

Light Vehicle Dry Stopping Distance - Vehicle Speed Correction, Tire Burnish, and Surface Friction Correction

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ABSTRACT

Consistent and accurate vehicle stopping distance measurements have been difficult to achieve across the industry including media vehicle evaluations. Initial test speed, brake pedal force application, tire burnish, road surface friction, and Anti-lock Brake System (ABS) efficiency are five test variables influencing variation in stopping distance measurements. This paper will discuss these five test variables and how to apply consistent test methods to reduce test variation.

INTRODUCTION

Vehicle stopping distance measurements can be performed today using optical or GPS based sensors. The vehicle stopping distance measurement initially appears to be a test not too complicated to perform until one understands the sources of test and vehicle variation. Variation in initial test speed, brake pedal force application, tire burnish, and road surface friction can result in significant vehicle stopping distance variation even when testing on the same vehicle. When testing tires, stopping distance for each tire will be dependent upon the calibration of the ABS system on the test vehicle and the interaction of the calibration with the individual tire performance. Controlling test variation increases in importance when testing vehicles over time and then making rank order comparisons of vehicles based on performance. Understanding the influence of the calibration of a vehicle's ABS system can be important when rank ordering tire stopping distance performance. This paper will discuss and provide data on the impact of variation in initial test speed variation, brake pedal force application, tire burnish, road surface friction, and ABS efficiency when conducting vehicle stopping distance measurements. This

paper will also discuss methods to control test variation included in SAE procedure J2909 (Light Vehicle Dry Stopping Distance) published during the first half of calendar year 2010.

INITIAL TEST SPEED AND BRAKE PEDAL FORCE APPLICATION

Initial stopping distance test speeds are typically 100 km per hour or 60 miles per hour. Accounting for initial test speed, brake pedal force and the rate of brake pedal application are critical in order to provide accurate and consistent stopping distance measurements. Variation in either the test method or data analysis at the beginning of the brake stop will result in significant variation in the measurement of stopping distance. The significant variation at the beginning of the brake stop is primarily due to the amplification of the vehicle speed; any variation in the method at this point affects the distance traveled more than what will occur later in the stop when the vehicle speed is lower. There are two primary factors to consider at the beginning of a stop, the initial velocity of the vehicle, the pedal force and rate of brake pedal application. A possible source of variation at the beginning of a stopping distance measurement is the point where the accumulation of stopping distance begins. Stopping distance is typically measured from the time the brake pedal is depressed until the vehicle comes to a complete stop. SAE J2909 defines brake pedal depression as the point in time when the brake pedal force exceeds 60 N. SAE J2909 specifies the brake pedal force must be high enough to guarantee ABS control throughout the entire stop after the initial ABS activation. The brake pedal application rate should be a minimum of 6000N per second and shall not exceed 12000N per second within the first 0.1 seconds after exceeding a brake force of

20N. The minimum brake pedal force of 667N shall be achieved within 0.2 seconds. After the initial brake pedal application, the pedal force is held at a level greater than 667N. Variation in brake pedal force and application rate that leads to a 0.1 second delay in accumulating stopping distance will result in a 2.78 meter reduction in stopping distance at an initial test speed of 100 km/h.

Initial test speed variation at the beginning of the stopping distance accumulation is another significant source of variation in stopping distance test results. The initial test speed is defined in SAE J2909 as the speed of the vehicle when brake pedal force exceeds 60 N. A vehicle with a 45 meter stopping distance at 100 km/h will have approximately a 45.9 meters stopping distance at 101 km/h. Stopping distance can be corrected for variation in the initial stopping test speed using the following equation [1]:

$$S_c = (S_m - (A * V_a)) * (V_r^2 / V_a^2) + (A * V_r) \quad [1]$$

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 Figure 1

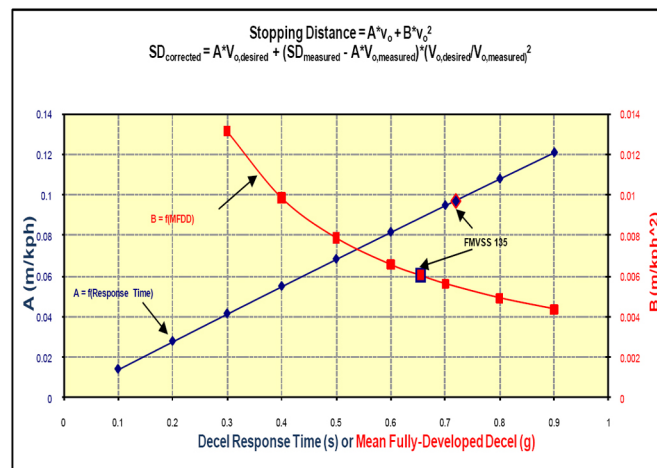


Figure 1. Brake Response Time Factor Graph

Using Figure 1, A is set to 0.025 m/km/h for dry stopping distance with a SAE J2909 brake apply due to deceleration response time not exceeding 0.2 seconds.

TIRE BURNISH

The state of tire burnish is a significant factor when measuring stopping distance and can lead to significant test variation without the application of test procedure controls.

Figure 2 shows a series of stopping distance measurements made on a sport utility vehicle following SAE J2909. The measurements made with a new tire, beginning at stop #1, show approximately a 5 meter decrease in stopping distance after completing 35 ABS stops from 100 km/h. By comparison, measurements made with tires having 4000 km of break-in also show a decrease in stopping distance performance after 10 ABS stops from 100 km/h. However, the magnitude of the decrease is significantly less than with the new tires. Also note the stopping distance measured with the 4000 km tire is in the range of the 10th through 15th stopping distances of the new tire. Figure 3 shows similar tire burnish effects on a passenger sedan.

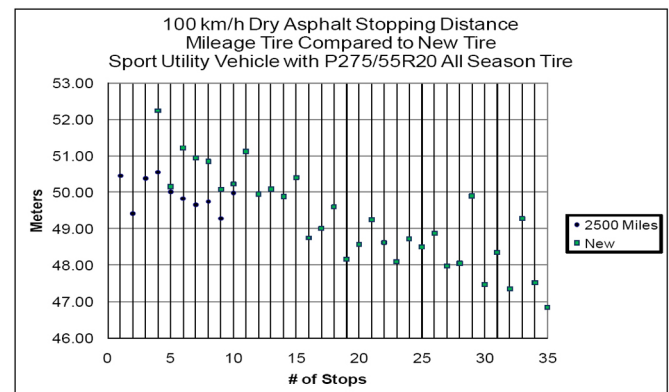


Figure 2. 100 km/h Dry Asphalt Stopping Distance Mileage Tire Compared to New Tire - SUV

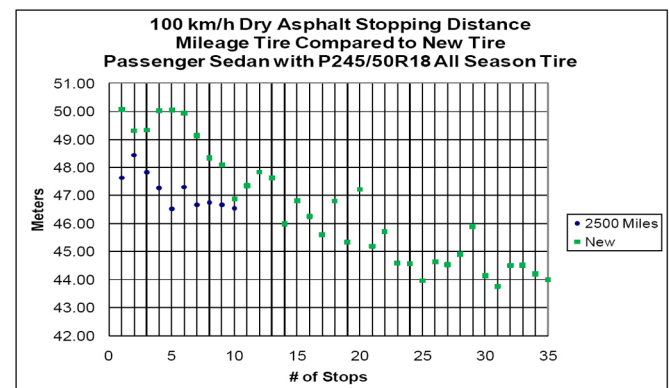


Figure 3. 100 km/h Dry Asphalt Stopping Distance Mileage Tire Compared to New Tire - Sedan

The overall decrease in stopping distance with the number of brake stops is affected by tire design. Summer only tires typically demonstrate a lower sensitivity to tire burnish with less overall decrease in stopping distance compared to all season tires after a given number of SAE J2909 ABS stops. Due to the tire burnish effect on stopping distance measurements, it is recommended stopping distance test procedures imply a method of controlling tire burnish. To understand the tire burnish effect on stopping distance

measurements, it is recommended 20 ABS stopping distance measurements from 100 km/h on dry asphalt be used to quantify stopping distance performance.

Employing a method of analyzing stopping distance measurements comprehending the tire burnish effect is recommended. It is also recommended to use all of the stopping distance measurements, beginning with the first stop, and fit this data as a function of the number of ABS stops to make the statistical fit of the test data more robust to the inherent variation. SAE procedure J2909 recommends the use of a hyperbolic tangent (TANH) function of the form shown below [2].

$$SD = C_1 + C_2 * \text{TANH}(C_3 + C_4 * R_n) \quad [2]$$

where:

SD = Stopping distance, m

C₁, C₂, C₃, C₄ = Fitting coefficients

R_n = Stopping distance test sequence number

SAE J2909 recommends performing 20 ABS stopping distance measurements and then fitting these measurements using [equation \[2\]](#). The vehicle stopping distance performance is reported as the stopping distance associated with the prediction from this fitted equation for the 13th stop. The predicted stopping distance for the 13th stop represents the best estimate of the stopping distance on a vehicle using tires with 4000 km of normal highway and city driving, similar to Consumer Reports mileage accumulation prior to stopping distance measurements. For vehicles with tires with 4000 km of break-in distance accumulated, SAE J2909 recommends performing 13 ABS stopping distance measurement and fitting the data with [equation \[2\]](#). Then, using the resulting equation, report the stopping distance predicted at the 6th stop as the stopping distance performance of the vehicle. See [Appendix A, Figures A1, A2, A3, A4, A5](#), for examples of vehicle stopping distance measurements using the SAE J2909 procedure each showing 20 ABS stops, the effects of tire burnish, and the statistical treatment of the data with Tanh curve fitting method.

ROAD SURFACE FRICTION

Road surface friction is a significant variable when measuring stopping distance. The basic stopping distance equation, neglecting brake response time, has the square of the initial vehicle velocity divided by twice the deceleration during the stop. The deceleration capability of the test vehicle is a function of tire traction capability, road surface friction, and ABS efficiency. For this reason, it is essential to know what the road surface friction is during testing to accurately assess vehicle stopping distance performance. A five percent change

in road surface friction may unknowingly be assessed as a proportional change in tire traction or ABS efficiency.

Road surface friction can be measured with an ASTM E1136 standard reference tire in accordance with ASTM E1337 method, at a speed of 64 km/h at the time of a stopping distance test. The purpose of this measurement is to provide a direct measure of the road surface friction which can be influenced by environmental conditions such as ambient temperature. Once known, stopping distance measurements can be compensated for the variation in the test surface friction properties. Compensating stopping distance measurements using road surface friction measurement based on the standard reference tire is made on the assumption the test vehicle tires sensitivity is similar to the sensitivity of the standard reference test tire due to changes in ambient and road surface temperatures. Road surface friction typically increases with lower road surface temperature for most passenger vehicle tires. Some high performance tire compounds will have temperature sensitivities opposite this trend by having increased traction as the ambient and road surface temperatures increase.

Road surface measurements made on a test track over time may demonstrate significant change (> 5.0%) in road surface friction due to the change in ambient and road surface temperatures. For vehicles with 100 km/h stopping distances in the range of 42 m, a 6.5 percent change in road surface friction can vary the stopping distance measurement by approximately 2.5 m. To correct for road surface friction, a reference road surface friction level must be selected. For dry asphalt stopping distance measurements, SAE J2909 compensates the stopping distance for road surface friction after correcting the measurement for initial vehicle speed using the following formula [3]:

$$S_f = (S_c - (A * V)) * (PFC_{act} / PFC_{spec}) + (A * V) \quad [3]$$

Where:

S_f = Surface corrected distance, m

PFC_{act} = Actual PFC of test road

PFC_{spec} = Reference road surface PFC

S_c = Corrected stopping distance, m

V = Requested test speed, km/h

A = brake response time factor (0.025 m/km/h)

See [Figures 4, 5, & 6](#) for an example of a vehicle's stopping distance data corrected to road surface friction levels of 0.93, 0.96, and 0.99, respectively.