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Passenger cars — Stopping distance at straight-line braking with ABS — Open-loop test method

Voitures particulières — Distance d'arrêt de freinage en ligne droite avec ABS — Méthode d'essai en boucle ouverte

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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21994 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 9, *Vehicle dynamics and road-holding ability*.

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Introduction

The stopping distance of a road vehicle is an important part of vehicle performance and active vehicle safety. Any given vehicle, together with its driver and the prevailing environment, constitutes a unique closed-loop system. The task of determining the stopping distance is therefore very difficult, since there is a significant interaction between these driver-vehicle-environment elements, each of which is complex in itself.

Test conditions and tyres have a strong influence on test results. Therefore, only vehicle stopping distances obtained under comparable test and tyre conditions are comparable to one another.

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Passenger cars — Stopping distance at straight-line braking with ABS — Open-loop test method

1 Scope

This International Standard specifies an open-loop test method to determine the stopping distance of a vehicle during a straight-line braking manoeuvre, with the Anti-lock Braking System (ABS) fully engaged. This International Standard applies to passenger cars as defined in ISO 3833 and light trucks.

This International Standard specifies a reference method and is especially designed to ensure high repeatability.

2 Normative references

The following referenced documents are indispensable for the application of this document. 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/TR 8349, *Road vehicles — Measurement of road surface friction*

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

ISO 15037-1:2006, *Road vehicles — Vehicle dynamics test methods — Part 1: General conditions for passenger cars*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8855 and the general conditions given in ISO 15037-1 shall apply. For specific terms see Annex C.

4 Principle

This International Standard specifies a method to determine the braking distances characterizing the deceleration build-up phase at the beginning of a braking manoeuvre and at full braking until the vehicle comes to a standstill.

The driving situation represents an emergency or panic braking phase (pushing the brake pedal with a very high activation speed) during straight-ahead driving on an even and dry road surface with a high coefficient of friction.

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Using this International Standard, three results become available:

— stopping distance from initial brake pedal contact until vehicle comes to a standstill (s_{A100});

— ABS-braking distance describing the distance travelled under full ABS-controlled braking from 90 km/h until vehicle comes to a standstill (s_{L90}); and

— estimation of the build-up distance from initial brake pedal contact until a velocity reduction of 10 km/h is achieved (s_{F10}).

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 individual pedal actuation of the driver. To minimize this influence, this International Standard specifies rules for brake pedal actuation.

To achieve reproducible, reliable and comparable measurement results, a multitude of further test conditions shall be observed.

Measurement results can only be compared if measurements took place under identical conditions. In particular, this means:

— same track (see also Annex C); and

— very similar weather and ambient conditions (wind, temperature, etc.).

5 Variables

5.1 Reference system

The reference system specified in ISO 15037-1 shall apply.

5.2 Variables to be measured

The following variables shall be measured:

— longitudinal velocity: (v_X);

— time of brake pedal actuation: (t_0);

— longitudinal distance: (s);

— brake pedal actuation force: (F_P).

The variable longitudinal velocity is defined in ISO 8855.

6 Measuring equipment

6.1 Description

All variables shall be measured by means of appropriate transducers, and their time histories shall be recorded by a multi-channel recording system. Alternatively, data measured may be recorded and processed directly in a calculation unit of the measuring system without the possibility to access time histories. Typical operating ranges, and recommended maximum errors of the transducer and recording system, are given in Table 1. If initial longitudinal velocities different from 100 km/h are chosen, the following operating ranges shall be changed accordingly, but maximum errors shall be unchanged.

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Table 1 — Variables, their typical operating ranges and recommended maximum errors — Additions and exceptions to ISO 15037-1

Variable	Typical operating range	Recommended maximum error of the combined transducer and recorder system
Initial longitudinal velocity[a]	102 km/h – 98 km/h	± 0,5 km/h
Longitudinal velocity[b]	93 km/h – 5 km/h	± 0,5 km/h
Longitudinal distance	100 m	± 1 % (⩽ 50 m) ± 0,50 m (> 50 m)
Brake force trigger	⩽ 10 N (triggering point)	± 5 N
Brake pedal actuation force[c]	0 N – 1 000 N (max. 1 500 N)	± 2 %

a Determined in averaging interval 0,2 s-0 s before brake pedal contact.

b Deviations of the measured velocity are normally found in the transition area from steady state driving to full braking.

c It is recommended to use a lateral force compensated brake force transducer.

The trigger signal for brake pedal contact shall be activated at a pedal force of 10 N or less. The time delay of the trigger signal shall be 5 ms or less. If the pedal force transducer does not fulfil this specification, it is recommended to use a contact switch on the brake pedal's step pad.

To monitor test preparation (run-in) and test conditions, the following measuring devices are required:

— brake (disc/drum or pad/lining) temperature sensor; and

— device for measuring and displaying vehicle deceleration (run-in).

6.2 Transducer installation

The requirements of 4.2 of ISO 15037-1:2006 shall apply. In addition, it shall be ensured that transient vehicle pitch angle changes during braking do not affect the measurement of the velocity and distance variables for the chosen transducer system.

6.3 Calibration

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

For a detailed procedure of calibration, see Annex E.

6.4 Data processing

The recording system and data processing requirements contained in 4.3 of ISO 15037-1:2006 shall apply.

7 Test conditions

7.1 General test conditions

The test conditions shall be in accordance with Clause 5 of ISO 15037-1:2006, unless otherwise specified in this International Standard.

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7.2 General data

General data on the test vehicle and test conditions shall be recorded as specified in ISO 15037-1:2006, 5.4.1 and Annexes A and B, with the additions of the braking system and tyre data as listed in Annex A of this International Standard.

7.3 Test track

All tests shall be carried out on a smooth, clean, dry and uniform paved road surface.

The gradient of the test surface to be used shall not exceed 1 % longitudinal inclination and 2 % transversal inclination when measured over any distance interval between that corresponding to the vehicle track and 25 m.

It is recommended to use a lane width of 3,5 m or more.

The friction coefficient of the test surface shall be a minimum of 0,9, and its variation shall not exceed ± 5 % over the length of the test surface. These requirements are generally fulfilled on concrete and rough asphalt surfaces. (See also C.2.2 and C.2.3.)

7.4 Environmental conditions

The weather conditions shall remain unchanged during a sequence of measurements. The ambient wind velocity (regardless of the wind direction) shall either not exceed 3 m/s or, if the wind velocity ranges between 3 m/s and 5 m/s maximum, an equal number of measurements specified shall be carried out in both driving directions. The total number of measurements shall remain the same (see 8.2.5).

The ambient temperature shall be between + 5 °C and + 35 °C and its variation during a sequence of measurements shall not exceed 10 °C.

The surface temperature of the test track shall be between + 10 °C and + 40 °C and its variation during a sequence of measurements shall not exceed 10 °C.

Additionally, the variation in surface temperature along the length of the test track (e.g. due to changes from sunlit to shaded areas) shall not exceed 10 °C.

Measurements performed within acceptable temperature ranges as specified above can only be compared if, additionally, the temperature difference between one another is below 10 °C. Special tests with specific structural components such as tyres may require much smaller tolerance ranges in order to become comparable.

7.5 Test vehicle

7.5.1 General vehicle condition

The condition of the test vehicle shall be in accordance with the vehicle manufacturer's specifications, particularly with respect to the complete brake system, the suspension geometries, power train (e.g. differentials and locks) configuration and tyres used.

7.5.2 Tyres

Generally, all measurements shall be conducted with summer tyres.

For a general tyre condition, new tyres shall be fitted on the test vehicle according to the manufacturer's specifications. If not specified otherwise by the tyre manufacturer, they shall be run in on the test vehicle for at least 150 km on a road surface with high friction or on an equivalent vehicle without excessively harsh use, for example braking, acceleration, cornering, hitting the kerb, etc. Therefore, longitudinal and lateral accelerations shall not exceed 3 m/s^2 during run-in. After run-in the tyres shall be used at the same vehicle locations for the tests.

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The existing tread depth and the type of wear have an impact on the length of the braking distance (see C.2.5). Therefore, when comparing vehicles or tyres, new tyres shall be used for the measurements as a general rule. If no new tyres are used, the tyre parameters and tread widths should show a steady wear condition with a tread depth of at least 90 % of the original value across the whole breadth of the tread and around the whole circumference of that of the new tyre.

Tyres shall be manufactured not more than one year before the test. The date of manufacturing (DOT-stamp) shall be noted in the presentation of test conditions (see Annex A).

Tyres shall be inflated to the pressure as specified by the vehicle manufacturer for the test vehicle configuration. The tolerance for setting the cold inflation pressure is ± 5 kPa for pressures up to 250 kPa and ± 2 % for pressure above 250 kPa.

Tyre data, the inflation pressure and tread depth of the tyres determined before tyre warm-up and after the test runs shall be recorded in the test report (see Annex B).

7.5.3 Braking system

The braking system shall be in a technically perfect condition (see also C.2.9). Any newly installed wheel brakes (brake discs, brake drums, brake pads) must be burnished in accordance with vehicle manufacturer specifications. Alternatively, the burnishing procedure for brakes as specified in C.2.5.2 may be applied. Hydraulic systems shall be fully bled (free of air residuals) in accordance with the manufacturer's instructions.

7.5.4 Loading conditions of the vehicle

The fuel tank shall be full and, in the course of the measurement sequence, the indicated fuel level should not drop below "half-full".

The total load of the driver plus instrumentation should not exceed 150 kg.

If the vehicle is to be tested in any other load condition (e.g. GVM), then the additional payload shall be evenly distributed such that cross-axle variations do not exceed 50 kg (see C.2.6).

8 Test procedure

8.1 Test preparation

8.1.1 Defining the measurement distance

To ensure constant friction characteristics, all test runs shall be performed on the same track section.

It shall be ensured that neither tread wear nor frequent braking can cause a relevant change of the track surface and hence a different road friction coefficient.

Comparative measurements should always be started at the same spot to avoid different friction coefficients.

However, to avoid punctual road contamination or damage in the long run, the initial braking point should vary along the track when carrying out entirely different measuring sequences.

Since friction coefficients often vary considerably across the driving track, it shall be ensured that the tests are all performed on the same driving track in order to achieve reproducible test results.

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8.1.2 Conditioning tyres and brake system

The tyres and at the same time the brakes are submitted to a two-step conditioning procedure on the test track directly before the braking distance measurements:

1) 5 (five) ABS controlled brakings from about 100 km/h to a stop without excessively heating the brake, i.e. the brake disc temperatures must not exceed 120 °C at the beginning of each braking; and

2) cooling down the tyres (normal ride for about 10 km recommended).

8.2 Measurements

8.2.1 Brake disc temperature

Before each measurement, the temperature of the front brake discs shall be between 80 °C and 120 °C and that of the rear brake discs (brake drums) below 120 °C (100 °C). If required, cooling phases shall be provided.

8.2.2 Initial driving condition

The initial driving condition is a steady-state straight ahead run (see 6.2.2 of ISO 15037-1). The longitudinal acceleration shall not exceed $\pm$ 0,3 m/s^2.

The specified vehicle velocity at the beginning of the braking is 100 km/h with a maximum tolerance of $\pm$ 2 km/h. To minimize dynamic effects, the vehicle should be driven at a steady velocity for at least 1,5 s (about 50 m) before braking is initiated (see also C.2.7).

Depending on the vehicle transmission type, one of the following driving conditions shall be selected:

— automatic transmission: standard drive mode D;

— manual transmission: starting; usually with the fourth or a higher gear engaged, disengaging in the course of the braking, i.e. it should be disengaged at the latest at a velocity of about 80 km/h.

The gear chosen (for automatic transmissions, selected driving range) shall be documented in the test record.

Alternatively, neutral gear may be selected before commencing the brake application. Comparisons of braking distances are only possible if the condition of engagement is the same (gearbox: disengaged/declutched, respectively in neutral mode “N”; or gearbox: engaged, respectively drive mode “D”).

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

8.2.3 Brake pedal actuation

8.2.3.1 Determination of the minimum brake pedal force

The brake pedal shall be applied very fast and with sufficient pedal force. The brake pedal force must be high enough to guarantee ABS-control throughout the whole braking phase of the test run. Therefore, a minimum force of 500 N shall be applied. This force shall be at least 1,5 times F_ABS or higher. F_ABS shall be determined for the test vehicle as described in Annex D.

8.2.3.2 Brake pedal application

The measurement shall start at the instant of 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.

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The brake pedal shall be applied with a minimum force of 500 N or 1,5 times F_ABS (whatever is higher). The gradient shall be higher than 3333 N/s (i.e. 500 N in 150 ms). The minimum pedal force shall be maintained until the vehicle comes to a standstill.

During the entire procedure, the pedal force shall not exceed a value of 1500 N.

8.2.4 Conditions during braking

To be able to keep the vehicle properly on track, no major steering corrections shall be applied during braking (see C.2.8). Any minor steering corrections during braking shall be documented in the test report.

8.2.5 Number of measurements

One measurement sequence consists of 10 (ten) valid individual measurements (i.e. measurements performed while observing all conditions specified).

9 Data evaluation and presentation of results

9.1 General

In the test report, general information should be presented as shown in Annex A. Each change in vehicle equipment (e.g. different load conditions) shall be documented.

Applying this International Standard will deliver up to three results:

1) **Normalized stopping distance $s_{\mathrm{A100,norm}}$**: Distance travelled between initial brake pedal contact until the vehicle comes to a standstill. The stopping distance is normalized to the nominal initial velocity (100 km/h).

2) **Normalized ABS-braking distance $s_{\mathrm{L90,norm}}$(100)**: Distance travelled under full ABS-controlled braking from 90 km/h until vehicle comes to a standstill.

3) **Normalised build-up distance $s_{\mathrm{F10,norm}}$(100)**: Distance travelled during deceleration build-up, defined as interval of a velocity decrease of 10 km/h ("First 10 km/h"): Distance between the point of first brake pedal contact, normalized to the nominal velocity of 100 km/h, until the velocity 90 km/h is reached.

Positions 2 and 3 are optional.

All calculated longitudinal decelerations shall be determined according to the following formula:

$$a_{\mathrm{x}} = \frac{v_1^2 - v_2^2}{2 \cdot s_{\mathrm{x}}} \tag{1}$$

where

a_{x} is the calculated deceleration;

v_1 is the initial velocity;

v_2 is the velocity at end of measurement;

s_{x} is the measured distance (between v_1 and v_2).

The velocity at the end of the measurement shall be 5 km/h to stay in the range of high measuring accuracy of many measuring systems.

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9.2 Nomenclature of distances and decelerations

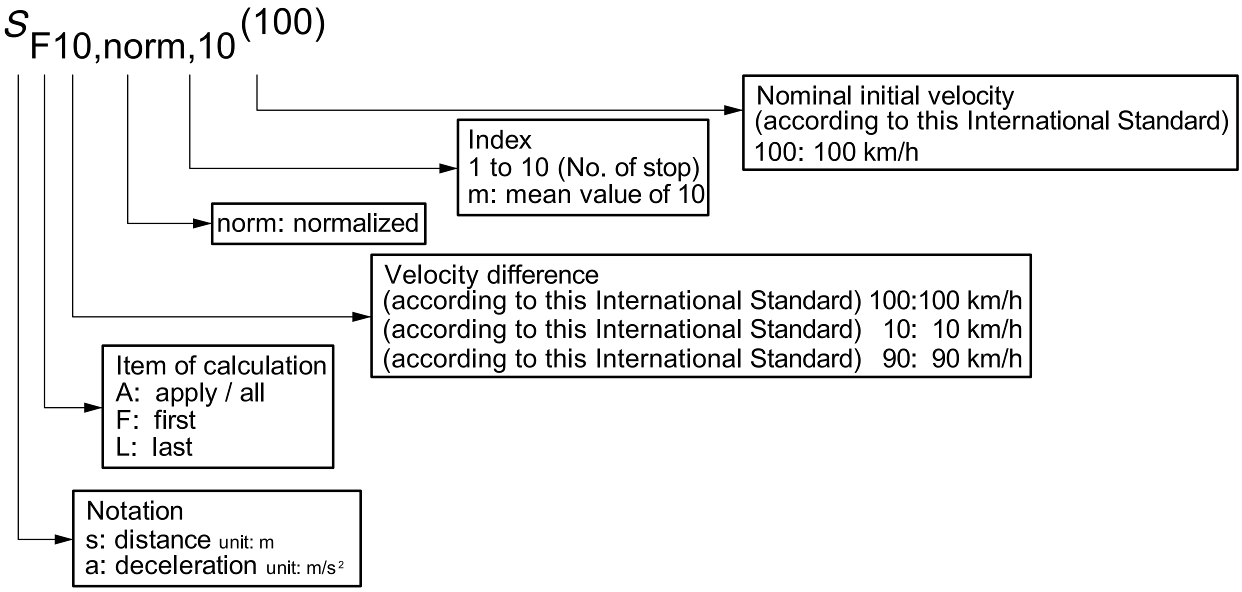

Figure 1 — Nomenclature of distance and deceleration

Indices include:

— First index:

  — A: Stopping distance (from brake pedal contact during the complete braking manoeuvre until standstill);

  — F: First range (starting at initial brake pedal contact);

  — L: Last range from a specified velocity (here 90 km/h) until standstill;

— Second index: Identifier for velocity range or velocity for start of measurement.

9.3 Determination of normalized stopping distance $s_{A100,norm}$

9.3.1 Determination of mean deceleration of a single test run

The mean deceleration a_i [m/s^2] for every single brake test run is calculated according to the following formula:

$$a_i = \frac{{v_{0,i}}^2 - {v_{2,i}}^2}{2 \cdot s_i} \tag{2}$$

where

a_i is the calculated deceleration from brake pedal contact to standstill;

$v_{0,i}$ is the actual velocity at the instant of first brake pedal contact (target: 100 km/h);

$v_{2,i}$ is the actual velocity at the end of the measurement (target: 5 km/h);

s_i is the measured braking distance.

In the equation, the actual velocities between which the distance measurement was performed shall be used.

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NOTE Since data is measured in constant time intervals due to the sampling rate used, the braking distance measurement is likely not to comprise the interval from 100,0 km/h to 5,0 km/h but instead will, for example, begin at 100,7 km/h and end at 4,9 km/h.

Additionally, it shall be ensured that there is no time offset between velocity signals and distance signals that may be caused by factors such as signal filtering, moving averaging or sensor delay times. In such cases, appropriate time corrections shall be applied.

9.3.2 Determination of the normalized stopping distance of a single test run

The normalized stopping distance $s_{\mathrm{A,norm,i}}$ is calculated as follows:

$$s_{\mathrm{A,norm,i}} = \frac{{v_{\mathrm{norm}}}^2}{2 \cdot a_{\mathrm{i}}} \qquad (3)$$

where

$s_{\mathrm{A,norm,i}}$ is the stopping distance for a single brake test run normalised to the nominal velocity;

v_{norm} is the nominal velocity for test series;

a_{i} is the mean deceleration for a single test run.

9.3.3 Determination of mean deceleration and mean normalized stopping distance

From the 10 individual valid values a_{i}, the mean deceleration a_{m} is calculated as arithmetic average:

$$a_{\mathrm{m}} = \frac{\sum a_{\mathrm{i}}}{\mathrm{i}} \qquad (4)$$

where

a_{i} is the calculated deceleration;

a_{m} is the mean deceleration;

i = 10.

From the 10 individual valid values $s_{\mathrm{A,norm,i}}$ the mean stopping distance $s_{\mathrm{A,norm,m}}$ is calculated as arithmetic average:

$$s_{\mathrm{A,norm,m}} = \frac{\sum s_{\mathrm{A,norm,i}}}{\mathrm{i}} \qquad (5)$$

where

$s_{\mathrm{A,norm,i}}$ is the normalized stopping distance;

$s_{\mathrm{A,norm,m}}$ is the mean normalized stopping distance;

i = 10.

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9.4 Determining of ABS-braking distance $s_{L90,norm}(100)$ (optional)

The average deceleration $a_{i,90}$ for a single test run is calculated as follows:

$$a_{L90,i} = \frac{v_{1,i}^2 - v_{2,i}^2}{2 \cdot s_{L90,i}} \quad (6)$$

where

$a_{L,90,i}$ is the calculated deceleration from approximately 90 km/h to 5 km/h;

$v_{1,i}$ is the velocity at the trigger point of 90 km/h (e.g. 89,9 km/h);

$v_{2,i}$ is the velocity at the end of the measurement (e.g. 4,8 km/h);

$s_{L90,i}$ is the measured braking distance between velocities $v_{1,i}$ and $v_{2,i}$.

In the equation the velocities between which the distance measurement was performed shall be used.

The normalized ABS-braking distance $s_{norm90,i}$ is calculated with Equation (7) for each single test run.

$$s_{L90,norm,i} = \frac{v_{90}^2}{2 \cdot a_{L90,i}} \quad (7)$$

where

$s_{L90,norm,i}$ is the ABS-braking distance for a single brake test run normalized to the nominal velocity range 90 km/h to standstill;

v_{90} is the nominal velocity for the test series;

$a_{l,90}$ is the average deceleration as calculated for a single test run with Equation (6).

The mean deceleration $a_{L90,norm,m}$ and the mean ABS-braking distance $s_{L90,norm,m}$ shall be calculated in a corresponding way as specified in 9.3.3.

9.5 Determination of normalised build-up distance $s_{F10,norm}$ (optional)

The normalized distance travelled during deceleration build-up (first 10 km/h) is the difference between the normalized stopping distance and the normalized ABS-braking distance travelled from 90 km/h until standstill.

$$s_{F10,norm,m}(100) = s_{A100,norm,m}(100) - s_{L90,norm,m}(100) \quad (8)$$

where

$s_{F10,norm,m}(100)$ is the calculated distance during build-up (first 10 km/h see 9.2);

$s_{A100,norm,m}(100)$ is the normalized stopping distance (see 9.3.2);

$s_{L90,norm,m}(100)$ is the normalized ABS-braking distance from 90 km/h to standstill (see 9.2).

Index “m” is the mean (see 9.2).

If other velocities are taken, the equations shall be modified accordingly.

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Annex A
(informative)

Test report — General data

Part I				
Vehicle identification	ID number: Type of vehicle: Manufacturer: Model: Key number:			
Drive train	Driven axle:	☐ Front axle	☐ Rear axle	
	Type of 4WDconcept: Special features:			
Engine	Type of engine: Displacement / no. of cylinders: Maximum power/engine speed: Maximum torque/engine speed:	☐ Spark engine __________ cm³ __________ kW __________ Nm	☐ Diesel ________ cylinders at ______ 1/min at ______ 1/min	
Transmission	Type / No. of gears:	☐ manual ________ gears ☐ automatic ________ ranges ☐ continuous (e.g. CVT)		
Vehicle Dimensions	Wheel base:	____________________ mm		
Weights		Front	Rear	Total
	Complete vehicle kerb mass (ISO-M06): Maximum authorized total mass (ISO-M08): Measured wheel loads of test vehicle, including driver and instrumentation:	_______ kg _______ kg left _____ kg right _____ kg total ______ kg	_______ kg _______ kg left _____ kg right _____ kg total ______ kg	________ kg ________ kg left _____ kg right _____ kg total ______ kg

Part II			
Brake actuation	Booster design type	type:	
	Booster type / dimension:		
	TMC:	diameter:	circuit split:
ABS	Manufacturer		
		Front	**Rear**
Wheel brake	Caliper / wheel cylinder: Disc / drum: Pad:		
Wheels (rims)	Dimension:		
Tyres	Manufacturer and type: Dimension: Tread depth: Load speed index:		
	Tyre inflation pressure - at complete vehicle kerb mass: - at maximum authorized total mass:	 ___________ kPa ___________ kPa	 ___________ kPa ___________ kPa
General comments and / or important details			

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Annex B
(informative)

Test report — Test conditions and results

Test Conditions			
Date:			
Proving ground	Location:		
Ambient Conditions	Road surface: Climate:	Type/material: Condition: Track temperature: Air temperature: Relative humidity: Wind speed:	 Min.___ / max.__ °C Min.___ / max.__ °C ____________ % ____________ m/s
Initial Driving Condition	Manual transmission: Automatic Transmission:	Gear engaged: Shift program: Shift position:	
Staff	Driver:	Evaluation:	
Deviation from standard test conditions			

Test Results I: Stopping distance (s_{A100})					
1,5 * F_ABS	□ below 500 N: Minimum pedal force requirement = 500 N				
	□ above 500 N: Minimum pedal force requirement = 1,5 * F_ABS F_ABS measured = ______ N ⩾ 1,5 * F_ABS = ______ N				
Measurement values	**Initial velocity v_0** value in km/h	**End velocity v_2** value in km/h	$s_{A100,i}$ value in m	$s_{A100,norm,i}$ value in m	**Pedal force at 150 ms in N**
Test 1					
Test 2					
Test 3					
Test 4					
Test 5					
Test 6					
Test 7					
Test 8					
Test 9					
Test 10					
Mean value from ten $s_{A100,vnorm,I}$,(_____) values:					

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If not all stops could be taken for evaluation, the number of failed test runs shall be documented:
No. of failed stops: ____________

Test Results II: ABS-braking distance (s_{L90})			
Measurement values	**Initial velocity, v_1** value in km/h	$s_{L90,i}$ value in m	$s_{L90,norm,i}$ value in m
Test 1			
Test 2			
Test 3			
Test 4			
Test 5			
Test 6			
Test 7			
Test 8			
Test 9			
Test 10			
Mean value from ten $s_{L90,norm,I}$(_____) values:			

NOTE End velocity v_2 for Test Results II see Test Results I.

Test Results III: Build-up distance (s_{F10})		
value $s_{F10,norm,m}$(_____):		

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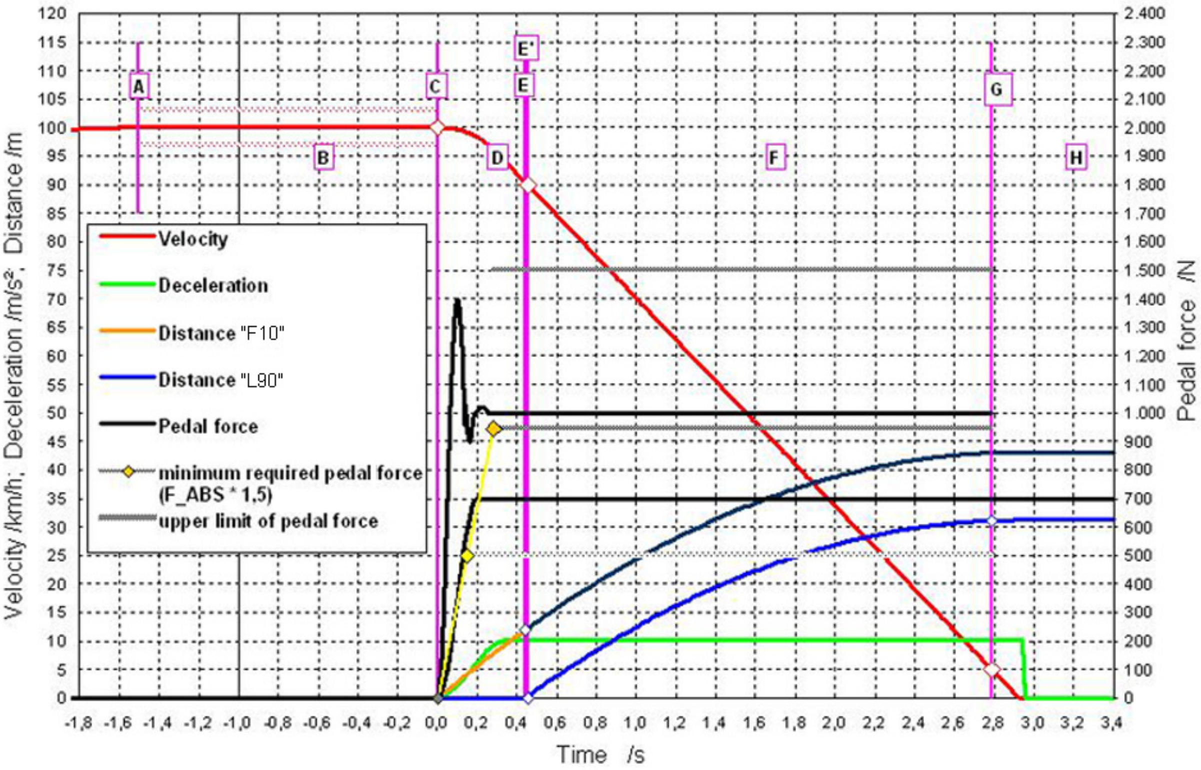
Annex C
(informative)

Test sequence, specific terms and background information

C.1 General sequence of dry braking tests and definition of terms

C.1.1 Principle

The definition of measurement parameters and terms is based on the time sequence of a braking *(*see Figure C.1*)*.



Key

A end of accelerating phase

B steady-state phase (constant velocity)

C trigger point 1 ($v_{0,\text{spec}}$ = 100 km/h) (brake application)

D build-up phase for deceleration

E trigger point 2 ($v_{1,\text{spec}}$ = 90 km/h)

F range in which braking distance is measured for calculation of s_{L90}

G trigger point 3 ($v_{2,\text{spec}}$ = 5 km/h) (for calculation of s_{A100} and s_{L90})

H remaining braking phase

Figure C.1 — Principle of test sequence

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C.1.2 Initial velocity at start of braking

Initial velocity v_0 at time “C“ (trigger1, instant of brake pedal contact). The specified nominal value $v_{0,spec}$ is 100 km/h ± 2 km/h.

C.1.3 $s_{Lv}(v_0)$ value (general)

The value $s_{Lv}(v_0)$ (e.g. $s_{L90}(100)$: “last 90“) refers to the distance travelled in the time period between the triggered velocity (in this case v_1 = 90 km/h) and vehicle standstill. Passing through the triggered velocity occurs in a mainly built-up state of the braking and the ABS control.

The $s_{Lv,i}(v_{0,i})$-value (individual measurement result from one braking) is defined as the distance travelled between trigger point 2 (specified velocity: $v_{1,spec}$ = 90 km/h) and trigger point 3 (specified velocity: $v_{3,spec}$ = 5 km/h). The measurement (see 9.2) only covers the distance travelled between the measured triggered velocities. Due to the fact, that the triggered velocities v_1 and v_2 cannot exactly be reproduced, the different values cannot be directly compared to one another. For this reason, the $s_{Lv,i}(v_1)$-value is transformed by standardizing it to a value $s_{Lv,norm}(v_0)$ which corresponds to the distance that would have been travelled having the calculated deceleration between normalized, specified velocity v_1 and vehicle standstill.

NOTE In addition to the initial velocity of 100 km/h specified in the standard, which will result in the values $s_{A100,norm,m}(100)$, $s_{L90,norm,m}(100)$ and $s_{F10,norm,m}(100)$ (see also Clause 9), the measurements can be carried out with different velocities (e.g. v_0 = 113 km/h). In that case, these different values will be determined according to the standard, e.g. $s_{L100,norm,m}(113)$.

C.1.4 Brake pedal force

The brake pedal force is defined as the force applied to the pedal in the direction of movement of the pedal (i.e. tangentially to the leg of trajectory of the pedal pad).

C.1.5 Actuation time

The actuation time is considered to be the period of time required after brake actuation to build up a brake torque on all wheels which enables full use of the available friction between the tyre and the road surface. It is composed of the brake pedal contact time t_A and the build-up time t_S.

The contact time t_A is the time from first brake pedal contact until first increase of pressure.

The build-up time t_S is the time from first increase of pressure until maximum pressure (correlating to pedal force) is achieved.

To get comparable results, in this International Standard the actuation time is defined to be the time to decrease the speed of the vehicle by 10 km/h from its initial value.

C.1.6 Reaction distance

The reaction distance is the distance travelled by the vehicle from information for the driver to brake until first brake pedal contact by his/her foot.

C.1.7 Stopping distance

The stopping distance is the distance travelled by the vehicle from first brake pedal contact until it comes to a standstill.

C.1.8 Total stopping distance

The total stopping distance is the sum of reaction distance and stopping distance.

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C.1.9 Build-up distance

The build-up distance is the distance travelled by the vehicle between first brake pedal contact and final full brake condition. In this International Standard, the final full brake application is assumed to be reached when the vehicle speed has decreased by 10 km/h from its initial value.

C.1.10 Braking distance

The braking distance is the distance travelled by the vehicle during the time required to reduce the velocity from a start velocity to an end velocity (e.g. from 101 km/h to 4.9 km/h).

C.2 Instructions and background information referring to the measurement procedure

C.2.1 Measuring equipment (6.2)

When installing devices for measuring distance or velocity, ensure that test results cannot be affected by spring deflection, vehicle rebound or by changed angle positions of sensors.

C.2.2 Road surface conditions (7.3)

The friction coefficient is a characteristic value of every individual test track, which depends on the road surface characteristics as well as on the interaction with the tyre used. Because of this, brake test results of identical vehicles (tyres) on different test tracks will normally deviate among each other. Experience shows that not only absolute deceleration values but also the relative braking performance of different vehicle-tyre combinations change often.

Therefore, only test results can be compared which are measured on the same test track under the same test and environmental conditions (see C.2.4).

C.2.3 Road surface friction coefficient (7.3)

The friction coefficient can be measured according to ISO 8349, ASTM E1337 and ASTM E274.

The value 0,9 can be confirmed e.g. by the fact that there is a multitude of measurement results with a mean deceleration above 8,8 m/s^2 (0,9 g).

C.2.4 Weather conditions (7.4)

Track and ambient temperatures have an impact on the friction between the tyre and the road surface and, consequently, the achievable braking distances. Test results can only be directly compared if weather and temperature conditions are comparable (see specifications in 7.4).

C.2.5 Run in and burnishing

C.2.5.1 Tyres (7.5.2)

Repeated severe braking results in a so-called brake-in effect of tyres that is characterized by a shortening of the braking distance in subsequent test runs. Therefore, an extensive pre-conditioning does not represent a real-life condition for driving. Braking distances will often be shorter than in emergency situations in normal traffic.

The reduction of braking distance caused by pre-conditioning depends on the characteristics of the tyre used. As tyres with high braking performance often show less brake-in effect than tyres with comparatively longer braking distance, too many conditioning runs may lower normally existing differences or even change rankings

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between test cars or tyre sets. In order to get typical and comparable data it is, therefore, important to use new tyre sets and to perform five stops to condition them (see 8.1.2).

C.2.5.2 Burnishing program for newly installed brakes (pads/shoes)

For disc brakes, a total of at least 60 burnishing runs shall be performed starting at about 100 km/h and ending at about 20 km/h. The load condition for the burnishing shall be in accordance with the testing condition (see 7.5.4).

— In the first 15 brakings, a deceleration of approx. 2 m/s^2 shall be applied;

— in the next 15 brakings, a deceleration of approx. 3 m/s^2 shall be applied; and

— in the final 30 brakings, a deceleration of approx. 5 m/s^2 shall be applied.

For newly installed drum brake pads 200 burnishing runs shall be performed:

— start with 50 brakings at a deceleration of approx. 2 m/s^2;

— continue with 50 brakings at a deceleration of approx. 3 m/s^2; and

— end burnishing with 100 brakings at a deceleration of approx. 5 m/s^2.

The deceleration according to this run-in 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 are not allowed to be used for the braking distance measurements.

C.2.6 Weight distribution (7.5.4)

To ensure comparability of measurement results at a later point in time, it should be considered to create a weight distribution plan.

C.2.7 Actuation time (8.2.3)

The actuation velocity of the brake pedal must be high enough to ensure that no delay is caused in pressure build-up. Therefore, a minimum force build-up is demanded during actuation time.

C.2.8 Steering corrections (8.2.4)

Steering corrections usually extend the braking distance. If major steering corrections are required to keep the vehicle on track, the results of this braking distance measurement shall not be used for evaluation. If steering corrections are required, this is indicative either of an unsuitable test track with inhomogeneous friction coefficients or of unfavourable vehicle-specific properties.

C.2.9 Condition of the braking system (7.5.3)

The following conditions have a negative impact on braking performance and must be avoided as to get valid and comparable test results:

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

— heavily, unevenly or tapered worn brake pads;

— heavily worn or cracky brake discs;

— corroded brake calipers, brake discs or brake drums;

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

— brake system leakages.

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Annex D
(normative)

Method for determination of F_ABS

D.1 Definition of F_ABS

The brake pedal force F_ABS is the minimum pedal force that shall be applied for a given vehicle and under the existing conditions to achieve maximum deceleration meaning ABS being fully active.

Multiplying this brake pedal force by the factor 1,5 results in the minimum brake pedal force that shall be applied in the brakings according to this standard.

NOTE For most passenger cars, the force required to achieve a consistent ABS control at both axles is below 333 N; consequently, a pedal force of 500 N is more than 1,5 times F_ABS and brake operation is carried out at a minimum force of 500 N according to the International Standard. When it is ensured that F_ABS is below 333 N, a precise determination of F_ABS is not required. Otherwise, a determination of F_ABS according to the procedure described below is required.

D.2 Test procedure

F_ABS can be determined on the basis of the five conditioning brakings (see 8.1.2).

All conditions (especially brake temperature) are taken from 8.1.2.

The procedure is as follows:

— The brake pedal shall be applied slowly, with a constant increase of deceleration. In any case, the pedal force must increase continuously (e.g. constant positive force gradient). The force build-up must be clearly higher than the force required for an ABS control (F_ABS) and must be increased until standstill of the vehicle or until maximum pedal force.

— Applying the brake pedal is done in such a way that the full deceleration (ABS control) should be reached within the timeframe of 2,0 ± 0,5 seconds after contacting the brake pedal. The deceleration curve must be within a corridor of ± 0,5 s around the centreline of the deceleration curve corridor. This one has its origin at the 0 point crossing the 1 g line at 2 seconds.

— The measurement shall be within the corridor for variance of deceleration increase (see Figure D.1). The test shall be repeated at least five times.

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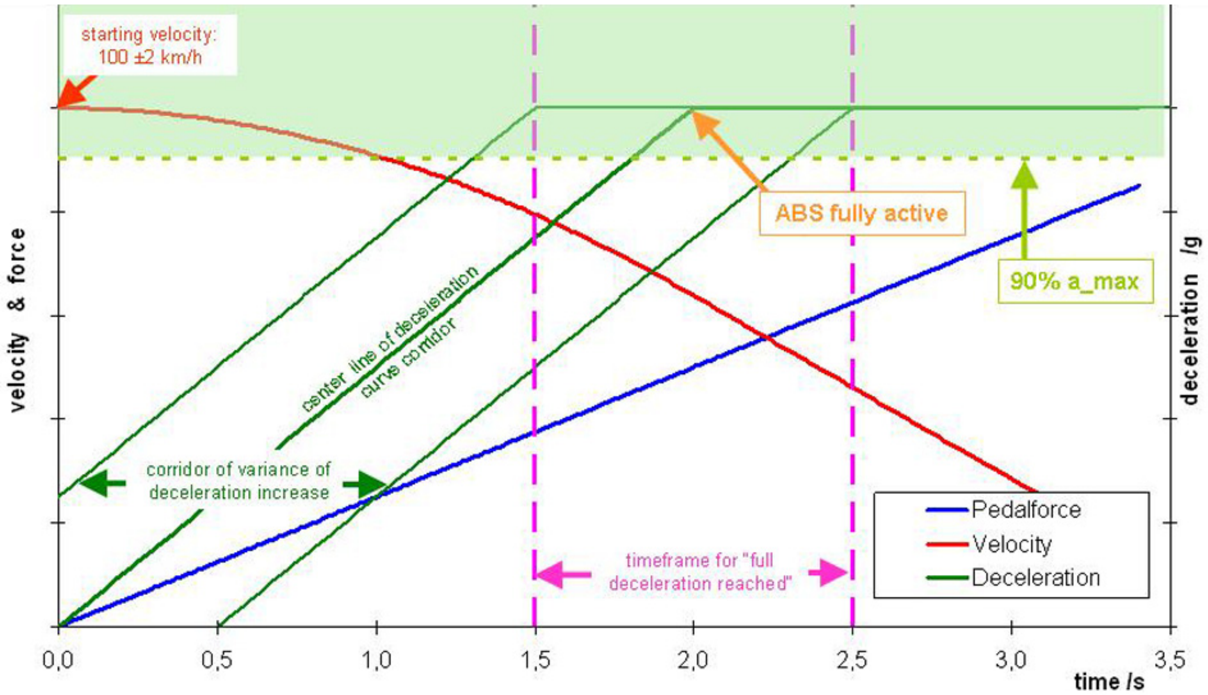

NOTE The light green area includes all measurement values which are above 90 % a_max.

Figure D.1 — Principle for execution

For vehicles equipped with a vacuum booster, the brake force depends on the vacuum level that exists in the vacuum brake booster. Therefore, a sufficient vacuum shall be ensured at the beginning of a braking. To achieve a sufficient vacuum level, it is recommended to move the vehicle in a drag operation for a short time during the cooling phases between the individual brakings. When doing so, the driving pedal can be released for 3 to 5 s at high engine speed (e.g. by engaging a suitable gear). Afterwards, the brake shall not be operated before the next measurement because this would reduce the vacuum level that was established before.

D.3 Test evaluation

Measurement values are only evaluated if the measurements were made at velocities higher than 30 km/h.

The time gradients of force on the pedal, vehicle velocity and vehicle deceleration are recorded.

The five records of vehicle deceleration as a function of force on the pedal are represented in five single diagrams and also one common diagram, which are used to generate the brake pedal force F_ABS as mentioned in steps 1 to 4 and represented in Figures D.1 and D.2 below.

Method used to generate the point F_ABS:

Signal processing:
For the determination of a_ma and F_ABS a low pass filter of 2 Hz for longitudinal deceleration as well as the pedal force shall be applied.

Step 1:
The value to be determined is the deceleration a_ABS during ABS control.

The maximum individual value (a_ma) for the vehicle deceleration is to be determined from each of the five individual curves. The mean value (a_max) of these five individual maximum values represents the upper limit of the deceleration achieved.

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$$a\_\max = \frac{\sum_{i=1}^{5} a\_ma_i}{5} \qquad a\_ma_i,\ i = 1, ..., 5 \tag{D.1}$$

All measurement values of all five stops, which are above 90 % of this deceleration value a_max, are averaged. This average value of “a” is the ABS deceleration (a_ABS) referred to in this International Standard.

The five individual curves for deceleration versus brake pedal force are averaged. The five deceleration values of the five curves shall be averaged in 1 N pedal force steps. The result is the mean deceleration versus brake pedal force curve, which will be referred to as the “maF curve” in this annex.

Step 2:
The minimum force on the pedal (F_min) sufficient to achieve the deceleration a_ABS calculated in step 1 is to be determined. It is defined as the value of F corresponding to a = a_ABS on the maF curve.

Step 3:
Using a linear regression, a straight line is drawn through all maF curve values below the pedal force F_min and above 0,7 x a_ABS.

Step 4:
The value of F at the point of intersection between the regression line and the horizontal line where a = a_ABS is defined as F_ABS (yellow/green diamond on Figure D.2).

The specified pedal force is defined as F_spec = F_ABS x 1,5 (yellow/red diamond on Figure D.2).

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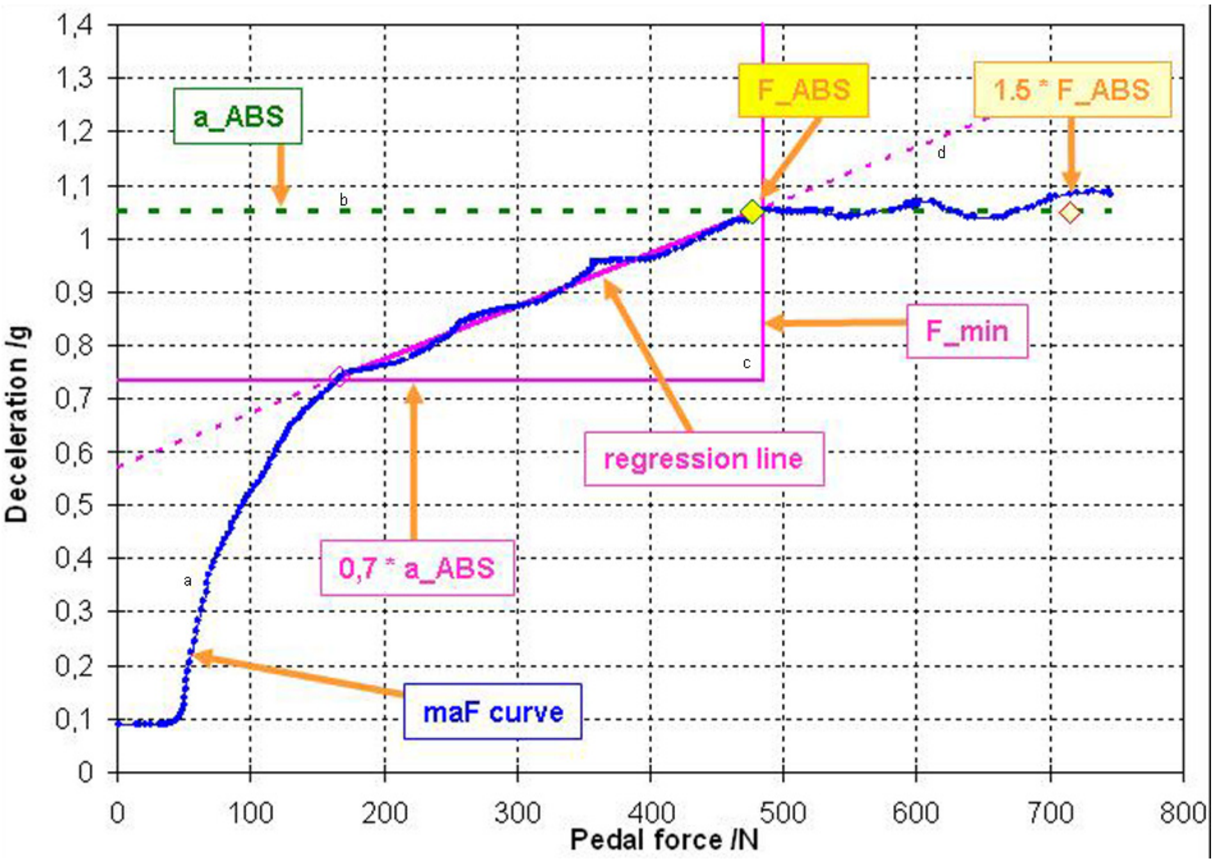
D.4 Principle chart

Figure D.1 presents the principle for determining F_ABS.



Key

1	a_ABS	=	1,05 g
2	0,7 x a_ABS	=	0,73 g
3	F_min	=	484 N
4	F_ABS	=	477 N
5	1,5 x F_ABS	=	715 N

a The blue line is the maF curve, the average of all five measured characteristics.

b The dashed green line is the mean value of all points above 0.9 * a_max; it defines a_ABS.

c The magenta frame includes all measurement values which are below F_min and above 0.7 * a_ABS.

d The magenta line is the regression line through all values inside this frame.

Figure D.2 — Principle for determining F_ABS

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Annex E
(normative)

Requirements for measurements and measuring equipment

E.1 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 90 km/h and 100 km/h. The standard calibration distance shall be 500 m straight ahead drive. If there is not enough testing space available and the time resolution of the measuring system allows to determine the calibration distance with the accuracy given below, shorter tracks with a minimum of 200 m may be used.

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 of the calibration distance).

The accuracy of a measuring system is sometimes different at steady-state driving or for a dynamic velocity change in a braking manoeuvre. For a quick check of the dynamic measuring accuracy, an ABS-controlled braking shall be conducted on the calibration track. This is also helpful to control that all settings for sensors or software in the measuring system are correctly adjusted.

For the dynamic check, the calibration distance shall be shortened to 100 m. This is necessary to restrict the share of constant driving in the result. Reflecting tapes shall be used to mark the beginning and end of the calibration distance. The calibration area shall be entered at a constant velocity of 100 km/h. After passing the reflection tape the vehicle is decelerated by ABS-braking to a speed below 20 km/h but above 10 km/h. Without accelerating again the vehicle shall be driven out of the calibration track. Ideally the calibration factor for the dynamic check matches the one for steady-state driving. If there are deviations of 3 % or more it is recommended to check the dynamic measuring accuracy with the procedure described in E.2.

E.2 Measuring accuracy of the measuring system used

An accurate way to check the accuracy of the brake distance measurement for the complete stopping distance from first pedal contact to standstill (s_A100) is to perform an ABS-braking on a test track and to compare the results of the measuring system with the reading from a measuring 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 track. 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.

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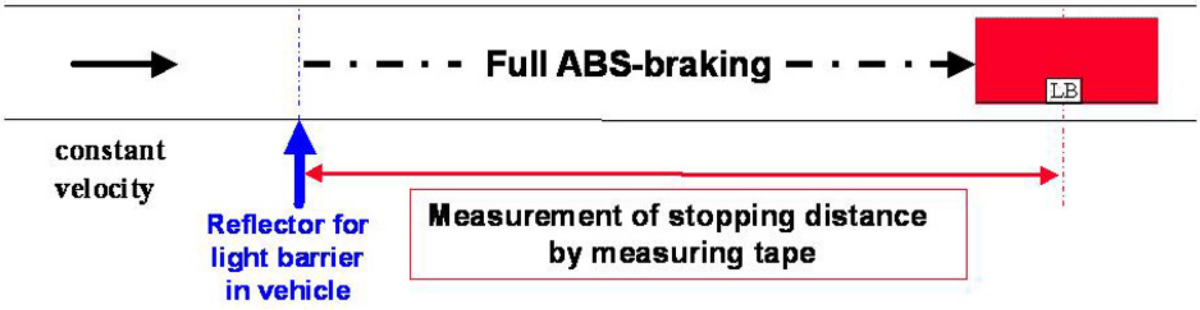

Figure E.1 — Scheme of procedure

To get more information about influence factors, the time of brake application may be shifted to a greater time delay after passing the reflection tape. Additionally, the ABS-braking may be started before the reflection tape is passed. As the measured distance is in all cases defined by the start signal from the reflector and standstill of the vehicle, comparisons between tape and measuring system should always give similar results.

Measuring systems with a high measuring accuracy were tested in this procedure to be within ± 0,2 m or less difference to a measuring tape.

E.3 Data processing

Many sensors have delay times between the instant of measurement and the output of the measured data, caused among others by internal processing times, filtering, averaging, smoothing, etc. Different delay times between recorded data channels were often found to degrade the precision of the brake distance measurement. Especially time delays between start trigger and the data of speed-/distance sensors shall be exactly compensated by means of time corrected data processing. A time shift of 10 ms between start trigger and distance data results, e.g. in a brake distance increase at 100 km/h of approximately 0,30 m.

The driving velocity at start of braking shall be averaged in the interval 0,2 s-0 s before brake pedal contact. As the initial velocity is used for normalisation of the measured brake distance to the nominal velocity (100 km/h), comparatively small measuring errors will result in considerable brake distance changes. For an initial velocity of 100,0 km/h and an average deceleration of 8 m/s^2, an often found measurement error of ± 0,3 km/h will result in a change of approx. ± 0,30 m for the normalised distance. Therefore, care shall be taken in internal/external processing of velocity signals to get correct values and to avoid uncorrelated (accidental) variations or random oscillation peaks of the signals. Any time shift of data caused by data smoothing or floating averaging must be corrected in the calculation process.

The distance s_{L90} is measured between 90 km/h and 5 km/h. In Equation (7), the actual velocities between which the distance measurement was performed have to be used. A single read out velocity value of an oscillating measuring signal may contain accidental errors. It is therefore recommended to search the 90 km/h-value by linear regression between velocity data from 92 km/h to 88 km/h. Potential reading errors around 5 km/h do not contribute significantly to the distance reading. Therefore, it is recommended to use the value directly read out without further recalculation.

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Annex F
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Structure of the stopping distance calculation

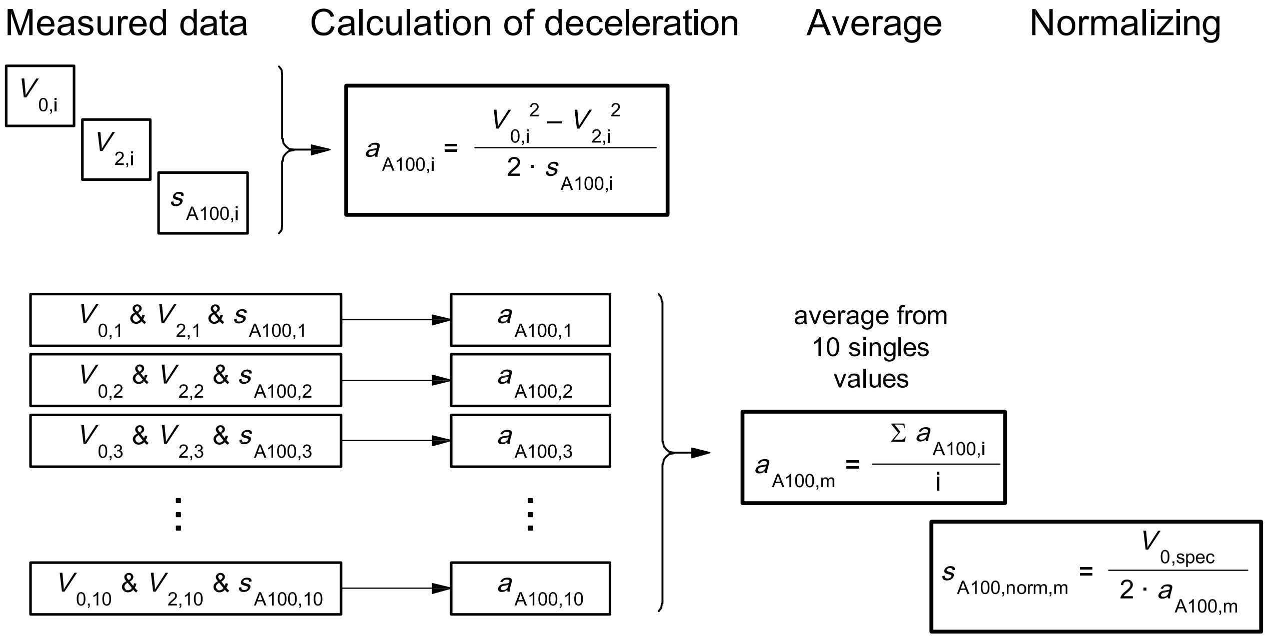

Figure F.1 — Structure of calculation

Optional from each $a_{A100,i}$, a corresponding $s_{A100,norm,i}$ can be calculated according to Equation (F.1), the average of the 10 results is the same as the calculation using $a_{A100,m}$.

The standard deviation σ_{am} of the mean deceleration a_m shall be calculated and documented in the test report.

$$\sigma_{am} = \sqrt{\frac{i \cdot \sum a_i^2 - \left(\sum a_i\right)^2}{i \cdot (i-1)}} \qquad (F.1)$$

Where

σ_{am} is the standard deviation;

a_i is the calculated deceleration;

i = 10.

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