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Test Track Procedures for Heavy-Vehicle Forward Collision Warning and Automatic Emergency Braking Systems

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This report describes objective test track procedures developed by NHTSA to collect performance data on trucks and buses with gross vehicle weight ratings over 4,536 kg (10,000 lbs) and equipped with forward collision warning (FCW) and automatic emergency braking (AEB) systems. These safety systems are designed to mitigate or avoid the most frequent rear-end crashes in the United States. The systems use forward-looking sensors such as radars and cameras to detect vehicles in the roadway. When a rear-end crash is imminent, the FCW system warns the driver of the threat. If the driver takes no action, such as braking or steering, or if the driver does brake, but with not enough effort to avoid the crash, an AEB system may automatically apply or supplement the brakes to avoid or mitigate the rear-end crash. The developed test procedures use a test target to represent a stopped, steady moving, and decelerating lead vehicle in the test scenarios. Two additional scenarios evaluate false positive incidents where FCW/AEB warnings/activations are typically suppressed.</td></tr>
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1.0 INTRODUCTION

The National Highway Traffic Safety Administration has developed objective test track procedures to perform test track research and collect performance data on trucks and buses with gross vehicle weight ratings (GVWR) over 4,536 kg (10,000 lbs.) and are equipped with forward collision warning (FCW) and automatic emergency braking (AEB) systems. The safety systems can assist the driver, through warnings and automatic brake applications in mitigating or avoiding the most frequent rear-end crash scenarios in the United States. These systems use forward-looking sensors, typically radars and/or cameras, to detect vehicles in the roadway. When a rear-end crash is imminent, the FCW system warns the driver of the threat. If the driver takes no action, such as braking or steering, or if the driver does brake, but with not enough effort to avoid the crash, an AEB system may automatically apply or supplement the brakes to avoid or mitigate the rear-end crash.

This document presents the test procedures that use a test target to represent a stopped, slower moving, and decelerating lead vehicle in representative rear-end crash scenarios. Two additional scenarios are used to evaluate potential incidents where FCW/AEB warnings/activations are typically suppressed. If a warning is observed in these scenarios it is considered a false positive. The first false positive test scenario uses a steel trench plate placed in the center of the lane of travel, and the second scenario places two parked vehicles on the adjacent lanes of travel.

For these test procedures, it is important to distinguish that AEB includes crash imminent braking (CIB) and dynamic brake support (DBS). CIB systems provide automatic braking when forward-looking sensors indicate that a crash is imminent and the driver has not applied the service brakes, whereas DBS systems provide supplemental braking when sensors determine that driver-applied braking is insufficient to avoid an imminent crash. Accordingly, test procedures were developed with and without driver applied insufficient braking. The procedures described herein were developed through NHTSA test track research described in the *Class 8 Truck-Tractor and Motorcoach Forward Collision Warning and Automatic Emergency Braking System Test Track Research – Phase II* report[1] (Salaani, Boday, & Elsasser, in press) and supporting documents published in the Heavy Truck Automatic Emergency Braking docket.[2]

This document presents summaries of the testing scenarios, a discussion of terminology, general testing conditions, and step-by-step procedures. The test procedures without driver applied braking to test CIB performance are described in Section 2.0 and test procedures developed with driver applied braking to test DBS performance are described in Section 3.0.

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[1] www.Regulations.gov, Docket NHTSA-2015-0024-0006
[2] www.Regulations.gov, Docket NHTSA-2015-0024

1.1 Test Scenario Summary

Stopped Lead Vehicle Scenario: This scenario is used to evaluate the ability of the FCW and AEB systems to detect and respond to a stopped lead vehicle in the immediate forward path of the subject vehicle.

Slower Moving Lead Vehicle Scenario: This scenario is used to evaluate the ability of the FCW and AEB systems to detect and respond to a slower-moving lead vehicle traveling at a constant speed in the immediate forward path of the subject vehicle.

Decelerating Lead Vehicle Scenario: This scenario is used to evaluate the ability of the FCW and AEB systems to detect and respond to a leading vehicle, which is slowing with a constant deceleration in the immediate forward path of the subject vehicle.

Steel Trench Plate False Positive Scenario: This scenario is used to evaluate the ability of the FCW and AEB systems to suppress driver warnings and brake activations by correctly identifying a non-threatening steel trench plate (STP) in the immediate forward path of the subject vehicle.

Stationary Vehicles False Positive Scenario: This scenario is used to evaluate the ability of the FCW and AEB systems to suppress driver warnings and brake activations by correctly identifying non-threatening parked/stationary vehicles along a roadway. Two stationary vehicles are positioned in the same direction of travel as the subject vehicle with an empty lane between them, with the rear of each vehicle aligned. In this test scenario, the subject vehicle travels at a constant speed in the lane between the stationary vehicles, and this scenario is identical to the European Union regulation EU No 347/2012, §2.8 False Reaction Test[3] (European Commission, 2009-2016).

1.2 Vehicle Terminology and Axes

Abbreviations:

AEB	- automatic emergency braking
BC	- brake controller
CIB	- crash imminent braking
DBS	- dynamic brake support
FCW	- forward collision warning
FMVSS	- Federal Motor Vehicle Safety Standard
POV	- principal other vehicle (target)
R_0	- steady headway or range of SV-to-POV (or fixed obstacles) during test initial condition
R	- headway or range of SV-to-POV (or fixed obstacles)
SV	- subject vehicle (heavy truck with GVWR above 4,536 kg (10,000 lbs))

[3] Standard: EU-No 347/2012, Regulations Commission Regulation Implementing Regulation (EC) No. 661/2009 of the European Parliament and of the Council with respect to Type-Approval Requirements for Certain Categories of Motor Vehicle with Regards to Advanced Emergency Braking Systems.

STP	- steel trench plate – (ASTM A36 steel, 2.4 m x 3.7 m x 25 mm (8 feet wide x 12 feet long x 1 inch thick))
TTC	- time-to-collision in seconds (relative distance divided by relative speed)
V_{pov}	- principal other vehicle speed
V_{sv}	- subject vehicle speed
A_x	-SV longitudinal deceleration
A_{xm}	-mean SV Longitudinal deceleration during 0.5 seconds after peak deceleration
t	-driver brake application time
t_{pc}	-the last instant where brake pedal input rate exceeds 100 mm/sec after the initial brake application
t_{fc}	-the first instant when the pedal rate achieves -40 mm/sec, in response to the brake pedal release action

This document uses the SAE J670 (J670, JAN2008) recommended vehicle dynamics terminology with Z-axis down as shown in Figure 1. The test procedures specify accurate measurement of subject vehicle relative position and speed vis-à-vis a principal other vehicle either in motion or stationary and fixed targets on the testing surface. Thus, a single earth-fixed axis system is defined as a reference for all vehicles and fixed targets. This axis system is indicated in Figure 1 as (X_E, Y_E, Z_E). Its XY-plane is vertically positioned at the testing surface and its X_E-axis is tracing the straightforward path to be followed during all test scenarios.

The SV axis system is (X_{SV}, Y_{SV}, Z_{SV}). It has its vehicle reference point positioned at the longitudinal plane of symmetry, with longitudinal and vertical position placed as practically as it can be to the vehicle center of gravity. The SV path is the vertical projection of the vehicle trajectory onto the testing surface defined by the (X_E, Y_E, Z_E) axis system.

The POV vehicle axis system is (X_{POV}, Y_{POV}, Z_{POV}). It has its vehicle reference point positioned at its longitudinal plane of symmetry, at the XZ-plane geometric center. The POV vehicle path is the vertical projection of the vehicle trajectory onto the testing surface defined by the (X_E, Y_E, Z_E) axis system.

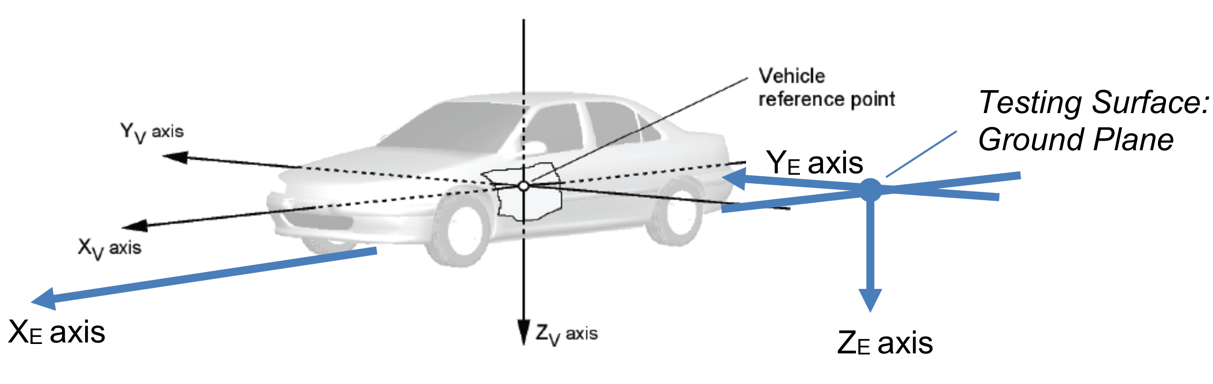

Figure 1. SAE J670 JUN2008 Axes

1.3 General Test Conditions

The straight path to be followed during test procedures (X_E-axis) can be measured with a GPS-based system. The road surface is a straight path, and wide enough to place two stationary vehicles separated laterally by at least 4.5 m, and symmetric about the straight path (X_E-axis). Positions for the STP and stationary vehicles used for false positive scenarios are measured with respect to (X_E, Y_E, Z_E) axis system on the testing surface.

The testing surface is dry with a **minimum**[4] peak friction coefficient of 0.9 when measured using ASTM SRTT (Standard Reference Test Tire) in accordance with ASTM Method E1337-90 (ASTM, 2012), at a speed of 64.4 km/h (40 mph), without water delivery. The surface is straight and flat, constructed from asphalt or concrete, and free of bumps/cracks/potholes that could induce excessive SV pitch motion. With exception to vehicles, test targets, and stationary objects that are called for in the test procedures, there are no vehicles, obstructions, or stationary objects within one lane width of 3.6 m (12 feet) of either side the vehicle path.

SV brake burnishes and pre-test initial brake temperature warmup is performed in accordance with FMVSS No. 105 (NHTSA, 2005), 121 (NHTSA, 2004), or 136 (NHTSA, 2015) by motor vehicle type, brake system, and GVWR. The pressure at each tire must be checked and adjusted to OEM recommended cold inflation pressure. The vehicle is loaded to its GVWR prior to testing as in FMVSS No. 121 for pneumatic brake systems and FMVSS No. 105 for hydraulic brake systems. Prior to testing, the SV tire pressures and test weight for each axle is measured and documented.

All testing trials are performed with automatic transmissions in ''Drive'' or with manual transmissions in the highest gear capable of sustaining the desired test speed. Manual transmission clutches are to remain engaged during all maneuvers.[5] The driver and passengers will use the vehicles safety restraints and follow the test vehicle's operator's manual instructions for safely operating the vehicle and safety systems. After each test trial, the vehicle is parked and the vehicle is powered down for a minimum duration of 3 minutes. Pending initial test trial outcomes, additional guidance maybe sought from the original equipment manufacturer for system initialization and power cycling procedures.

Each individual test scenario is composed of three consecutive periods: vehicles' initial positional setting and accelerating to the test speed, vehicles controlled steady-motion conditions, and FCW/AEB warnings/activations system response. A fixed set of procedural protocols are defined for each period to produce repeatable and reproducible test results.

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[4] FMVSS No. 105 S6.9.2, FMVSS No. 121 S6.1.7, and FMVSS No. 136 S6.2.2 state a peak friction coefficient of 0.9. Test track surface friction measurements indicate that the surface peak friction usually exceeds the specified 0.9 values. Example measurements taken monthly on a concrete test surface in 2015: 0.95, 0.97, 0.90, 0.92, and 0.98. Example measurements taken monthly on an asphalt test surface in 2015: 0.90, 0.93, 0.97, 0.95, and 0.94.

[5] For an SV equipped with a manual transmission consideration should be given to disengagement of the clutch when the SV stops. If the transmission clutch is engaged and a vehicle that is equipped with a manual transmission is stopped the engine will also be stopped.

The first test period starts with positioning the vehicles on the testing surface and accelerating up to the test speed. The SV X_{SV} -axis and POV X_{POV}-axis are positioned along the straight path of travel identified by the X_E-axis, with the POV in front of the SV, and headed in the same direction of travel.

The second test period is evaluated to determine if the SV and POV vehicles' initial conditions are established and are appropriate to produce repeatable valid test results. The time interval of this period is identified in the procedures by two terms that define its beginning and completion; respectively, they are: "TEST INITIAL CONDITION STARTS" and "TEST INITIAL CONDITION ENDS." Upon initiation of this period, an SV brake pedal force input is not applied by the driver unless the SV collides with the POV or to abort a test trial. If any of the kinetic tolerances (speed, position, orientation) are not met, then this test is deemed invalid and discarded. The tolerance for the initial specified vehicle speed is ±2 km/h (±1.24 mph). Steering-wheel angle inputs are applied for counteracting any side pulling to disturbance inputs[6] to maintain on-center position within the lane. For both the SV and the POV, the lateral offset of each vehicle path with respect to the straight path (X_E-axis) is 0 ±0.5 m (±1.64 feet). The yaw rate of the SV is 0 ±2 degrees per second.

The third and last test period is used to evaluate test validity, vehicle performance, and to take actions in response to the FCW and/or AEB activation. The time interval of this period starts at "TEST INITIAL CONDITION ENDS" and ends at "TEST ENDS" in the procedural protocols. Test validity specifies that steering-wheel angle inputs are applied by the driver to maintain a straight path of travel, with lateral offsets tolerances the same as in the initial conditions. The SV service brake pedal force inputs are not applied, unless called upon by procedure protocols for DBS testing, or to abort a test trial.

To evaluate the repeatability of each test scenario, a total of seven valid test trials are collected. If a trial is deemed invalid, that is, not conforming to experimental parameters defined in the procedures, additional trials are made until seven valid trials are complete. The testing trials are scheduled in a single batch, performed one after another with identical AEB and SV-POV configurations, and with the same weather and track conditions. Ambient temperature for testing is between 2 °C and 40 °C (35 °F and 104 °F), and wind speed is less than 18 km/h (11.2 mph).

Tests are not performed during periods of inclement weather. This includes rain, snow, hail, fog, smoke, and/or ash.

The tests are conducted during daylight hours with good atmospheric visibility, defined as an absence of fog and the ability to see clearly for more than 5 km (3.1 miles). The tests are not conducted during very low sun angle conditions (where the sun is oriented 15 degrees or less from horizontal) as camera "washout" or system inoperability may result.

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[6] Disturbance inputs definition in §9.1.4 of SAE J670 JAN2008 is an influence on the vehicle that induces a change in motion of the vehicle.

All tests are conducted in an area void of overhead signs, bridges, or other significant structures over the testing site. Each trial is conducted with no unrelated vehicles, obstructions, or stationary objects within one lane width of either side of the SV path. Shadows cast by objects other than the SV, POV, POV test apparatus, POV tow vehicle, or steel trench plate are not present in the SV lane of travel, or within one lane width of either side of the SV path.

1.4 POV Specifications

The POV is an artificial vehicle with visual, dimensional, and reflective (for scans from radar, lidar, etc. sensors) characteristics representative of an actual vehicle when approached from the rear aspect.

1.5 Recommended Data Collection

The following specifications are needed to obtain FCW/AEB minimum performance measures and to evaluate system efficacy for all tests. All measurements are in conformity with the axis system presented earlier and SAE J670 (SAE, 2008) recommended terminology.

- **Vehicle Dimensional Measurements** - For the SV, the following are measured at least once: wheelbase, vehicle XY-plane center of gravity, vehicle reference point, relative distance between the SV reference point and the most extreme forward point on the vehicle, track width, and vehicle weight. For the POV, vehicle reference point, and relative distance between the POV reference point and the most extreme rearward point on the vehicle are measured.
- **Test Surface Measurements** - Road surface conditions and friction, temperature, and time of the day are logged at a minimum prior to performing each test scenario.
- **Accelerator Pedal Position** - SV accelerator pedal position is measured during each test trial at a minimum of 100 Hz.
- **Accelerator Pedal Force**- SV accelerator pedal force is measured during each test trial at a minimum of 100 Hz.
- **Yaw Rate -**SV yaw rate is measured during each test trial at a minimum of 100 Hz. Alternatively, differentially-corrected GPS data can be used to calculate yaw rate in lieu of direct measurement, provided the resulting accuracy is comparable.
- **Longitudinal Speed** - SV and POV longitudinal vehicle speed shall be measured during each test trial at a minimum of 10 Hz, using either contact or non-contact-based speed sensors.
- **Longitudinal and Lateral Position** - Longitudinal and lateral positions of the SV and POV are measured during each test trial at a minimum of 10 Hz. Position can be measured by several different sensors and/or measurement techniques provided they cover the range of distances described in the test procedures. The

longitudinal and lateral positions of the SV and POV are reported in the same coordinate system so that the range between SV and POV can be measured[7].

- **Audio/Visual Records** -The auditory and visual warnings of the FCW/AEB Driver Vehicle Interface system are recorded and synchronized with the data acquisition system with time difference less than 100 msec. This recording will be used to establish time records of the appearance of FCW/AEB system headway (range) and imminent collision detection warnings.
- **Brake Pressure** - Brake pressure acting on each wheel's service brake is measured during each test trial at a minimum of 100 Hz. This measurement is used to detect AEB activation.
- **Brake Temperature** – Temperature of the brake shoe or disc pad is measured during each test trial at a minimum of 1 Hz. This measurement is used to monitor the temperature of the brakes while performing the brake burnish procedure, AEB test procedures, and to establish pre-test brake temperature conditions.

[7] NHTSA transmits the range (R) to a dashboard display unit in the SV. This allows the SV operator to accurately monitor SV-to-POV headway.

2.0 CRASH IMMINENT BRAKING (CIB) TESTS

2.1 Stopped Lead Vehicle (LVS_40/0)

a. The SV is driven forward toward the POV while the X_{SV} and X_{POV} axes are oriented on the same direction as the straight testing path (X_E -axis).
b. The SV is driven to a nominal constant test vehicle speed of 40 ±2 km/h (24.9 ±1.24 mph).
c. The **TEST INITIAL CONDITION STARTS** when the SV relative position to the POV is at R_0 equal to 56 ±3 m (183.7 ±9.8 feet) as shown on Figure 2, which is at TTC = 5.0 seconds. The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV and POV vehicle paths with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per seconds.
d. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the POV, the SV accelerator pedal is released after braking is initiated. [8] The initiation of the release is to occur within 0.5 seconds[9] (FR No. 241, 2015) after the time braking initiated. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.
e. The **TEST ENDS** when either of the following happens:
    i. The SV stops before contacting the POV.
    ii. The SV makes mechanical contact with the POV. What defines "SV-to-POV Contact" is a mechanical touch of the SV front-most-point to the POV rear-most-point. This can be assessed by contact sensors or GPS-based range data.

[8] NHTSA, for this research, is currently using 34.5 kpa (5 psi) of brake pressure for air braked vehicles and 172 kpa (25 psi) for hydraulically braked vehicles as the threshold for determining AEB has activated, like FMVSS No. 136. Previously we have used a threshold of -0.05 g of longitudinal acceleration to identify when AEB is initiated.
[9] This value is set equal to the value used in NHTSA light vehicle New Car Assessment Program (NCAP) CIB test procedures. Heavy vehicle data suggest that it can be raised to 0.8 seconds without affecting test results reproducibility. This value is used throughout the test procedures.

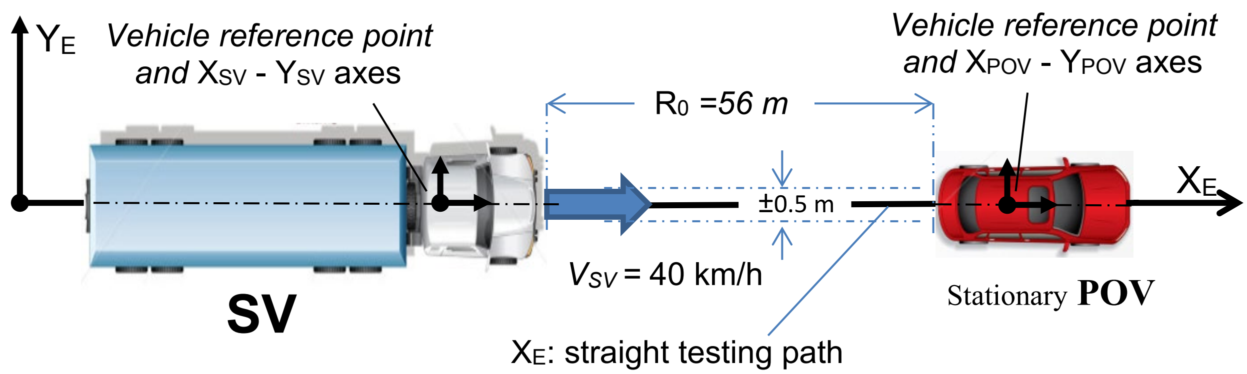

Figure 2. Stopped Lead Vehicle – Test Initial Condition

2.2 Slower Moving Lead Vehicle (LVM_40/15 & LVM_75/35)

This procedure is performed for two series of consecutive tests. The first series consists of 7 consecutive test trials performed with the 40/15 km/h SV-to-POV speed combination. The second series of tests consists of 7 consecutive test trials performed with the 75/35 km/h SV-to-POV speed combination as described in the step-by-step procedures shown below.

a. The SV is driven forward toward the POV while the X_{SV} and X_{POV} axes are oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the POV is greater than 100.0 m to ensure enough headway for the next steps.
b. The SV and the POV are driven at one of two nominal vehicle speeds for at least 1.0 seconds defined as:
   i. SV at 40 ±2 km/h (24.9 ±1.24 mph) and POV at 15 ±2 km/h (9.3 ±1.24 mph).
   ii. SV at 75 ±2 km/h (46.6 ±1.24 mph) and POV at 35 ±2 km/h (21.8 ±1.24 mph).
c. At a TTC equal to 5.0 seconds, the **TEST INITIAL CONDITION STARTS**, that is:
   i. At speed defined in b.i), the SV-to-POV initial range R_0 is equal to 35 ±3 m (114.8 ±9.8 feet) as shown in Figure 3**.**
   ii. At speed defined in b.ii), the SV-to-POV initial range R_0 is equal to 56 ±3 m (183.7 ±9.8 feet) as shown in Figure 4.
d. The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV and POV vehicle paths with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per second.
e. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the POV, the SV accelerator pedal is released after braking is initiated. The initiation of the release

is to occur within 0.5 seconds after the time braking initiated. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.

f. The **TEST ENDS** when either of the following happens:

   i. The SV AEB intervention has reduced speed to a value equal or less than that of the POV.

   ii. The SV makes mechanical contact with the POV. What defines "SV-to-POV Contact" is a mechanical touch of SV front-most-point to POV rear-most-point. This can be assessed by contact sensors or GPS-based range data.

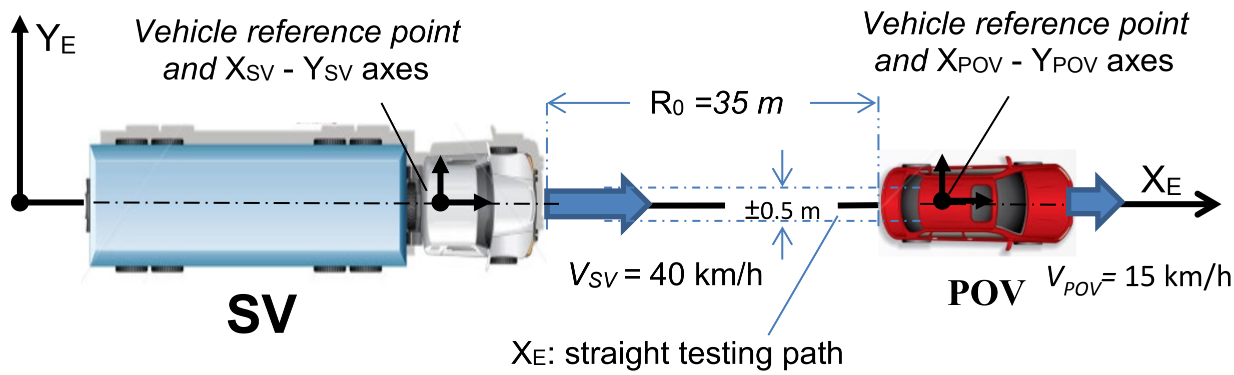

Figure 3. Slower Moving Lead Vehicle – Test Initial Condition @40/15 km/h

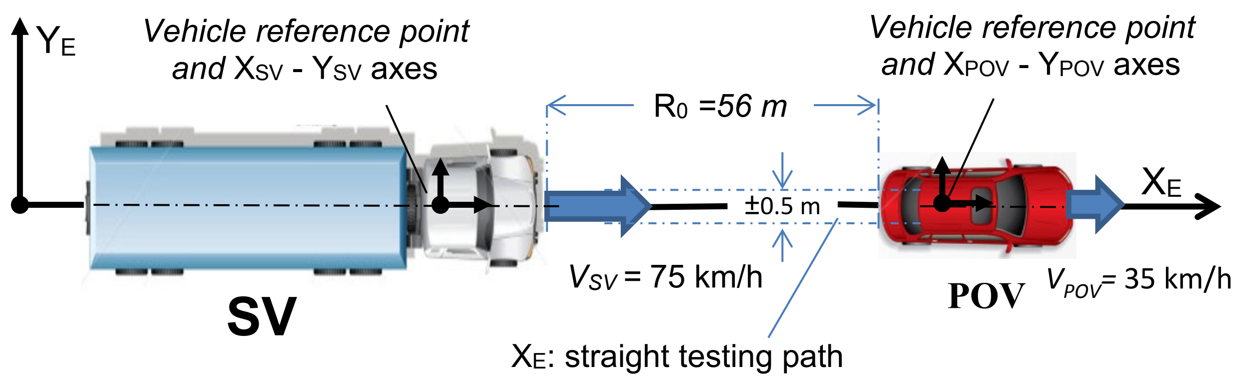

Figure 4. Slower Moving Lead Vehicle – Test Initial Condition @75/35 km/h

2.3 <u>Decelerating Lead Vehicle (80m) (LVD_40/40)</u>

a. The SV is driven forward toward the POV while the X_{SV} and X_{POV} axes are oriented on the same direction as the straight testing path (X_E-axis). The starting range that separates the SV from the POV is 80.0 m to maintain headway for the next steps.

b. The SV and the POV are driven at a nominal vehicle speed of 40 ±2 km/h (24.9 ±1.24 mph) with SV-to-POV range R_0 equal to 80 ± 3m (262.5 ± 9.8 feet)
c. The **TEST INITIAL CONDITION STARTS** by driving for a minimum of 1.0 seconds while maintaining the nominal vehicle speed with a consistent range R_0 equal to 80 ± 3m as shown in Figure 5. The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV and POV vehicle paths with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degree per second.
d. The POV deceleration is controlled to have a constant longitudinal acceleration equal to -3.0 m/sec^2 (-0.31g). The timing tolerance for achieving the specified POV longitudinal acceleration is 1.5 ±0.1 seconds**.** The average POV acceleration does not deviate from -3.0 m/sec^2 by more than ±0.3 m/sec^2 from 1.5 seconds after the onset of POV braking to the time one of the following two conditions is satisfied.
   i. 0.25 seconds prior to the POV coming to a stop
   ii. The SV contacts the POV.
e. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the POV, the SV accelerator pedal is released after braking is initiated. The initiation of the release is to occur within 0.5 seconds after the time braking initiated. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.
f. The **TEST ENDS** when either of the following happens.
   i. The SV stops before contacting the POV.
   ii. The SV makes mechanical contact with the POV. What defines “SV-to-POV Contact” is a mechanical touch of SV front-most-point to POV rear-most-point. This can be assessed by contact sensors or GPS-based range data.

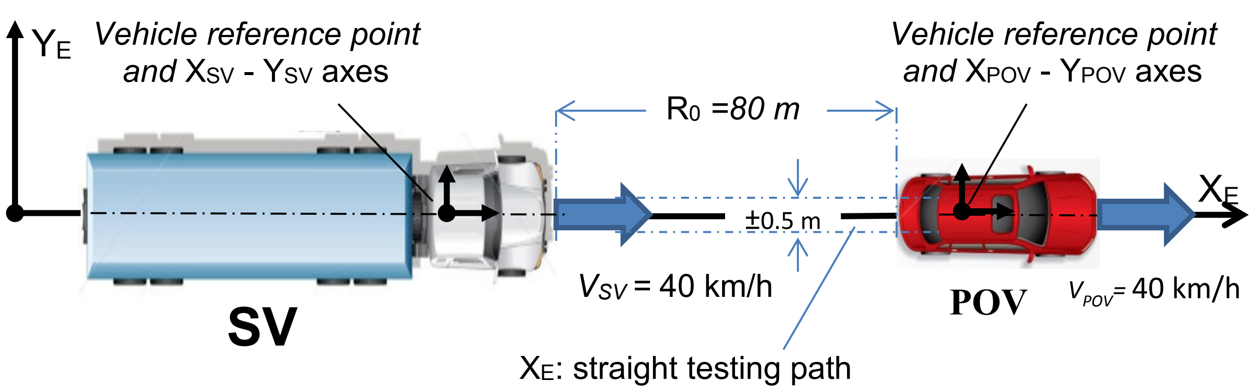

Figure 5. Decelerating Lead Vehicle (80m) - Test Initial Condition

2.4 Decelerating Lead Vehicle (23m) (LVD_55/55)

a. The SV is driven forward toward the POV while the X_{SV} and X_{POV} axes are oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the POV is 23.0 m to maintain headway for the next steps.
b. The SV and the POV are driven at a nominal vehicle speed of 55 ±2 km/h (34.2 mph) with SV-to-POV range R_0 equal to 23 ± 3m (75.5 ± 9.8 feet).
c. The **TEST INITIAL CONDITION STARTS** by driving for a minimum of 1.0 seconds while maintaining the nominal vehicle speed with a consistent range R_0 equal to 23 ± 3m, as shown in Figure 6. The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV and POV vehicle paths with respect to the straight testing path (X_E -axis) is 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per second.
d. The POV deceleration is controlled to have a constant longitudinal acceleration equal to -3.0 m/sec^2 (-0.31g). The timing tolerance for achieving the specified POV longitudinal acceleration is 1.5 ±0.1 seconds**.** The average POV acceleration does not deviate from -3.0 m/sec^2 by more than ±0.3 m/sec^2 from 1.5 seconds after the onset of POV braking to the time one of the following two conditions is satisfied:
    i. 0.25 seconds prior to the POV coming to a stop
    ii. The SV contacts the POV.
e. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the POV, the SV accelerator pedal is released after braking is initiated. The initiation of the release is to occur within 0.5 seconds after the time braking initiated. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.
f. The **TEST ENDS** when either of the following happens:
    i. The SV stops before contacting the POV.
    ii. The SV makes mechanical contact with the POV. What defines “SV-to-POV Contact” is a mechanical touch of SV front-most-point to POV rear-most-point. This can be assessed by contact sensors or GPS-based range data.

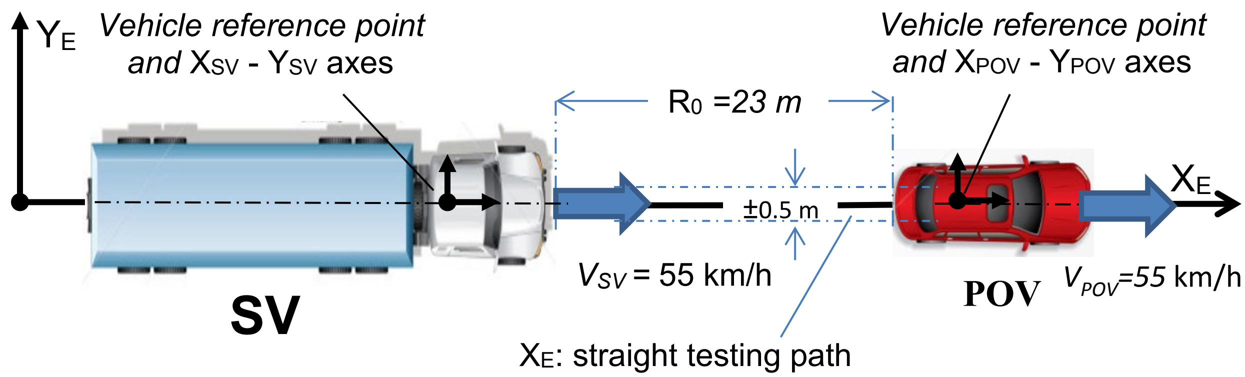

Figure 6. Decelerating Lead Vehicle (23m) - Test Initial Condition

2.5 <u>False Positive Evaluations–Steel Trench Plate Test (STP_40 & STP_75)</u>

This procedure is performed for two series of consecutive tests. The first series consists of 7 consecutive test trials performed at 40 km/h. The second series of tests consists of 7 consecutive test trials performed with the 75 km/h as described in the step-by-step procedures shown below.

a. The STP is placed on the road surface with its center position on the X_E-axis and its 3.7 m (12-foot) length parallel to the X_E-axis as shown in Figure 7.
b. The SV is driven forward toward the STP while the X_{SV} -axis is oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the STP is greater than 110.0 m to ensure enough headway for the next steps.
c. The SV is driven to a nominal vehicle speed for at least 1.0 seconds, defined as:
    i. 40 ±2 km/h (24.9 ±1.24 mph)
    ii. 75 ±2 km/h (46.6 ±1.24 mph)
d. The **TEST INITIAL CONDITION STARTS** when the SV position is at:
    i. At speed c.i.), SV-to-STP range R_0 = 56 ±3 m (183.7±9.8 feet)
    ii. At speed c.ii.), SV-to-STP range R_0 = 105 ±3 m (344.5±9.8 feet)
e. The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV path with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per second.
f. The **TEST INITIAL CONDITION ENDS,** when either of the following happens:
    i. The SV drives over the STP, proceed to the end of test.
    ii. AEB activates. Upon initiation of AEB, the SV accelerator pedal is released within 0.5 seconds from the time when AEB is initiated.
g. Lateral offset tolerances of the SV and center of the STP are maintained until the end of test.

h. The **TEST ENDS** when either of the following happens:
   i. When the SV drives over the STP.
   ii. The SV stops before crossing over the STP.

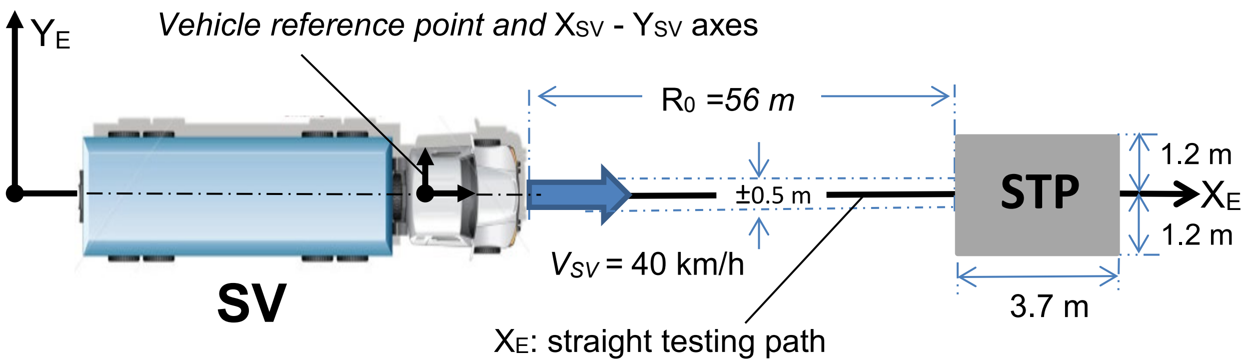

Figure 7. SV encounter a fixed STP – Test Initial Condition @40 km/h

2.6 <u>Stationary Vehicles False Positive (FPSV_50)</u>

a. The two stationary vehicles are positioned as shown in Figure 8:
   i. to face in the same direction as the straight testing path, X_E-axis;
   ii. with a lateral distance of 4.5 m between them; and
   iii. with the rear of each vehicle aligned with the other
b. The SV is driven forward while its X_{SV} -axis is oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the stationary vehicles is greater than 100.0 m to ensure enough headway for the next steps.
c. The SV is driven to a nominal speed 50 ±2 km/h (31.1 ±1.24 mph) for at least 1.0 seconds.
d. The **TEST INITIAL CONDITION STARTS** when TTC =4.32 seconds[10], that is, SV to stationary vehicles range R_0 is equal to 60 ±3m (196.9 ±9.8 feet). The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of the SV path with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per second.
e. The **TEST INITIAL CONDITION ENDS,** when either of the following happens:
   i. The SV passes the two stationary vehicles, proceed to the end of test.
   ii. AEB activates. Upon initiation of AEB, the SV accelerator pedal is released within 0.5 seconds from the time when AEB is initiated.

[10] A TTC of 4.32 seconds is equal to 60 m divided by 13.89 m/sec (50 km/h).

f. Lateral offset tolerances of the SV are maintained with the straight testing path up to the end of test.
g. The **TEST ENDS** when either of the following happens:
    i. When SV passes the two stationary vehicles.
    ii. The SV stops before passing the two stationary vehicles.

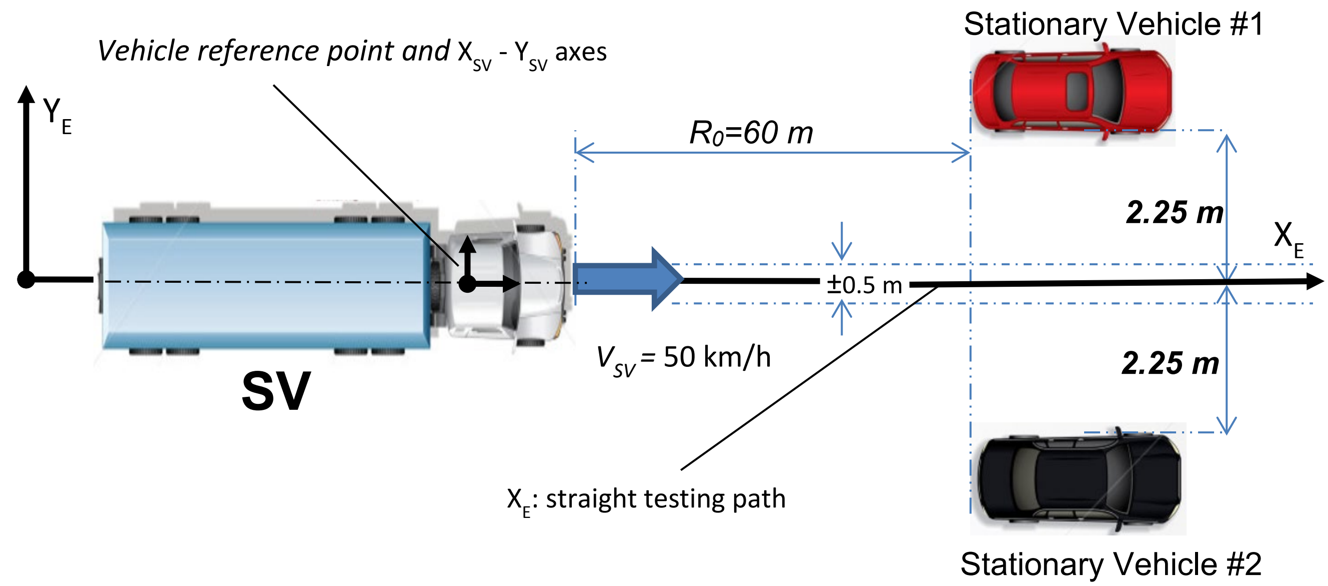

Figure 8. Stationary False Positive -Test Initial Condition

3.0 DYNAMIC BRAKE SUPPORT

3.1 *DBS Test Procedure Introduction*

This section describes test procedures for DBS test scenarios. DBS systems provide supplemental braking when forward-looking sensors determine that driver-applied braking is insufficient to avoid an imminent crash with a lead vehicle. The performance test scenarios are the same as used to test CIB. While the scenarios for testing DBS are the same as CIB, the test procedures are different and include the application of the brake pedal. To improve test trial-to-trial repeatability, an SV brake pedal characterization test is performed prior to DBS performance tests.

The SV brake system characterization test runs are used to objectively quantify the brake response of a test vehicle without the contribution of advanced technologies like the DBS on the test track. For the characterization test, the SV is decelerated to the maximum deceleration level in a controlled manner from an initial speed of 55 ± 2.0 km/h. The POV is not used in this test. Once the test is completed, the characterization data are then post-processed to determine the brake pedal position that generates -3.0 m/sec^2 (-0.31g) of acceleration. This brake pedal position is then used as the initial input to the brake system in the DBS performance test scenarios.

To initiate the DBS system in each test trial conducted in the performance test scenarios, the SV brake pedal is applied to the -3.0 m/sec^2 brake pedal position determined in characterization testing. The range at which the brake is applied is adjusted for proximity to the POV target for each of the performance test scenarios. This deceleration profile mimics drivers' panic braking timing and rate. However, the magnitude of the specified deceleration is insufficient to avoid contact with the POV. The test procedures are provided in the following sections in this chapter.

3.2 Brake Position Characterization and Baseline Verification Tests

Prior to performing the objective DBS performance test procedures described in Section 3.3, brake characterization data is collected to determine the magnitude of the brake pedal application to generate -3.0 m/sec^2 (-0.31g) of acceleration. The following subsections describe the brake characterization test procedure, characterization data processing to obtain brake pedal input magnitude, and brake pedal baseline verification test procedures. The POV is not placed in the forward path of the SV for characterization and verification test trials.

3.2.1 Steady Brake Position *C*haracterization Test

Three brake characterization test trials are performed using the test procedure steps described as follows:

a. The SV is driven forward while its X_{SV} -axis is oriented on the same direction as the straight testing path (X_E -axis). Note: The POV is not used in characterization tests.
b. The SV is driven to a nominal constant test vehicle speed of 55 ±2 km/h (35 ±1.24 mph) for 2.0 seconds.
c. The accelerator pedal is released at least 1.0 seconds before the onset of the brake pedal applications.
d. Apply brake pedal at a steady rate until the pedal achieves maximum displacement. The rate of brake pedal position input is set such that SV maximum deceleration reaches its saturation level (maximum deceleration) between the time interval of 3.5 to 4.5 seconds from the start of the brake application.
e. The test trial is complete once the vehicle's speed is reduced to 0 km/h.

The brake pedal steady input rate described in step d. is adjusted on a vehicle-by-vehicle basis to accommodate different types of heavy vehicle brake system characteristics. Test procedure development indicated that a constant pedal application rate would not maintain quasi-steady conditions, where quasi-steady conditions are defined as a slowly changing longitudinal dynamics state. To help illustrate this phenomenon, examples of brake application and vehicle deceleration data from brake characterization test trials performed with vehicles equipped with pneumatic and hydraulic brake systems is presented in Figure 9. From the figure, the brake application rate for the hydraulic brake system is set to span 104 mm (4 inches) at 25 mm/sec (1 inch/sec). The SV maximum deceleration was saturated at approximately 4 seconds from the start of brake application. For the pneumatic brake system shown in Figure 9, a brake position span of 71 mm (2.78 inches) and a pedal application rate of 9.375 mm/sec (3/8 inch/sec) was necessary to saturate the vehicle's longitudinal deceleration inside the 3.5 to 4.5 seconds time interval.

The values used for brake pedal input rate for the hydraulic and pneumatic brake systems are two examples that can be used in the initial trial of this characterization phase. If the maximum deceleration falls outside the time interval of 3.5 to 4.5 seconds, then the rate of input is adjusted accordingly. Three successful steady brake position characterization tests are needed to check data consistency.

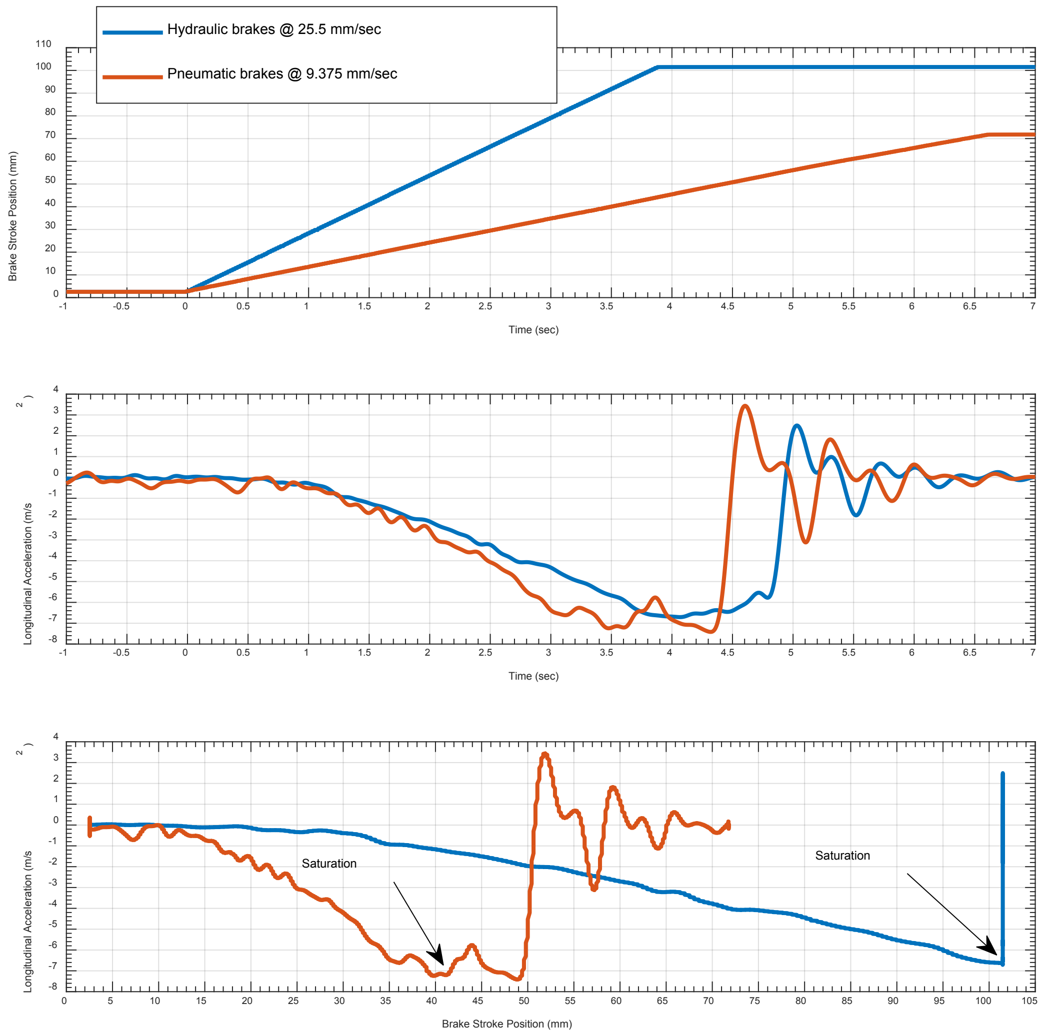

Figure 9. Brake application and Longitudinal Acceleration

3.2.2 Brake Characterization Data Processing

An interpolation method is used to estimate the brake pedal position input that corresponds to an acceleration level of -3.0 m/sec^2 (-0.31g). A graphical example of this process is shown in Figure 10. In this example, a linear polynomial best fit of pedal position to vehicle longitudinal acceleration in the interval of [-3.75, -2.25] m/sec^2 (in a least-squares sense) was used to estimate pedal position input at -3.0 m/sec^2 (-0.31g). The vehicle longitudinal acceleration data is filtered with a low pass zero-phase digital filter with a cutoff frequency set at 6 Hz. The acceleration is processed in both the forward and reverse direction with 6-pole Butterworth filter parameters. To improve testing efficiency, a linear actuator with position feedback may be used to apply the brake pedal at precise rates and positions described in the test procedures.[11]

Pedal_Position_Steady_Command is the parameter name used to refer to the estimated pedal position that corresponds to a -3.0 m/sec^2 (-0.31g) acceleration. The steady characterization process is repeated three times to check system consistency, and a median value is used for DBS test scenarios. Post-processed brake characterization data from the hydraulic brake system test trials shown in Figure 10 are presented in Table 1.

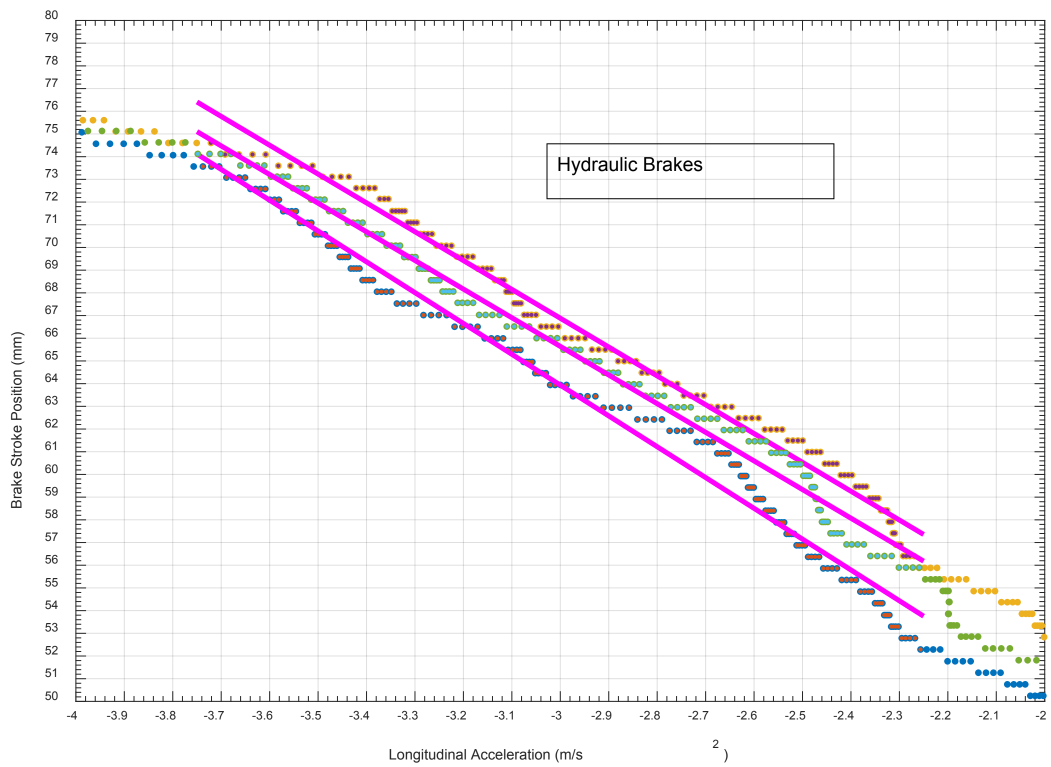

Figure 10. Example brake position/Longitudinal Acceleration interpolation

Table 1. Pedal position estimation at -3.0 m/sec^2 (-0.31g)

Test#	Longitudinal Acceleration (m/sec^2)	*Pedal_Position_Steady_Command* (mm)
1	-3.0	63.74
2	-3.0	62.99
3	-3.0	65.28
	median	**63.74**

[11] The linear actuator used to apply the brake pedal during the development of these test procedures applies open-loop control and does not use a closed-loop vehicle motion feedback control, like longitudinal deceleration, to adjust brake controller gains to get the desired deceleration. The latter is more complicated to formulate.

3.2.3 Baseline Brake Application Test (Characterization Test Validity Check)

The Pedal_Position_Steady_Command variable estimated to generate -3.0 m/sec^2 of acceleration is validated and adjusted in this baseline test procedure prior to running each of the DBS performance tests in Section 3.3. The pedal position variable is checked by performing three test trials at the designated speed of each of the DBS performance tests. If the Pedal_Position_Steady_Command variable is observed to produce a measured deceleration that falls outside the margin of error [-3.25, -2.75] m/sec^2, the commanded brake application is adjusted as described at the end of this section.

The variable name for the commanded pedal position magnitude during the baseline test trial is *Pedal_Position_Command.* For the initial trial, *Pedal_Position_Command = Pedal_Position_Steady_Command.* The measured brake pedal position variable is called *Pedal_Position_Measured.*

The step-by-step procedure for this validity check is as follows:

a. The SV is driven forward while its X_{SV} -axis is oriented on the same direction as the straight testing path (X_E -axis). Note: The POV is not used in baseline tests.
b. The SV is driven at the constant designated test vehicle speed for a minimum of 2.0 seconds. The DBS performance test SV speeds are 40 ± 2.0 km/h, 50 ± 2.0 km/h, 55 ± 2.0 km/h, or 75 ± 2.0 km/h.
c. The accelerator pedal is released prior to the onset of the brake pedal application.
d. Apply brake pedal input at the *Pedal_Position_Command* value at a target rate of 254.0 ±25 mm/sec (10.0 ±1 inch/sec).
e. The test trial is complete once the vehicle's speed is reduced to 0 km/h.
f. This baseline test is complete when two out of three test trials meet the conditions described below.

Upon completion of the baseline test trials the data are post-processed to obtain pedal application and SV deceleration performance metrics to assess if they fall within given tolerances prior to running the DBS performance tests. Figure 11 shows an example of the hydraulic brake application, and Figure 12 shows an example of the pneumatic brake application. Brake pedal application and deceleration performance metric calculations and tolerances are described in the following paragraphs.

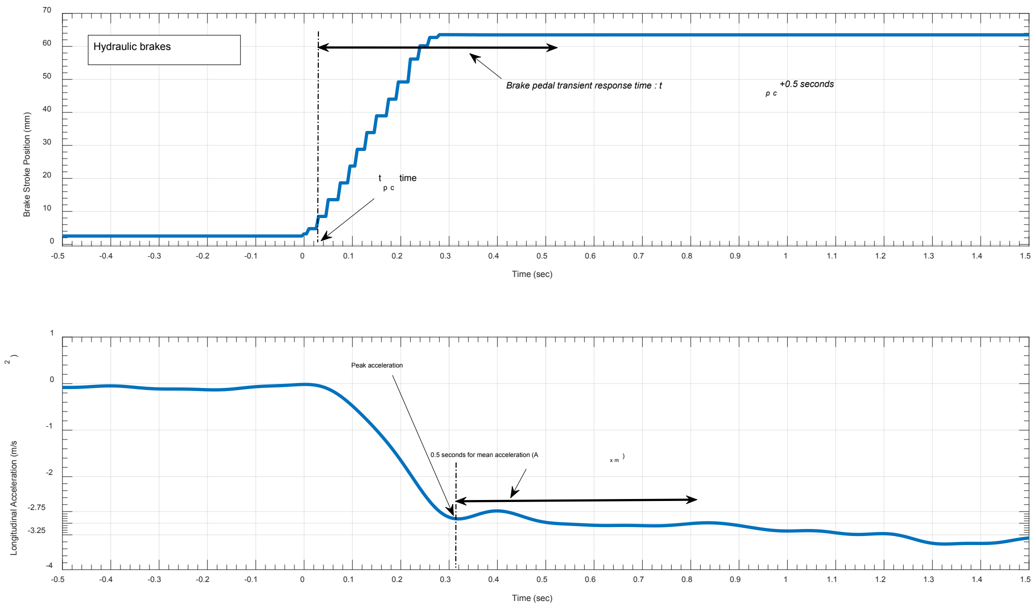

Figure 11. Brake application at 254 mm/sec (10 inch/sec) - Hydraulic brakes

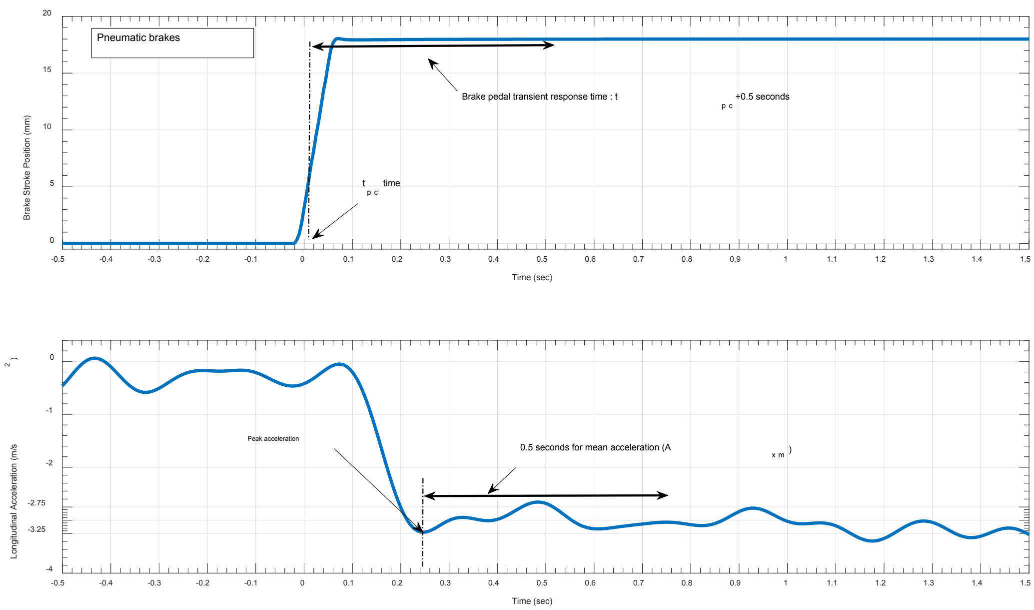

Figure 12. Brake pedal application at 254 mm/sec (10 inch/sec) - pneumatic brakes

The brake pedal is applied consistent with the following specifications.

a. System transient response: Pedal position error (difference between commanded and measured pedal positions) over a specific time domain ($t_{pc} < t < t_{pc} + 0.5$) is less than 10 percent of commanded position, and it is quantified as follows (Equation 1):

Equation 1

$$t_{pc} < t < t_{pc} + 0.5\ ;$$
$$\left|\frac{Pedal\_Position\_Measured - Pedal\_Position\_Command}{Pedal\_Position\_Command}\right| < 0.1$$

Where,
t_{pc}: The last instant where brake pedal input rate exceeds 100 mm/sec after the initial brake application.
t: Time from the start of brake pedal application

b. Steady performance: The pedal position steady error is not greater than 5 percent of commanded position during a specific time domain ($t_{pc} + 0.5 < t < t_{fc}$) and it is quantified as follows (Equation 2):

Equation 2

$$t_{pc} + 0.5 < t < t_{fc};$$
$$\left|\frac{Pedal\_Position\_Measured - Pedal\_Position\_Command}{Pedal\_Position\_Command}\right| < 0.05$$

Where,
t_{fc}: The first instant when the pedal rate achieves -40 mm/sec, in response to the brake pedal release action.

c. Brake pedal rate is checked by calculating the slope of a linear regression line applied to brake pedal position data over a range from 25 to 75 percent of the commanded input signal. If the commanded brake pedal position is less than or equal to 28 mm, peak pedal rate must be greater than commanded position divided by 125 milliseconds in the range from 25 to 75 percent of the commanded input signal, and is less than 279 (254+25) mm/sec.

The variable name for the measured steady acceleration during this test is A_x. The mean acceleration during 0.5 seconds after peak A_x is A_{xm}. If A_{xm} is outside [-3.25, -2.75] m/sec^2 ([-0.33, -0.28] g) range, as shown by the "Acceleration Conditions for Scaling" below, the brake pedal commanded position is scaled following Equation 3.

Acceleration Conditions for Scaling

$$if\ A_{xm} > -2.75\ \text{m/sec}^2\ \ OR\ \ A_{xm} < -3.25\ \text{m/sec}^2\ then$$

Equation 3

$$Pedal\_Position\_Command = \frac{-3.0}{A_{xm}} Pedal\_Position\_Steady\_Command$$

The commanded pedal position can be scaled with this formula for different testing speeds and whenever the measured deceleration from the brake controller application falls outside the margin of error.

Vehicle steady deceleration might increase with vehicle speed reduction, and for this reason only the steady value with the settling time need to be accounted for and not up to the end of the test. The DBS system reacts within this short period, and for this reason the mean deceleration value assessment is limited to this duration.

3.3 Dynamic Brake Support Tests

Each braking test trial is performed with the brake pedal in its retracted/unapplied position, with no preload or position offset. Seven testing trials of each scenario are conducted.

3.3.1 Stopped Lead Vehicle (LVS_40/0)

a. Perform Baseline Brake Application Test (Characterization Test Validity Check) as detailed in section 3.2.3 at 40 ±2 km/h (24.9 ±1.24 mph) to determine *Pedal_Position_Command*.
b. The SV is driven forward toward the POV while the X_{SV} and X_{POV} axes are oriented on the same direction as the straight testing path (X_E -axis).
c. The SV is driven to a nominal constant test vehicle speed of 40 ±2 km/h (24.9 ±1.24 mph).
d. The **TEST INITIAL CONDITION STARTS** when the SV relative position to the POV is at R_0 equal to 56 ±3 m (183.7 ±9.8 feet, same as CIB test), which is at TTC = 5.0 seconds. The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV and POV vehicle paths with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per seconds.
e. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the POV:
    i. At SV-to-POV range R = 16.83 ± 0.5 m (TTC = 1.51 seconds) as shown in Figure 13, the SV brakes are applied to achieve an acceleration of -2.75 m/sec2 or less using the Pedal_Position_Command at a target rate of 254.0 ±25 mm/sec. The onset of the brake pedal input is defined when the brake pedal rate is greater than 50 mm/sec.

ii. The SV accelerator pedal is released after braking is initiated. The initiation of the release is to occur within 0.5 seconds after the time braking initiated.

f. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.

g. The **TEST ENDS** when either of the following happens:
   i. The SV stops before contacting the POV.
   ii. The SV makes mechanical contact with the POV. What defines “SV-to-POV Contact” is a mechanical touch of SV front-most-point to POV rear-most-point. This can be assessed by contact sensors or GPS-based range data.

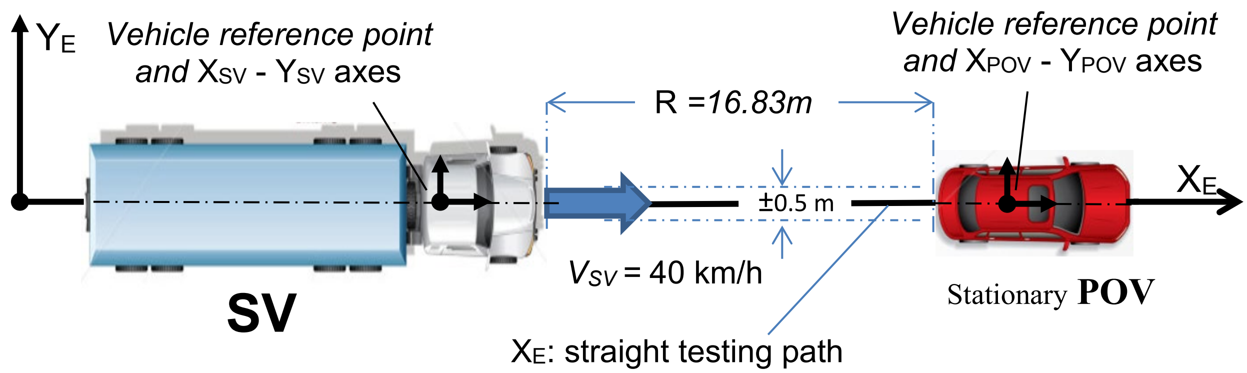

Figure 13. Stopped Lead Vehicle – DBS Test End of Initial Condition

3.3.2 <u>Slower Moving Lead Vehicle (LVM_40/15 & LVM_75/35)</u>

This procedure is performed for two series of consecutive tests. The first series consists of 7 consecutive test trials performed with the 40/15 km/h SV-to-POV speed combination. The second series of tests consists of 7 consecutive test trials performed with the 75/35 km/h SV-to-POV speed combination as described in the step-by-step procedures shown below.

a. Perform Baseline Brake Application Test (Characterization Test Validity Check) as detailed in section 3.2.3 to determine *Pedal_Position_Command* at:
   i. SV at 40 ±2 km/h (24.9 ±1.24 mph).
   ii. SV at 75 ±2 km/h (46.6 ±1.24 mph).

b. The SV is driven forward toward the POV while the X_{SV} and X_{POV} axes are oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the POV are greater than 100.0 m to ensure enough headway for the next steps.

c. The SV and the POV are driven at one of two nominal vehicle speeds for at least 1.0 seconds defined as:

    i. SV at 40 ±2 km/h (24.9 ±1.24 mph) and POV at 15 ±2 km/h (9.3 ±1.24 mph).
    ii. SV at 75 ±2 km/h (46.6 ±1.24 mph) and POV at 35 ±2 km/h (21.8 ±1.24 mph).

d. At a TTC equal to 5.0 seconds, the **TEST INITIAL CONDITION STARTS**, that is:
    i. At speed defined in c.i), the SV-to-POV initial range R_0 is equal to 35 ±3 m (114.8 ±9.8 feet, same as CIB test).
    ii. At speed defined in c.ii), the SV-to-POV initial range R_0 is equal to 56 ±3 m (183.7 ±9.8 feet, same as CIB test).

e. The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV and POV vehicle paths with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per second.

f. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the POV:
    i. At SV-to-POV range R = 7.51 ± 0.5 m (TTC = 1.08 seconds) for c.i) as shown in Figure 14 and at range R = 16.83 ± 0.5 m (TTC = 1.51 seconds) for c.ii) as shown in Figure 15, the SV brakes are applied to achieve an acceleration of -2.75 m/sec^2 or less using the *Pedal_Position_Command* at a target rate of 254.0 ±25 mm/sec. The onset of the brake pedal input is defined when the brake pedal rate is greater than 50 mm/sec.
    ii. The SV accelerator pedal is released after braking is initiated. The initiation of the release is to occur within 0.5 seconds after the time braking initiated.

g. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.

h. The **TEST ENDS** when either of the following happens:
    i. The SV AEB intervention has reduced speed to a value equal or less than that of the POV.
    ii. The SV makes mechanical contact with the POV. What defines “SV-to-POV Contact” is a mechanical touch of SV front-most-point to POV rear-most-point. This can be assessed by contact sensors or GPS-based range data.

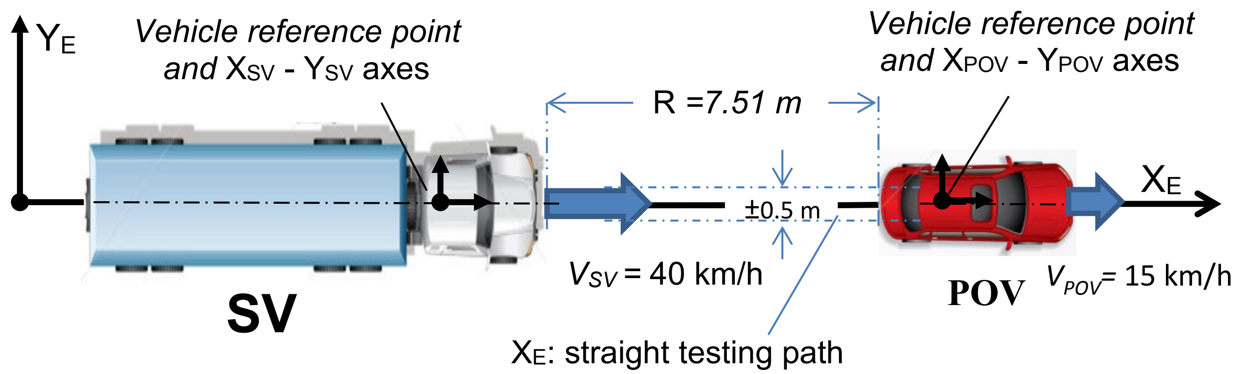

Figure 14. Slower Moving Lead Vehicle – End of Test Initial Condition @40/15 km/h

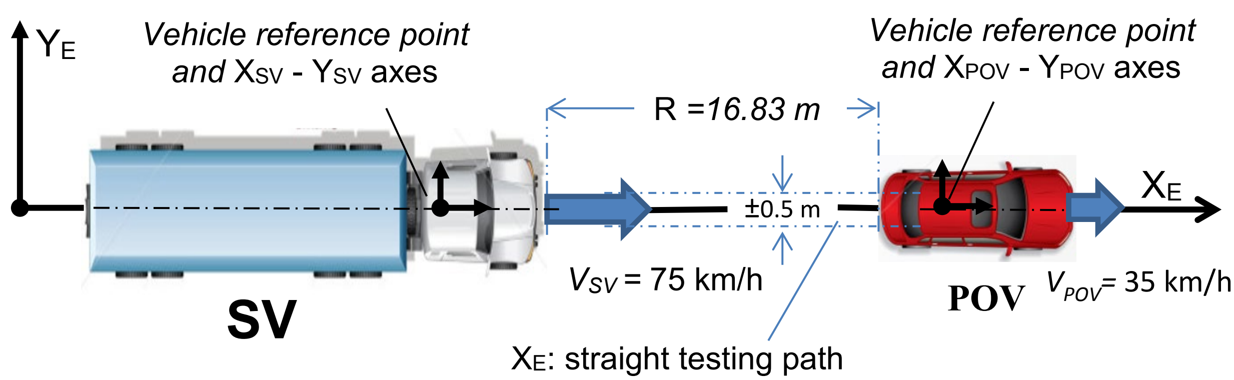

Figure 15. Slower Moving Lead Vehicle – End of Test Initial Condition @75/35 km/h

3.3.3 Decelerating Lead Vehicle (80m) (LVD_40/40)

a. Perform Baseline Brake Application Test (Characterization Test Validity Check) as detailed in section 3.2.3 at 40 ±2 km/h (24.9 ±1.24 mph) to determine *Pedal_Position_Command*.

b. The SV is driven forward toward the POV while the X_{SV} and X_{POV} axes are oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the POV is 80.0 m to maintain headway for the next steps.

c. The SV and the POV are driven at a nominal vehicle speed of 40 ±2 km/h (24.9 ±1.24 mph) with SV-to-POV range R_0 equal to 80 ± 3m (262.5 ± 9.8 feet).

d. The **TEST INITIAL CONDITION STARTS** by driving for a minimum of 1.0 seconds while maintaining the nominal vehicle speed with a consistent range R_0 equal to 80 ± 3m (same as CIB test). The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV and POV vehicle paths with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degree per second.

e. The POV deceleration is controlled to have a constant longitudinal acceleration equal to -3.0 m/sec^2 (-0.31g). The timing tolerance for achieving the specified POV longitudinal acceleration is 1.5 ±0.1 seconds**.** The average POV acceleration will not deviate from -3.0 m/sec^2 by more than ±0.3 m/sec^2 from 1.5 seconds after the onset of POV braking to the time one of the following two conditions is satisfied:
   i. 0.25 seconds prior to the POV coming to a stop.
   ii. The SV makes mechanical contact with the POV.

f. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the POV:
   i. At range R = 7.51 ± 0.5 m (TTC = 0.675 seconds) as shown in Figure 16, the SV brakes are applied to achieve an acceleration of -2.75 m/sec^2 or less using the *Pedal_Position_Command* at a target rate of 254.0 ±25 mm/sec. The onset of the brake pedal input is defined when the brake pedal rate is greater than 50 mm/sec.
   ii. The SV accelerator pedal is released after braking is initiated. The initiation of the release is to occur within 0.5 seconds after the time braking initiated.

g. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.

h. The **TEST ENDS** when either of the following happens:
   i. The SV stops before contacting the POV.
   ii. The SV makes mechanical contact with the POV. What defines “SV-to-POV Contact” is a mechanical touch of SV front-most-point to POV rear-most-point. This can be assessed by contact sensors or GPS-based range data.

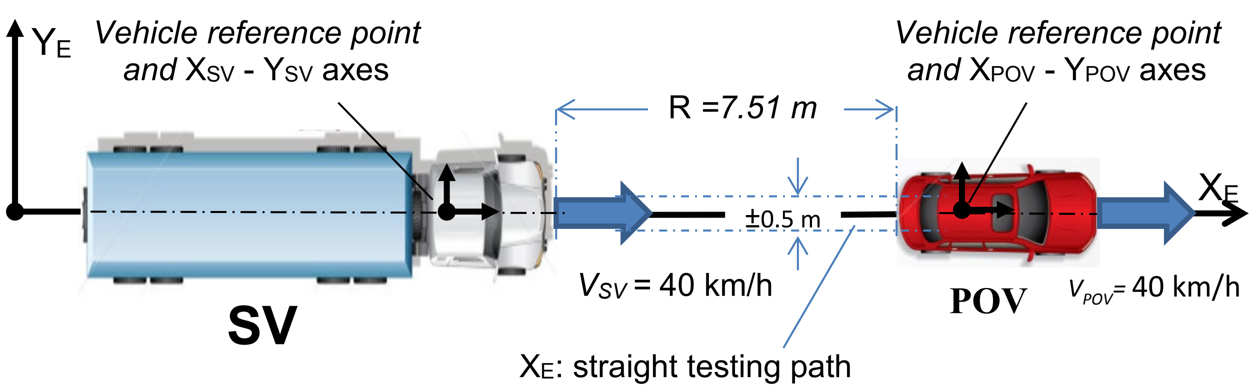

Figure 16. Decelerating Lead Vehicle (80m) – End of Test Initial Condition

3.3.4 Decelerating Lead Vehicle (23m) (LVD_55/55)

a. Perform Baseline Brake Application Test (Characterization Test Validity Check) as detailed in section 3.2.3 at 55 ±2 km/h (35 ±1.24 mph) to determine *Pedal_Position_Command*.
b. The SV is driven forward toward the POV while the X_{SV} and X_{POV} axes are oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the POV is 23.0 m to maintain headway for the next steps.
c. The SV and the POV are driven at a nominal vehicle speed of 55 ±2 km/h (35 ±1.24 mph) with SV-to-POV range R_0 equal to 23 ± 3m (75.5 ± 9.8 feet).
d. The **TEST INITIAL CONDITION STARTS** by driving for a minimum of 1.0 seconds while maintaining the nominal vehicle speed with a consistent range R_0 equal to 23 ± 3m (same as CIB test). The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV and POV vehicle paths with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degree per second.
e. The POV deceleration is controlled to have a constant longitudinal acceleration equal to -3.0 m/sec^2 (-0.31g). The timing tolerance for achieving the specified POV longitudinal acceleration is 1.5 ±0.1 seconds. The average POV acceleration will not deviate from -3.0 m/sec^2 by more than ±0.3 m/sec^2 from 1.5 seconds after the onset of POV braking to the time one of the following two conditions is satisfied:
    i. 0.25 seconds prior to the POV coming to a stop.
    ii. The SV makes mechanical contact with the POV.
f. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the POV:
    i. At range R = 15.65 ± 0.5 m (TTC = 2.41 seconds) as shown in Figure 17, the SV brakes are applied to achieve an acceleration of -2.75 m/sec2 or less using the Pedal_Position_Command at a target rate of 254.0 ±25 mm/sec. The onset of the brake pedal input is defined when the brake pedal rate is greater than 50 mm/sec.
    ii. The SV accelerator pedal is released after braking is initiated. The initiation of the release is to occur within 0.5 seconds after the time braking initiated.
g. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.
h. The **TEST ENDS** when either of the following happens:
    i. The SV stops before contacting the POV.

ii. The SV makes mechanical contact with the POV. What defines "SV-to-POV Contact" is a mechanical touch of SV front-most-point to POV rear-most-point. This can be assessed by contact sensors or GPS-based range data.

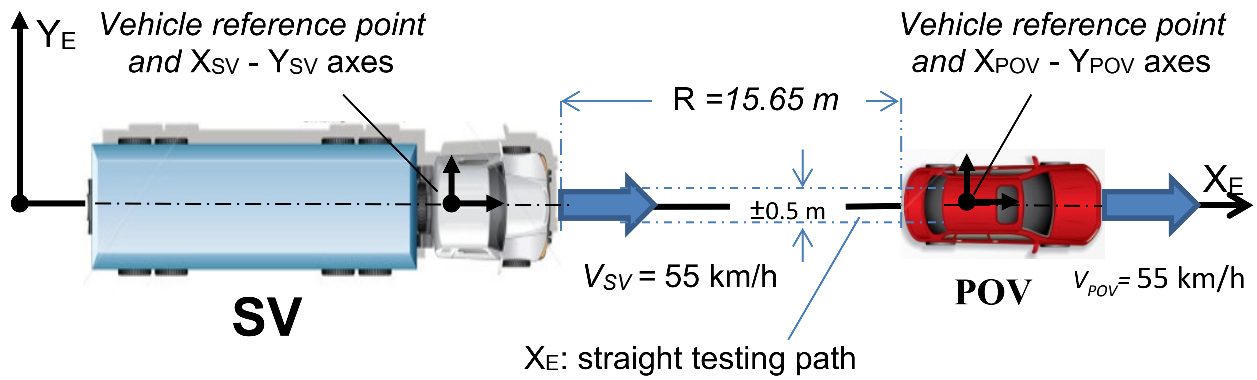

Figure 17. Decelerating Lead Vehicle (23m) – End of Test Initial Condition

3.3.5 <u>False Positive Evaluations–Steel Trench Plate Test (STP_40 & STP_75)</u>

This procedure is performed for two series of tests. The first series consists of 7 consecutive test trials performed at 40 km/h. The second series of tests consists of 7 consecutive test trials performed at 75 km/h as described in the step-by-step procedures shown below.

a. Perform Baseline Brake Application Test (Characterization Test Validity Check) as detailed in section 3.2.3 to determine *Pedal_Position_Command* to determine *Pedal_Position_Command* at:
   i. SV at 40 ±2 km/h (24.9 ±1.24 mph).
   ii. SV at 75 ±2 km/h (46.6 ±1.24 mph).
b. The STP is placed on the road surface with its center position on the X_E-axis and its 3.7 m (12-foot) length parallel to the X_E-axis as shown in Figure 18.
c. The SV is driven forward toward the STP while the X_{SV} -axis is oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the STP is greater than 110.0 m to ensure enough headway for the next steps.
d. The SV is driven to a nominal vehicle speed for at least 1.0 seconds, defined as:
   i. 40 ±2 km/h (24.9 ±1.24 mph).
   ii. 75 ±2 km/h (46.6 ±1.24 mph).
e. The **TEST INITIAL CONDITION STARTS** when the SV position is at:
   i. At speed d.i.), SV-to-STP range R_0 = 56 ±3 m (183.7±9.8 feet).
   ii. At speed d.ii.), SV-to-STP range R_0 = 105 ±3 m (344.5±9.8 feet).

f. The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of SV path with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per second.

g. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the STP:
   i. At SV-to-STP range R = 16.83 ± 0.5 m (TTC = 1.51 seconds) for SV speed at d.i) 40 ±2 km/h as shown in Figure 18, and at SV-to-STP range R = 40.88 ± 0.5 m (TTC = 1.96 seconds) for SV speed at d.ii) 75 ±2 km/h, the SV brakes are applied to achieve an acceleration of -2.75 m/sec^2 or less using the *Pedal_Position_Command* at a target rate of 254.0 ±25 mm/sec. The onset of the brake pedal input is defined when the brake pedal rate is greater than 50 mm/sec.
   ii. The SV accelerator pedal is released after braking is initiated. The initiation of the release is to occur within 0.5 seconds after the time braking initiated.

h. Lateral offset tolerances of the SV and POV vehicle paths are maintained up to the end of test.

i. The **TEST ENDS** when either of the following happens:
   i. When the SV drives over the STP.
   ii. The SV stops before crossing over the STP.

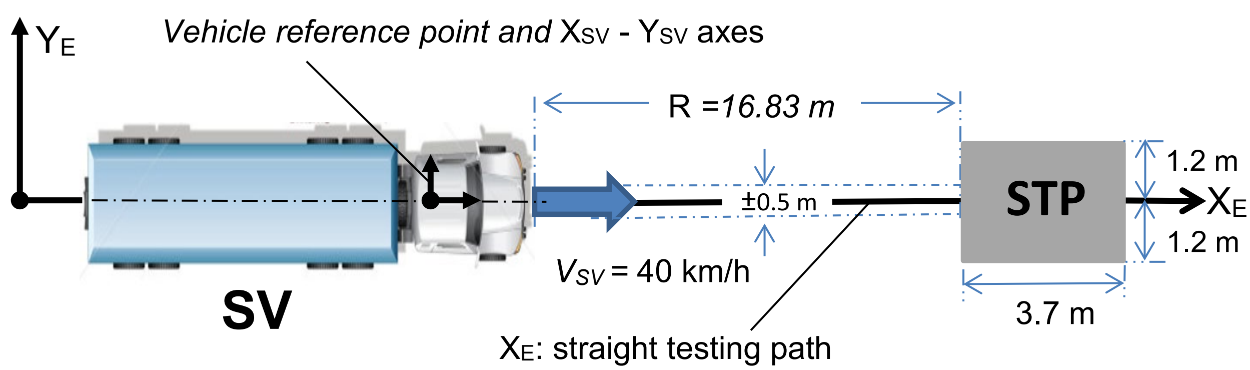

Figure 18. SV encounter a fixed STP – Test Initial Condition @40 km/h at the start of driver braking

3.3.6 *Stationary Vehicles False Positive (FPSV_50)*

a. Perform Baseline Brake Application Test (Characterization Test Validity Check) as detailed in section 3.2.3 at 50 ±2 km/h (31.1 ±1.24 mph) to determine *Pedal_Position_Command*.

b. The two stationary vehicles are positioned as shown in Figure 19:
   i. to face in the same direction as the straight testing path, XE-axis.
   ii. with a lateral distance of 4.5 m between them.
   iii. with the rear of each vehicle aligned with the other.

c. The SV is driven forward while its X_{SV} -axis is oriented on the same direction as the straight testing path (X_E -axis). The starting range that separates the SV from the stationary vehicles is greater than 100.0 m to ensure enough headway for the next steps.
d. The SV is driven to a nominal speed 50 ±2 km/h (31.1 ±1.24 mph) for at least 1.0 seconds.
e. The **TEST INITIAL CONDITION STARTS** when TTC =4.32 seconds[12], that is, SV to stationary vehicles range R_0 is equal to 60 ±3m (196.9 ±9.8 feet). The SV steering-wheel angle is applied to maintain on-center position to counteract vehicle side pulling; lateral deviations of the SV path with respect to the straight testing path (X_E -axis) are 0 ± 0.5 m (0±1.64 feet). The SV yaw rate is 0 ± 2 degrees per second.
f. The **TEST INITIAL CONDITION ENDS,** as the SV approaches the stationary vehicles:
    i. At range R = 23.74 ± 0.5 m (TTC = 1.55 seconds) as shown in Figure 19, the SV brakes are applied to achieve an acceleration of -2.75 m/sec2 or less using the Pedal_Position_Command at a target rate of 254.0 ±25 mm/sec. The onset of the brake pedal input is defined when the brake pedal rate is greater than 50 mm/sec.
    ii. The SV accelerator pedal is released after braking is initiated. The initiation of the release is to occur within 0.5 seconds after the time braking initiated
g. Lateral offset tolerances of the SV are maintained with the straight testing path up to the end of test.
h. The **TEST ENDS** when either of the following happens:
    i. When SV passes the two stationary vehicles.
    ii. The SV stops before passing the two stationary vehicles.

[12] A TTC of 4.32 seconds is equal to 60 m divided by 13.89 m/sec (50 km/h).

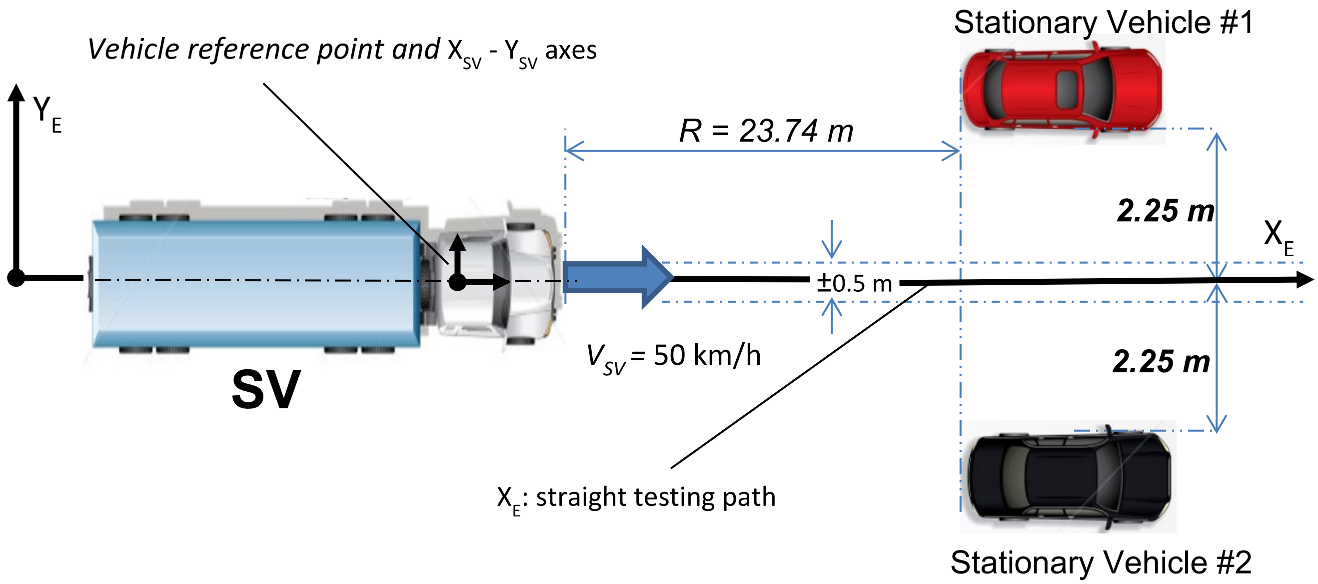

Figure 19. Stationary False Positive -Test Initial Condition at the start of driver braking

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