by the end-user
S_c = Corrected stopping distance as described in 7.2 (m)
V = Requested test speed (km/h)
A = Brake response time factor (0.025 m/km/h) – See Appendix D

See Appendix F for an example.

7.4 Stopping Distance Conversion Formulas

7.4.1 Metric to English

$$Df = \left\{\left[\left(D_m - A*100\right)\left(\frac{96.561}{100}\right)^2\right] + A*96.561\right\} \Big/ \left(0.3048\, m/ft\right)$$

7.4.2 Apply this standard equation to convert Stopping Distance in meters at 100 km/h to Stopping Distance in feet at 60 mph.

This reduces to:

Df = 3.059064*Dm + 0.27237 For A=0.025 (m/km/h) ABS Spike Apply

where:

Df = 60 mph stopping distance in feet
Dm = 100 km/h stopping distance in meters

7.4.3 English to Metric

$$Dm = \left[\left(D_f * (0.3048\, m/ft) - A*96.561\right)\left(\frac{100}{96.561}\right)^2\right] + A*100$$

7.4.4 Apply this standard equation to convert Stopping Distance in feet at 60 mph to Stopping Distance in meters at 100 km/h.

This reduces to:

Dm = 0.326987*Df – 0.08904 For A=0.025 (m/km/h) ABS Spike Apply

where:

Dm = 100 km/h stopping distance in meters
Df = 60 mph stopping distance in feet

7.5 Documentation

In addition to recording vehicle stopping distance, the following information is relevant to the state of the vehicle when tested:

a. Test speed and method of measurement, including method of determining trigger point to begin calculating stopping distance.

b. Tire description, tire inflation pressure, and tire burnish description.

c. Brake burnish description.

d. Surface friction or equivalent at time of test.

e. Driveline mode of vehicle during test (2 wheel drive, 4 wheel drive high, all wheel drive, etc.).

f. Ambient and road surface temperature.

g. Recommended reporting format for results is the stopping distance from the target speed (examples: 43.1 m from 100 km/h, 135 ft from 60.0 mph). It is recommended that stopping distance reported in meters be rounded to the nearest tenth and feet to the nearest integer. It is recommended for the target speed in km/h to be rounded to nearest integer and in miles per hour to the nearest tenth.

8. NOTES

8.1 Marginal Indicia

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

APPENDIX A - EXAMPLES OF TIRE BURNISH EFFECT ON STOPPING DISTANCE

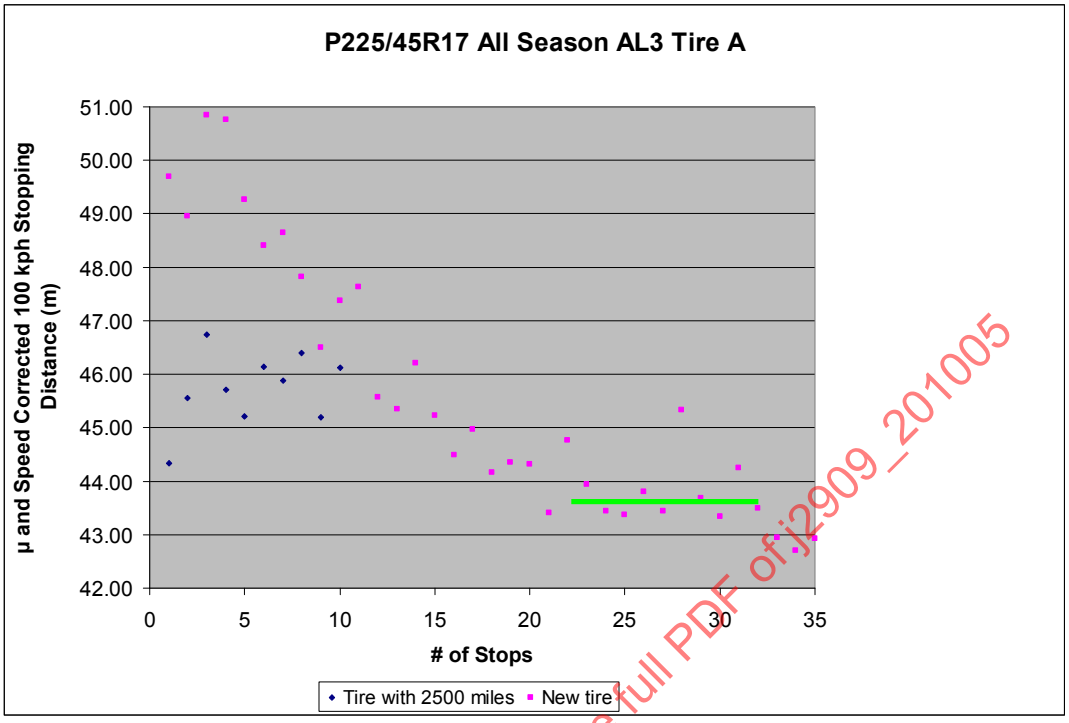

FIGURE A1

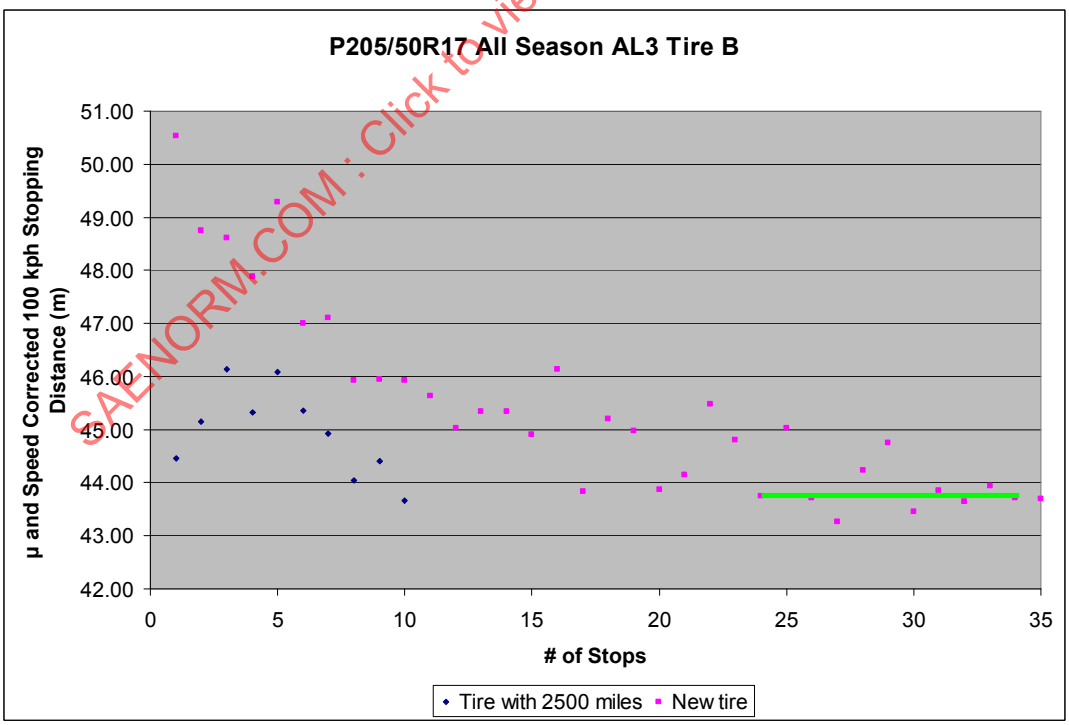

FIGURE A2

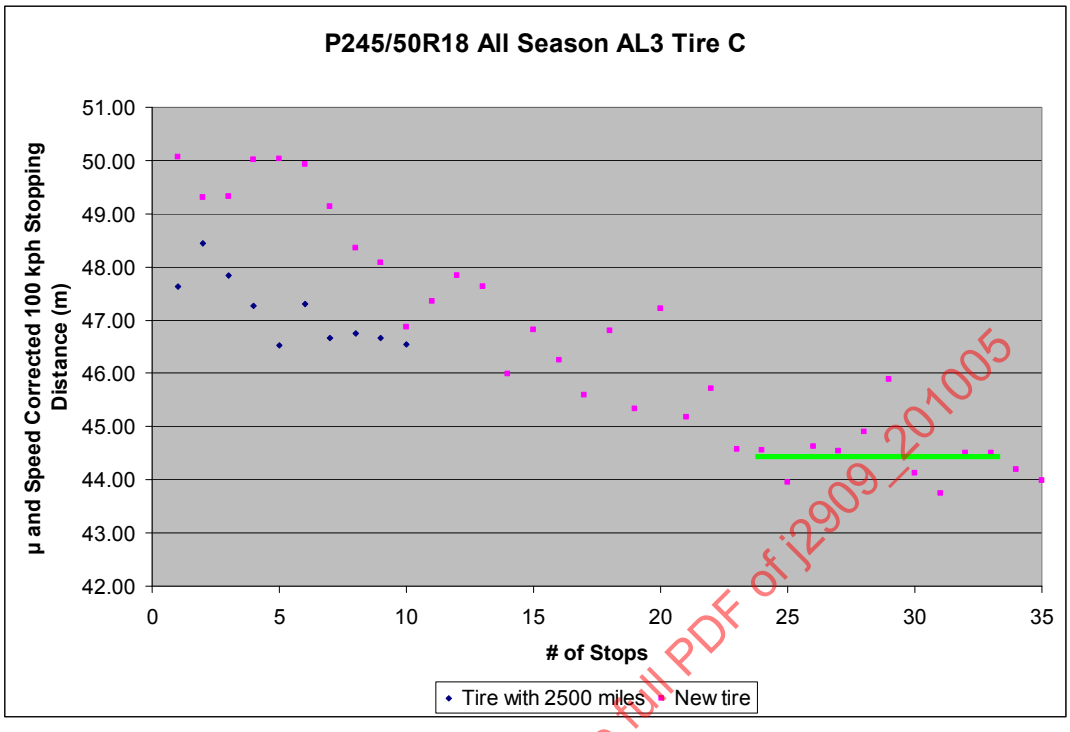

FIGURE A3

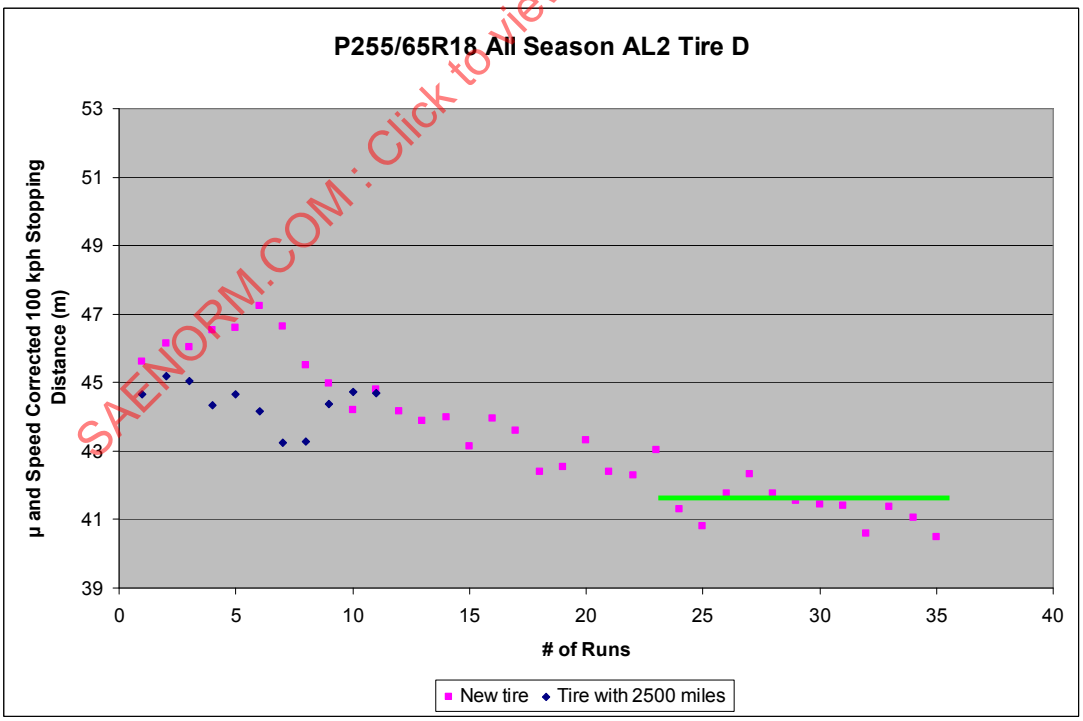

FIGURE A4

APPENDIX B - SURFACE FRICTION EXAMPLES

2007 Measurements - Old Asphalt Surface

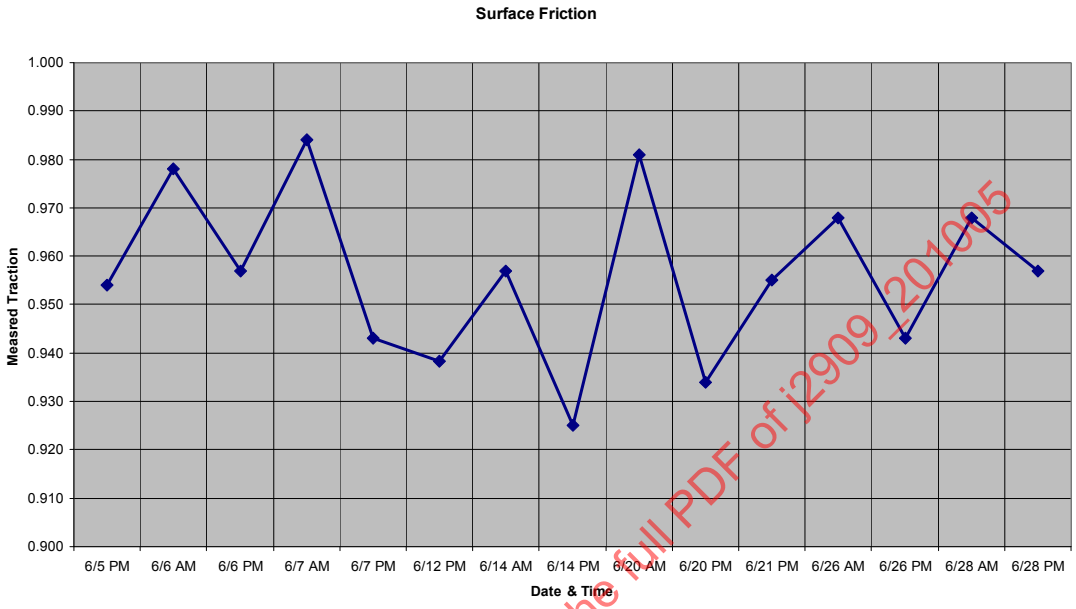

FIGURE B1

2008 Measurements - New Asphalt Surface

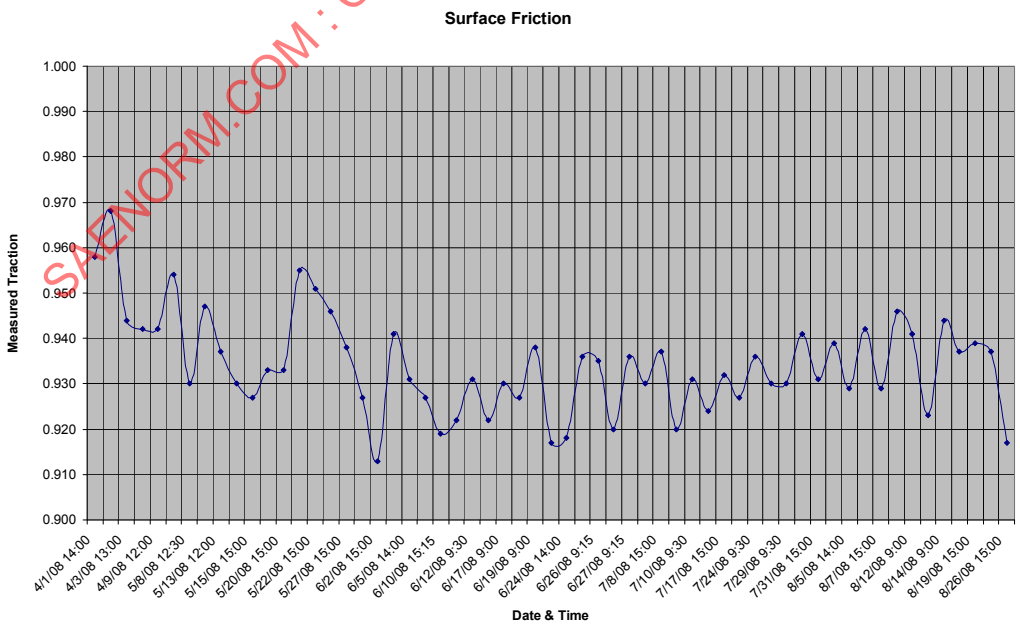

FIGURE B2

APPENDIX C - FMVSS135 BRAKE BURNISH DESCRIPTION (SECTION S7.1)

S7.1.2. Vehicle Conditions.

(a) Vehicle load: GVWR only.
(b) Transmission position: In gear.

S7.1.3. Test conditions and procedures. The road test surface conditions specified in S6.2 do not apply to the burnish procedure.

(a) IBT: <= 100 degrees Celsius (212 degrees Fahrenheit).
(b) Test speed: 80 km/h (49.7 mph).
(c) Pedal force: Adjust as necessary to maintain specified constant deceleration rate.
(d) Deceleration rate: Maintain a constant deceleration rate of 3.0 m/s^2 (9.8 fps^2).
(e) Wheel lockup: No lockup of any wheel allowed for longer than 0.1 seconds at speeds greater than 15 km/h (9.3 mph).
(f) Number of runs: 200 stops.
(g) Interval between runs: The interval from the start of one service brake application to the start of the next is either the time necessary to reduce the IBT to 100 degrees Celsius (212 degrees Fahrenheit) or less, or the distance of 2 km (1.24 miles), whichever occurs first.
(h) Accelerate to 80 km/h (49.7 mph) after each stop and maintain that speed until making the next stop.
(i) After burnishing, adjust the brakes as specified in S6.3.4.

APPENDIX D - BRAKE RESPONSE TIME EFFECT ON STOPPING DISTANCE CONVERSION

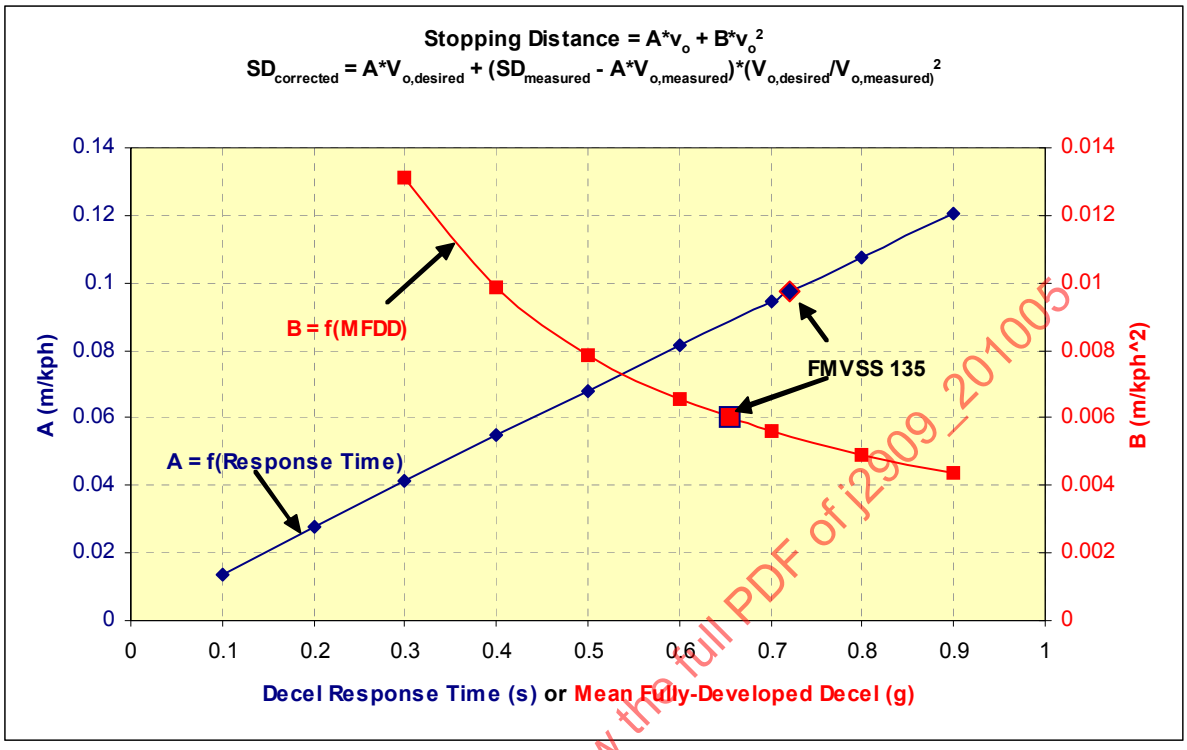

FIGURE D1

A is set to 0.025 m/km/h for dry stopping distance with spike brake apply due to deceleration response time not exceeding 0.2 s.

APPENDIX E - SURFACE FRICTION CORRECTION BASED ON SURFACE TEMPERATURE EXAMPLE FOR DETERMINING THE EQUATION OFFSET CORRESPONDING TO THE FACILITY TESTED AT

Equation from Figure 1:

$y = -0.0000001476x^3 + 0.0000308145x^2 – 0.0023675387x + 0.9852362928$

Test surface has one measurement of 0.96 at a surface temperature of 30 °C.

The equation from Figure 1 yields a surface friction of 0.937 at 30 °C. A compensation factor of 0.022042 can be added to the right hand side of the equation in Figure 1 to yield:

$y = -0.0000001476x^3 + 0.0000308145x^2 – 0.0023675387x + 1.0072782928$

The compensated equation can then be used to make surface friction predictions based on surface temperature in degrees Celsius.