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Heavy commercial vehicles and buses — Stopping distance in straight-line braking with ABS — Open loop and closed loop test methods

Véhicules utilitaires lourds — Distance d'arrêt de freinage en ligne droite avec ABS — Méthodes d'essai en boucle ouverte et boucle fermée

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 9, *Vehicle dynamics and road-holding ability*.

Introduction

The main purpose of this International Standard is to provide repeatable and discriminatory test results.

The stopping distance and the dynamic behaviour of a road vehicle is a most important aspect of active vehicle safety. Any given vehicle, together with its driver and the prevailing environment, constitutes a closed-loop system which is unique. The task of evaluating the dynamic behaviour is therefore very difficult, since the significant interaction of these driver-vehicle-road elements are each complex in themselves. A complete and accurate description of the behaviour of the road vehicle shall inevitably involve information obtained from a number of different tests.

Since this test method quantifies only one small part of the complete handling characteristics, the results of this test can only be considered significant for a correspondingly small part of the overall dynamic behaviour.

Moreover, insufficient knowledge is available to correlate overall vehicle dynamic properties with accident prevention. A substantial amount of work is necessary to acquire sufficient and reliable data on the correlation between accident prevention and vehicle dynamic properties in general and the results of this test in particular. Consequently, any application of this test method for regulation purposes will require proven correlation between test results and accident statistics.

Test conditions and tyres have a strong influence on test results. Therefore, only results obtained under comparable test and tyre conditions are comparable.

Heavy commercial vehicles and buses — Stopping distance in straight-line braking with ABS — Open loop and closed loop test methods

1 Scope

This International Standard describes test methods for determining the stopping distance during a straight-line braking manoeuvre with the braking system fully operational. It applies to heavy vehicles equipped with an anti-lock braking system (ABS), including commercial vehicles, commercial vehicle combinations, buses and articulated buses as defined in ISO 3833 (trucks and trailers with maximum weight above 3,5 tonnes and buses and articulated buses with maximum weight above 5 tonnes, according to ECE and EC vehicle classification, categories M3, N2, N3, O3, and O4).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3833, *Road vehicles — Types — Terms and definitions*

ISO 8349, *Road vehicles — Measurement of road surface friction*

ISO 8855, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

ISO 15037-2:2002, *Road vehicles — Vehicle dynamics test methods — Part 2: General conditions for heavy commercial vehicles and buses*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855, ISO 15037-2:2002 and the following apply.

3.1
actuation time
time interval from the first pedal contact until the speed of the vehicle is reduced 20 % from its initial value

3.2
stopping distance
distance travelled by the vehicle from the first pedal contact until it comes to a standstill

3.3
build-up distance
distance travelled by the vehicle during the actuation time

3.4
braking distance
distance travelled by the vehicle during the time between two specified velocities

4 Principle

This International Standard specifies a method to determine the stopping distance and other braking distances during full braking at certain nominal initial velocities. The driving situation represents an emergency or panic brake application during straight-ahead driving on an even road surface with a uniform coefficient of friction.

The evaluation range is ideally from the actuation of the brakes to standstill of the vehicle. As it might be difficult to measure accurately at low velocities, the evaluation range may be ended at a certain low velocity. From the initial velocity and the velocity at the end of the evaluation range, and the distance between these two velocities, the mean longitudinal deceleration is determined.

$$a_{\mathrm{x}} = \frac{v_0^2 - v_2^2}{2s_{\mathrm{x}}} \quad (1)$$

where

a_{x} is the calculated deceleration;

v_0 is the initial velocity;

v_2 is the velocity at the end of the evaluation range;

s_{x} is the measured distance between v_0 and v_2.

The stopping distance from the nominal initial velocity is calculated from

$$s_{ref} = \frac{v_{nom}^2}{2a_{\mathrm{x}}} \quad (2)$$

where

s_{ref} is the stopping distance for a single test run referenced to the nominal velocity;

v_{nom} is the nominal initial velocity for the test series.

Test results can only be compared if measurements took place under identical conditions, on the same test surface and under very similar ambient conditions. Therefore, comparison of results should only be made for tests done on a given surface within a short time period. Apart from the technical equipment and especially the braking characteristics of the vehicle, the distance travelled after the first pedal contact very strongly depends on the specific character of brake-pedal actuation. To minimize this influence, this International Standard specifies rules for brake pedal actuation.

For vehicle combinations, test results depend on the performance of each vehicle unit. Therefore, the performance of first vehicle units can only be compared when the following units are identical in the vehicle combination. When measuring the performance of vehicle combinations, weight transfer between the units has significant influence on the results. Furthermore, electronic braking systems can include settings for the compatibility between the vehicle units, which can also influence the results.

5 Variables

5.1 Reference system

The reference system specified in ISO 15037-2 shall apply.

5.2 Variables to be measured

The variables of motion used to describe the behaviour of the vehicle shall be related to the intermediate axis system (*X, Y, Z)* of the first vehicle unit (see ISO 8855). The variables that shall be determined for compliance with this International Standard are the following:

— longitudinal velocity, v_X;

— time of brake pedal actuation (t_0);

— longitudinal distance (s);

— brake pedal position (s_B) or actuation force (F_P).

It is recommended that the following variables also be determined:

— longitudinal acceleration, a_X;

— lateral deviation, Y_1, of the reference point of the first vehicle unit from the axis X of the initial straight-ahead vehicle velocity, v_0;

— steering-wheel angle, δ_H;

— yaw angle, ψ;

— brake temperature for each axle.

6 Measuring equipment

The measuring equipment, transducer installation, and data processing shall be in accordance with ISO 15037-2:2002.

Typical operating ranges of the variables to be determined for this International Standard are shown in Table 1 and in ISO 15037-2:2002. It shall be ensured that changes in vehicle pitch angle during braking do not affect the measurement of the velocity and distance variables.

To monitor the running in of tyres and burnishing of brakes, and to monitor test conditions, brake temperature sensors and a device for measuring and displaying vehicle deceleration are required.

Table 1 — Variables, typical operating ranges and recommended maximum errors of variables not listed in ISO 15037-2

Variable	Typical operating range	Recommended maximum errors of the combined transducer and recorder system
Longitudinal velocity	0 km/h to 100 km/h	±0,5 km/h
Longitudinal distance	0 m to 100 m	±0,05 m
Lateral deviation	0 m to 5 m	±0,05 m
Brake pedal position, if rotational	0° to 45°	±0,5°
Brake pedal position, if translational	0 mm to 100 mm	±1 mm
Brake pedal actuation force	0 N to 1000 N	±10 N
Yaw angle	±20°	±1°

NOTE The accuracy of the measured longitudinal distance depends not only on the resolution of the recorded signals, but also on the on the sampling frequency. For instance, at 90 km/h, a sampling rate of 100 Hz gives 0,25 m travelled distance per sample.

7 Test conditions

7.1 General

The test conditions described in ISO 15037-2:2002, along with the following additions, shall apply to this International Standard. General data of the test vehicle shall be recorded as specified in Annex A.

7.2 Test track

All tests shall be carried out on an even road surface with a uniform coefficient of friction. The gradient of the test surface shall not exceed 0,5 % longitudinal inclination when measured over any distance interval greater than or equal to the vehicle track. The friction coefficient shall not vary more than ±5 % over the length of the test surface. The friction coefficient should be measured according to ISO 8349.

7.3 Ambient conditions

For performing the tests on dry road surfaces, the ambient temperature and the temperature of the test surface should be between +5 °C and +40 °C, and their variation shall not exceed 10 °C.

Tests performed on other than dry road surfaces and special tests for the comparison of specific components, such as tyres, can require much smaller temperature ranges in order to be comparable. When performing tests on winter surfaces, other ambient parameters such as intensity and duration of sunshine can influence the test results.

7.4 Test vehicle

7.4.1 General vehicle conditions

The reference condition of the test vehicle is in accordance with the vehicle manufacturer's specifications, particularly with respect to the brake system, the suspension, power train configuration (e.g. differentials and locks), and tyres used, and shall be in accordance with ISO 15037-2:2002. Deviations from this reference condition shall be reported in the test results.

If the vehicle is equipped with additional drive train braking devices (e.g. retarder) or functions other than ABS that influence braking performance (e.g. cross-axle braking difference compensation), the actual condition shall be reported.

7.4.2 Tyres

For the tyres of the test vehicle, the conditions specified in ISO 15037-2:2002 shall apply, with the following additions:

— During run-in, longitudinal and lateral accelerations should not exceed 2 m/s^2. After run-in, the tyres shall be used at the same position during the tests.

— If test results are to be compared, other than in the case of comparing tyres, the tyres at each axle shall be identical in terms of make, model, size, and thread pattern. It is also recommended that the tyres at each axle come from the same manufacturing batch.

NOTE Repeated severe braking results in a so-called brake-in effect of tyres which shortens the braking distance in subsequent tests and which does not represent a real-life condition. It is therefore important to use new tyre sets and to conduct only the run-in procedure described in ISO 15037-2:2002 to condition them.

7.4.3 Brake system

The brake system shall be in a well-maintained condition. The following conditions have a negative impact on braking performance and shall be avoided so as to achieve valid and comparable test results:

— overstressed brake pads or linings (e.g. due to fading tests);

— glazed, heavily, unevenly, or tapered worn brake pads or linings;

— heavily worn or cracked brake discs or brake drums;

— corroded brake callipers, brake discs, or brake drums;

— contaminated friction surfaces (e.g. with de-icing salt, oil);

— incorrect brake supply pressure;

— brake system leaks;

— unequally adjusted brakes.

Any newly installed wheel brakes shall be burnished in accordance with vehicle manufacturer specifications. Alternatively, the burnishing procedure specified in Annex A can be applied. Hydraulic systems shall be fully bled (free of air residuals), in accordance with the manufacturer's instructions. The brakes of the test vehicle shall not be contaminated with foreign material.

It is recommended to determine and report the maximum pneumatic pressure of the air braking system before conducting the tests.

7.4.4 Loading condition

The loading condition of the vehicle shall be in accordance with ISO 15037-2:2002. Results gained with different vehicles or different vehicle configurations can only be compared under the same loading conditions.

8 Test method

8.1 General

8.1.1 Test preparation

To ensure constant friction characteristics, all test runs shall be performed on the same test surface. Comparative measurements should always be started at the same spot to avoid different friction coefficients. However, to avoid long-term road contamination or damage, the initial braking point should vary along the test surface when carrying out entirely different measuring sequences. For conducting the test on a test track with ice or snow surface, different braking lanes should be chosen to avoid polishing of the test track surface.

It shall be ensured that neither tread wear nor frequent braking cause a significant change of the friction coefficient of the test surface.

8.1.2 Warm-up

A warm-up procedure according to ISO 15037-2:2002 shall be carried out. The temperature of the brake discs/drums at each axle shall not vary more than ±30 °C prior to each measurement within a series of tests. The initial brake temperature for each test run shall be reported. Overheating of the brakes shall be avoided. If required, cooling phases shall be provided.

8.2 Performance of the braking procedure

8.2.1 Initial driving conditions

The initial driving condition for the test shall be driving straight ahead as specified in ISO 15037-2:2002. The standard nominal initial vehicle velocity at the beginning of the braking is 80 km/h. Other initial velocities may be used, especially for tests on low coefficient of friction surfaces.

8.2.2 Brake pedal actuation

After reaching the initial driving conditions, the brakes shall be applied as quickly as possible to 100 % of full braking and maintained during the period of evaluation. Full application of the brake pedal shall be reached within 0,2 s after the first foot contact. For air brake systems, full braking corresponds to 100 % of full stroke of the brake pedal; and for hydraulic brake systems, full braking corresponds to a brake-pedal force of no less than 500 N. This pedal position or pedal force shall be maintained until the vehicle comes to a standstill.

The measurement shall start at the instant of the first foot contact with the brake pedal. This instant is defined by either a signal of a contact switch or determined from the pedal force signal. The signal representing the initial pedal contact shall be triggered at a pedal force of 10 N or lower or at a pedal travel of 2 % of full stroke or lower.

8.2.3 Conditions during braking

The test can be conducted either in open-loop or closed-loop. For an open-loop test, the steering wheel shall be held fixed after reaching the initial condition. For a closed-loop test, the driver keeps the vehicle on a straight line by corrective steering actions. In both cases, the steering wheel angle shall be reported in the test results.

For manual transmissions, the clutch shall be disengaged throughout the course of braking. For automatic transmissions, the transmission can be either in neutral or in drive condition. In all cases, the actual condition shall be reported. Comparisons of stopping distances are only possible if the condition of engagement is the same.

8.2.4 Number of test runs

One test sequence consists of at least five valid individual test runs, i.e. test runs performed while observing all conditions specified

9 Data evaluation and presentation of results

9.1 General

In the test report, test conditions shall be presented as shown in Annex A. Each change in vehicle equipment (e.g. different loading conditions) shall be documented. Annex B shows an example of reporting the results.

For every test run, time histories of the variables listed in Clause 5 shall be presented. Apart from their evaluation purposes, the time histories serve to monitor correct test performance and functioning of the transducers. Annex D shows an example of time histories of the vehicle velocity.

The evaluation range of the measurement shall start at the initial brake pedal contact and shall end when the velocity has reached 10 % of the initial velocity to stay in the range of high measuring accuracy of many measuring systems.

For determining the braking distance and the build-up distance, the actuation time is assumed to be the time between initial brake pedal contact and the instant when the vehicle velocity has reached 80 % of the initial velocity.

9.2 Stopping distance

The mean deceleration, a_i, (m/s^2), for each individual test run is calculated from:

$$a_i = \frac{v_{0,i}^2 - v_{2,i}^2}{2 s_{x,i}} \tag{3}$$

where

a_i is the calculated mean deceleration from brake pedal contact until standstill;

$v_{0,i}$ is the measured velocity at the instant of first brake pedal;

$v_{2,i}$ is the measured velocity at the end of the evaluation range;

$s_{x,i}$ is the measured distance between $v_{0,i}$ and $v_{2,i}$.

The reference stopping distance, $s_{A,ref}$, for the nominal initial velocity for each individual test run is calculated from:

$$s_{A,ref,i} = \frac{v_{nom}^2}{2 a_i} \tag{4}$$

where

$s_{A,ref,i}$ is the stopping distance for a single test run referenced to the nominal velocity;

v_{nom} is the nominal initial velocity for the test series;

a_i is the mean deceleration for a single test run.

The mean stopping distance, $s_{A,ref,m}$, is calculated as an arithmetic average of at least five approved test runs.

The mean stopping distance, its standard deviation, and the results from the individual test runs shall be reported.

9.3 Deceleration at full braking (optional)

The average deceleration, $a_{L,i}$, during the full braking phase for a single test run is calculated as follows:

$$a_{L,i} = \frac{v_{1,i}^2 - v_{2,i}^2}{2 s_{L,i}} \tag{5}$$

where

$a_{L,i}$ is the calculated mean deceleration between $v_{1,i}$ and $v_{2,i}$;

$v_{1,i}$ is the measured velocity at the end of the actuation time;

$v_{2,i}$ is the measured velocity at the end of the evaluation range;

$s_{L,i}$ is the measured distance between $v_{1,i}$ and $v_{2,i}$.

9.4 Braking distance (optional)

The reference braking distance, $s_{L,ref,i}$ is calculated for each single test run as follows:

$$s_{L,ref,i} = \frac{v_L^2}{2a_{L,i}} \tag{6}$$

where

$s_{L,ref,i}$ is the braking distance for a single test run referenced to the nominal initial velocity;

v_L is the nominal velocity at the end of the actuation time for the test series;

$a_{L,i}$ is the average deceleration for a single test run.

The mean braking distance, $s_{L,ref,m}$ is calculated as an arithmetic average of at least five approved test runs.

The mean braking distance, its standard deviation, and the results from the individual test runs shall be reported.

9.5 Build-up distance (optional)

The build-up distance is obtained from the difference between the stopping distance and the braking distance.

$$s_{F,ref,m} = s_{A,ref,m} - s_{L,ref,m} \tag{7}$$

where

$s_{F,ref,m}$ is the calculated distance during deceleration build-up;

$s_{A,ref,m}$ is the mean stopping distance;

$s_{L,ref,m}$ is the mean braking distance.

9.6 Lateral deviation, Y_1 (optional, for open-loop tests)

The lateral deviation, Y_1, is the distance of the vehicle reference point of the first vehicle unit from the longitudinal axis given by the initial vehicle velocity vector before brake pedal contact. The time signal of the lateral deviation from brake pedal contact until standstill and its final value at vehicle standstill shall be reported for each test run and the mean value for the test series shall be reported (see Annex B).

9.7 Yaw angle deviation, ψ (optional, for open-loop tests)

The yaw angle deviation is the difference between the yaw angle measured at the first brake pedal contact and the yaw angle measured when the vehicle has reached standstill. The time signal of the yaw angle during each test run and the mean value of the yaw angle deviation for the test series shall be reported (see Annex B).

The yaw angle deviation is the difference between the yaw angle measured at the first brake pedal contact and the yaw angle measured when the vehicle has reached standstill. The time signal of the yaw angle during each test run and the mean value of the yaw angle deviation for the test series shall be reported (see Annex B).

9.8 Steering-wheel angle, δ_H (optional, for closed-loop test)

The time signal of steering wheel angle from brake pedal contact until standstill and its maximum value, $\delta_{H,max,m}$, during braking shall be reported for each test run (see Annex B).

Annex A
(normative)

Test report — General data and test conditions

A.1 General data

The test report for general data shall be as given in ISO 15037-2:2002, Annex A.

A.2 Test conditions

The test report for test conditions shall be as given in ISO 15037-2:2002, Annex B.

Annex B
(informative)

Test report — Results

Table B.1 — Test results I

Test results I: Stopping distance, s_A					
Nominal initial velocity (km/h):					
Coefficient of friction of the road surface:					
Measurement values	**Initial velocity** v_0 (km/h)	**End velocity** v_2 (km/h)	$s_{A,i}$ (m)	$s_{A,ref,i}$ (m)	**Initial brake temperature** (°)
Test 1					
Test 2					
Test 3					
Test 4					
Test 5					
Test 6					
Test 7					
Test 8					
Test 9					
Test 10					
Mean $s_{A,ref,i}$ from all valid test runs:					

If not all stops could be taken for evaluation, the number of failed test runs shall be documented:

No. of failed stops: ___________

Table B.2 — Test results II

Test results II: Braking distance, s_L			
Measurement values	**Initial velocity** v_1 (km/h)	$s_{L,i}$ (m)	$s_{L,ref,i}$ (m)
Test 1			
Test 2			
Test 3			
Test 4			
Test 5			
Test 6			
Test 7			
Test 8			
Test 9			
Test 10			
Mean $s_{L,ref,i}$ from all valid test runs:			

Table B.3 — Test results III

Test results III: Build-up distance, s_F	
Value $s_{F,ref,m}$:	

NOTE I. Nominal initial velocity, coefficient of friction, and end velocity, v_2, for test results II/III; see test results I.

Table B.4 — Test results IV

Test results IV: Lateral deviation, Y_1, and yaw angle deviation, ψ, for open-loop test			
Measurement values	**Initial velocity** v_0 (km/h)	$Y_{1,i}$ (m)	ψ (°)
Test 1			
Test 2			
Test 3			
Test 4			
Test 5			
Test 6			
Test 7			
Test 8			
Test 9			
Test 10			
Mean $Y_{1,i}$ from all valid test runs:			

Table B.5 — Test results V

Test results V: Maximum steering wheel angle (δ_H) for closed-loop test			
Measurement values	**Initial velocity** v_0 (km/h)	$s_{A60,i}$ (m)	$\delta_{H,max,i}$ (°)
Test 1			
Test 2			
Test 3			
Test 4			
Test 5			
Test 6			
Test 7			
Test 8			
Test 9			
Test 10			
Mean $\delta_{H,max,i}$ from all valid test runs:			

NOTE I. Nominal initial velocity, coefficient of friction, and end velocity, v_2, for test results IV/V; see test results I.

Annex C
(informative)

Brake burnishing and calibrations

C.1 Burnishing program for newly installed brakes

For newly installed disc brakes, a total of at least 60 burnishing runs shall be performed starting at about 80 km/h and ending at about 20 km/h. In the first 15 runs, a deceleration of approx. 2 m/s^2 shall be applied. In the next 15 runs, a deceleration of approx. 3 m/s^2 shall be applied. In the last 30 runs, a deceleration of approx. 4 m/s^2 shall be applied.

For newly installed drum brakes, a total of at least 200 burnishing runs shall be performed starting at about 80 km/h and ending at about 20 km/h. In the first 50 runs, a deceleration of approx. 2 m/s^2 shall be applied. In the next 50 runs, a deceleration of approx. 3 m/s^2 shall be applied. In the last 100 runs, a deceleration of approx. 4 m/s^2 shall be applied.

The deceleration according to this program shall be indicated by a suitable measuring device. The brake temperature before every stop shall be below 120 °C. The tyres used for burnishing the brakes are severely pre-conditioned and should not be used for the braking distance measurements.

C.2 Calibration of velocity and distance measurement device

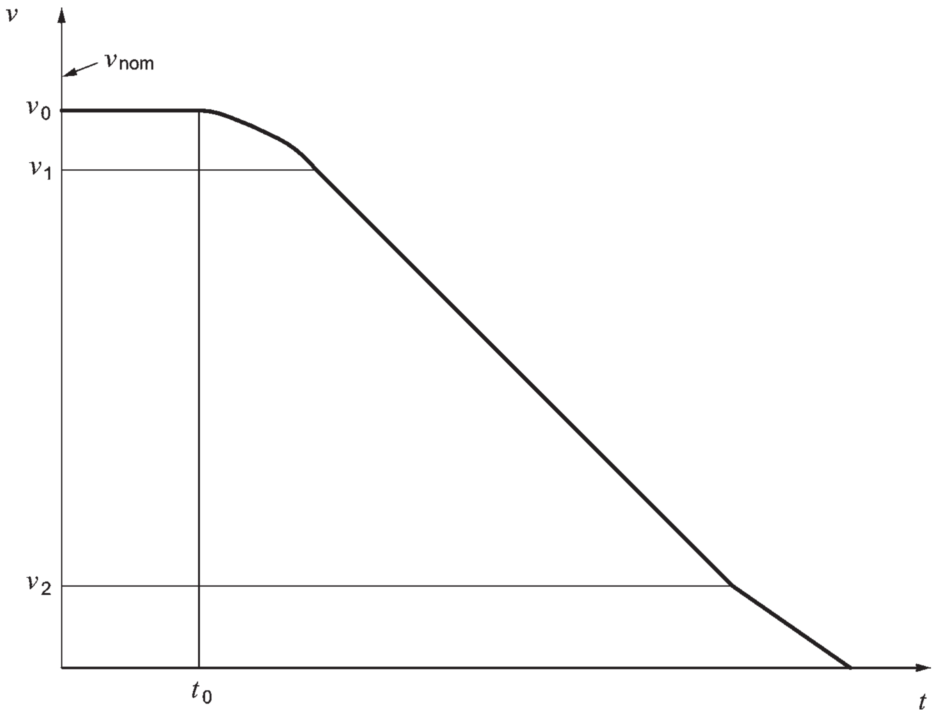
Drives for the calibration of the longitudinal distance measurement equipment shall be performed at a constant longitudinal velocity between 60 km/h and 80 km/h. The standard calibration distance shall be 500 m straight ahead drive. Light barriers on the vehicle and reflecting tapes on the calibration track are recommended for start and stop triggers for the measuring system. The maximum tolerance of the measured value for the calibration distance is ±0,25 % referring to the total length.

For a quick check of the dynamic measuring accuracy, it is recommended to conduct an ABS-controlled braking on the calibration track.

A recommended way to check the brake distance measurement is to perform an ABS braking on the test surface and to compare the results of the measuring system with the reading from a measurement tape. A small reflector (reflection tape) on the measuring track is used to start the measuring system via a light barrier attached to the outside of the vehicle. The reflector is also the starting point for the tape measurement. The vehicle is driven at steady-state with nominal test speed on the test surface. Directly after passing the reflector and by triggering the measuring system, a full ABS braking is performed. After the vehicle has come to a standstill, the distance between reflector and light barrier on the vehicle is measured with a precise measuring tape. The distances measured with tape and measuring system shall be compared.

Annex D
(informative)

Principle graphs

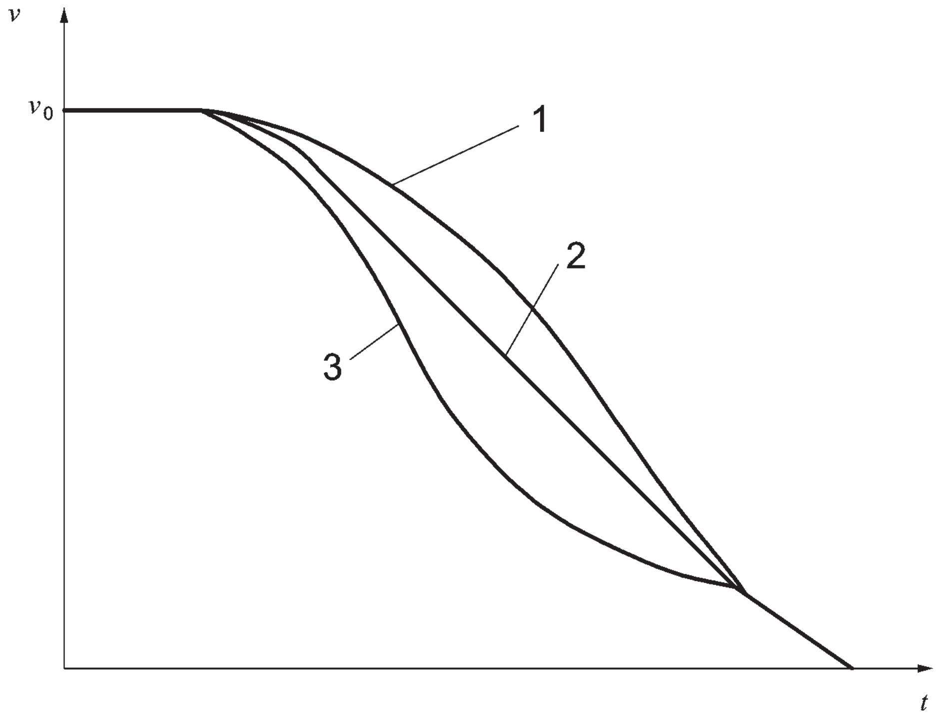


Key

v velocity

t time

Figure D.1 — Principle graph for velocity and time nomenclature



Key

v velocity

t time

1 non-linear deceleration during full braking with longer stopping distance

2 linear deceleration during full braking

3 non-linear deceleration during full braking with shorter stopping distance

Figure D.2 — Principle graph for possible non-linear shapes of deceleration

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