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Road vehicles — Field load specification for brake actuation and modulation systems

Véhicules routiers — Spécification de la charge pour les systèmes d'actionnement et de modulation des freins

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Contents

Page

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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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics and chassis components*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Vehicle development programs tend to grow in complexity and integration of the braking system with chassis dynamics and mechatronics, demanding more robust and comprehensive evaluation programs. Also, to remain competitive, braking systems and their components' functionality and application across multiple vehicle architectures and platforms are increased.

The proper selection and adaptation of field load spectra and profiles to the specific program ensure functionality, reliability and braking system availability. This document defines a library of field load schedules to help developing simulation and testing programs tailored to the vehicle or system specification and requirements. Specific cycles and load collectives including the main functions associated with everyday driving and operation and exceptional load cases are described to ensure safe braking behaviour. This document's field load was typically derived from analysing field data collected from almost 1 million vehicles having driven more than 45 billion km. Several vehicle and brake system suppliers from vehicles used in different regions worldwide contributed to this field data collection. In addition, data from driving studies with specific measurement equipment was used. Wherever the data available from field or studies was not sufficient, existing specifications or expert judgement served to derive conservative assumptions.

This document provides field loads independent of the vehicle technology, vehicle specification, intended use and field usage. It remains the manufacturer's responsibility to include and adapt the field loads to the specific vehicle configuration. The adaptation includes at least:

— define sampling and testing plans, including vehicle configuration(s), road conditions selection of the specific profiles and load spectra of this document;

— define level of evaluation and integration of simulation, Hardware-in-the-Loop, physical testing methods, along with other components and software functions part of the testing program;

— agree on performance and reliability criteria (including statistical tools and metrics);

— reflect specific system architectures and control technologies for the unit(s) under testing.

Road vehicles — Field load specification for brake actuation and modulation systems

1 Scope

This document specifies expected field loads for functions provided by the braking system actuator and modulator and applies to passenger cars and light commercial vehicles (classes M1 and N1, according to UNECE).

Functions addressed in this document are:

— dynamic stability functions (e.g. electronic stability control);

— brake torque optimizing functions (e.g. electronic brake force distribution);

— brake assistance functions (e.g. hill start assist).

This document only covers functions where data of appropriate maturity are available. There are additional functions of a braking system, which are not covered by this document.

By describing the expected field loads, this document specifies representative manoeuvres and occurrences for different functions. These serve as an orientation for the derivation of test procedures.

This document applies to vehicles up to conditional automation (SAE J 3016 level 3) with a maximum of 30 % automated brake operations.

NOTE Field loads for automation levels above level 3 are under consideration for future editions.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
brake booster
part of the actuation unit, excluding master cylinder, in systems with separate actuator and modulator

Note 1 to entry: A brake booster is not part of braking systems with integrated actuator and modulator (see Figure 1).

3.2
fading
decrease of braking torque as a function of temperature or vehicle speed at constant application force

Note 1 to entry: Amongst others, the decrease of the friction by the temperature is the most important effect.

[SOURCE: ISO 611:2003, 7.1.7, modified — The original term was "brake fade", the word “vehicle” and Note 1 to entry were added, and the examples were removed.]

3.3
brake friction coefficient
ratio between the tangential force and the normal force, acting between linings and drum or disc

[SOURCE: ISO 611:2003, 9.19.1, modified — The symbols and formula were removed, the original term was "coefficient of friction".]

3.4
coefficient of adhesion
μ
ratio between the tangential force transmitted to the road by a tyre and the normal force

[SOURCE: ISO 611:2003, 9.19.2, modified — "k" was changed to "μ", the symbols, formula and note were removed.]

3.5
control time
duration the braking system is controlling the pressure

3.6
fully active brake operation
deceleration intended by the driver and automatically initiated and operated by the braking system

3.7
nominal runout pressure
lowest master cylinder pressure where maximum support from the actuator is reached in quasi-static operation

Note 1 to entry: Only applies to separated actuator and modulator.

Note 2 to entry: For vacuum-based actuation systems, the nominal runout pressure refers to sea level.

Note 3 to entry: Above this pressure, only the unsupported pressure increase is possible.

3.8
partially active brake operation
deceleration initiated by the driver and supported by the modulation of the wheel brake pressure

3.9
standstill
stopping situation during a trip in which the vehicle is not moving

EXAMPLE Stopping at traffic lights or in heavy traffic situations.

Note 1 to entry: Standstill does not include parking situations.

3.10
steering angle
mean value of angle of left and right front wheel relative to the longitudinal axis of the vehicle

Note 1 to entry: Rear-wheel steering is not considered in this document.

4 General

This document describes use cases represented by manoeuvres and their occurrences for various functions of the braking system to describe the expected field loads for a braking system. Unless otherwise specified, these manoeuvres and occurrences are derived from empirical values and collected field data.

The manoeuvres and occurrences described in this document serve as an orientation to develop test procedures. The applicability of the generalized field loads detailed in this document needs to consider the specific braking system and vehicle configuration.

Figure 1 depicts the components of the braking system addressed in this document.

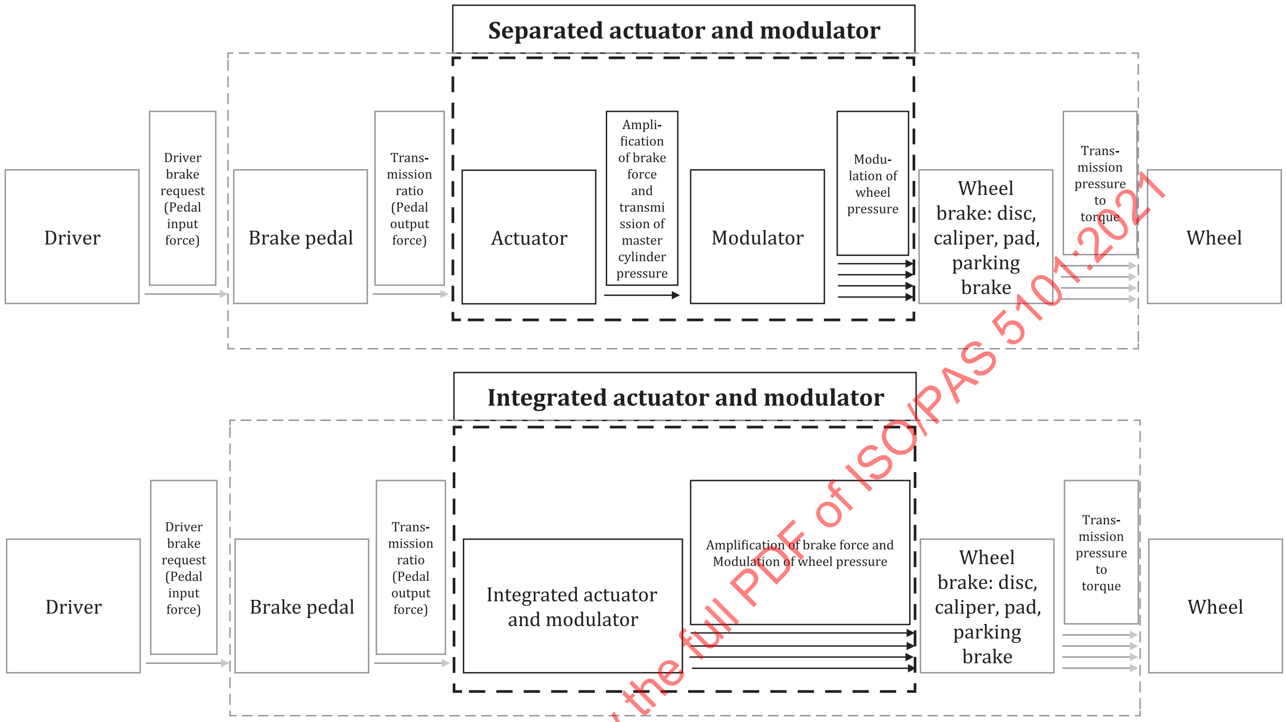


Figure 1 — Components of the braking system

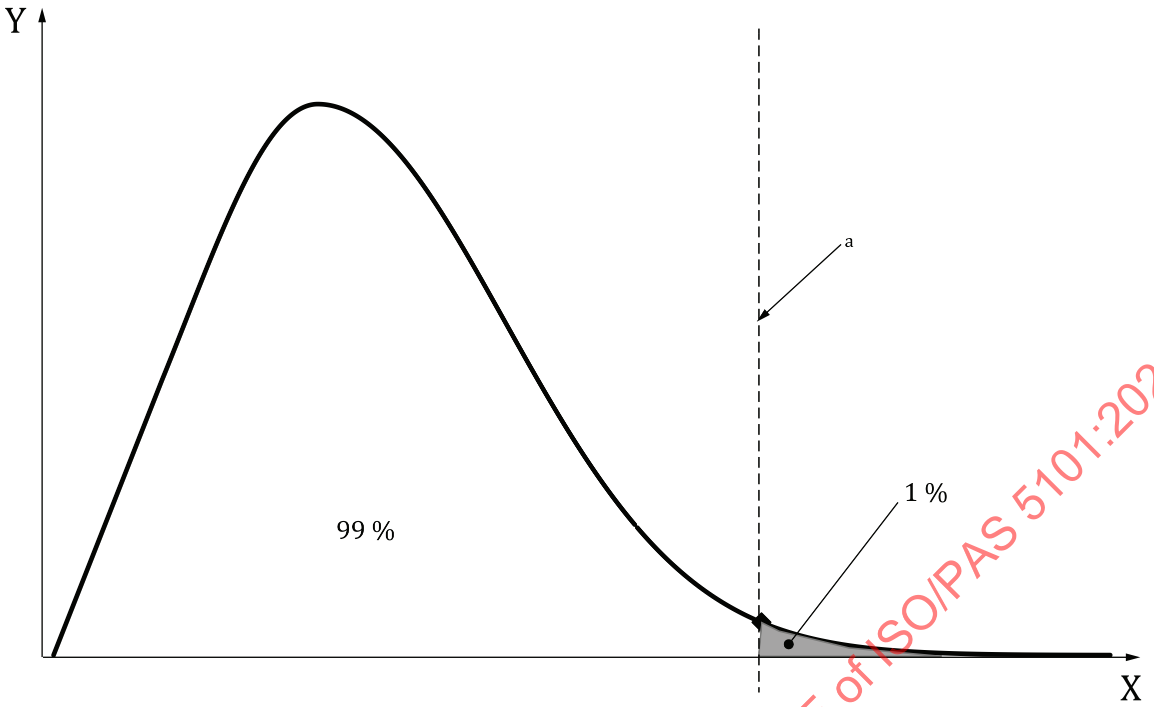
5 Percentiles of field coverage

The braking system supports multiple vehicle dynamics functions. The probability of high usage of all functions in an individual vehicle is much lower than the probability of high usage of only one single function in an individual vehicle. A specification aiming to cover the 100th percentile vehicle for every individual function would lead to an over-specification.

The field load for electronic brake force distribution (EBD), antilock braking system (ABS) and adaptive cruise control (ACC) aims to describe the 99th percentile vehicle usage. All other functions described in Clause 7 cover the 95th percentile vehicle usage for each function. However, it is unlikely that all functions – given the multitude of functions - are used up to the specification limit in one individual vehicle. This approach leads to a field coverage significantly above 99 %.

NOTE 1 ABS, EBD and the standard brake function are specified to cover the 99th percentile vehicle usage because products only providing this set of functions exist and therefore, the combination effect is weak. ACC is specified to cover the 99th percentile because it is an automation of the standard braking function.

Figure 2 illustrates an example of the usage of an individual function.



Key

X load or stress level with consistent engineering units

Y probability density

[a] 99th percentile.

Figure 2 — Schematic example of the probability density function *P* for the load *σ*

NOTE 2 Few vehicles experience a very low load; few vehicles experience a very high load; most vehicles experience a medium level of load.

NOTE 3 Typically, braking system components can endure loads above their specification. Furthermore, the load a component experiences is typically lower than the load described.

6 Base assumptions and boundary conditions

6.1 General

This clause defines the assumptions for the vehicle lifetime and braking system lifetime. These assumptions serve as the baseline for the manoeuvres and occurrences of the functions described in Clause 7.

NOTE Clause 7 describes the field load for braking system functions but not for wearing parts such as brake pads and brake discs.

6.2 Lifetime specifications

6.2.1 Vehicle lifetime

The field loads described in this document correspond to a vehicle lifetime of either 300 000 km or 8 000 h ignition-on time or 15 years, whichever occurs first.

The expected amount of trips is up to 50 000 over a vehicle lifetime.

6.2.2 Standstill events, slopes and durations

The expected amount of brake operations that lead to a standstill is 480 000 over a vehicle lifetime. Table 1 shows the distribution of slopes at the standstill events. The values shown include uphill and downhill slopes and cover the 99th percentile. An even distribution between up- and downhill situations is assumed.

Table 1 — Distribution of standstill events versus slope angle

Slope at a standstill [%]	Probability [%]
> 30 - 50	0,006
> 20 - 30	0,194
> 15 - 20	0,8
> 10 - 15	2
> 5 - 10	9
≤ 5	88

6.2.3 Standstill duration distribution

In total 480 000 standstill events are defined over vehicle lifetime. Table 2 shows the distribution of their duration. The durations are independent of any active function when the vehicle ignition is on. The distribution covers the 99th percentile usage.

NOTE The parking times between two trips are not considered.

Table 2 — Distribution of standstill duration

Standstill duration [s]	Frequency
0 - 2	126 000
2 - 10	162 000
10 - 30	100 000
30 - 60	47 000
60 - 180	34 000
180 - 900	9 000
> 900	2 000
Sum	**480 000**

6.2.4 Brake duration distribution

Table 3 shows values of the brake duration distribution of an average driver.

Table 3 — Distribution of brake duration

Brake duration [s]	Percentage per class [%]
0 – 2	57
2 – 5	25
5 - 10	9
10 - 60	8
> 60	1
Sum	**100**

6.3 Number of brake operations

Over a vehicle lifetime, the 99th percentile of brake operations corresponds to 2,2 million brake operations. Of these 2,2 million brake operations, 600 000 events take place during standstill.

The frequency of brake operations during standstill represents brake operations that begin and end during vehicle standstill.

Table 4 shows the number of brake operations in deceleration classes of 0,05 *g*.

The frequencies shown in Table 4 include the base brake function and all functions intended to decelerate or hold the vehicle.

This document assumes 10 000 kPa is equivalent to 1,0 *g* for a typically laden vehicle.

Table 4 — Distribution of brake operations versus deceleration and brake pedal force

Deceleration [*g*]	Brake pedal force [N]	Frequency per class while driving [a]	Frequency per class during standstill	Frequency per class
0,00 ≤ x ≤ 0,05	20	205 033	84 569	289 602
0,05 < x ≤ 0,10	20	639 927	243 706	883 633
0,10 < x ≤ 0,15	29	404 300	115 070	519 370
0,15 < x ≤ 0,20	38	200 177	56 182	256 359
0,20 < x ≤ 0,25	48	84 266	25 350	109 616
0,25 < x ≤ 0,30	57	35 147	16 912	52 059
0,30 < x ≤ 0,35	67	14 463	12 771	27 234
0,35 < x ≤,0,40	77	7 168	9 810	16 978
0,40 < x ≤ 0,45	86	3 893	7 793	11 686
0,45 < x ≤ 0,50	96	2 144	5 892	8 036
0,50 < x ≤ 0,55	105	1 252	4 585	5 837
0,55 < x ≤ 0,60	115	745	3 474	4 219
0,60 < x ≤ 0,65	124	466	2 718	3 184
0,65 < x ≤ 0,70	134	332	2 218	2 550
0,70 < x ≤ 0,75	143	198	1 613	1 811
0,75 < x ≤ 0,80	153	91	1 067	1 158
0,80 < x ≤ 0,85	163	77	995	1 072
0,85 < x ≤ 0,90	172	63	917	980
0,90 < x ≤ 0,95	182	52	831	883
0,95 < x ≤ 1,00	191	41	739	780
1,00 < x ≤ 1,05	201	32	640	672
1,05 < x ≤ 1,10	210	25	534	559
1,10 < x ≤ 1,15	220	19	421	440
1,15 < x ≤ 1,20	230	14	301	315
1,20 < x ≤ 1,25	239	10	175	185
1,25 < x ≤ 1,30	249	9	105	114
> 1,30	> 250	56	612	668
		1 600 000	**600 000**	**2 200 000**

[a] Including brake operations leading to a vehicle standstill.

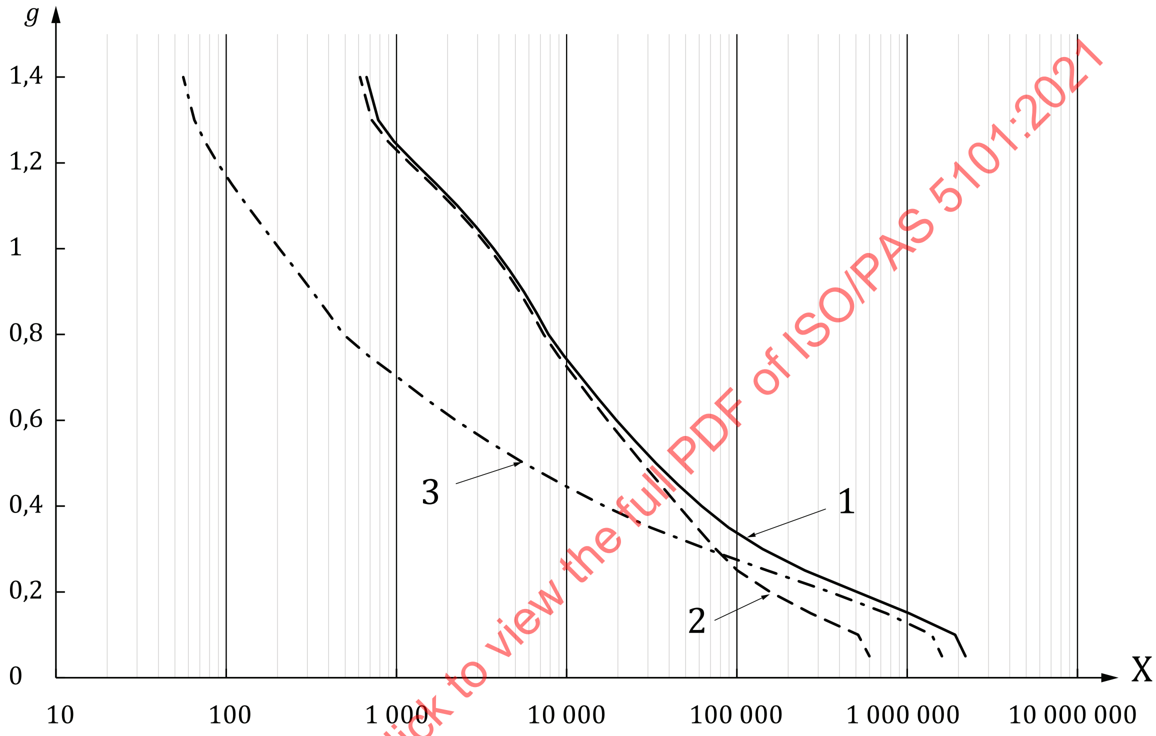
NOTE 1 Table 4 shows data over a vehicle lifetime according to 6.2.1.

NOTE 2 Brake pedal forces are derived from the deceleration to brake pedal force characteristic of vehicles which delivered the corresponding field data.

NOTE 3 Brake pedal forces values are used for brake pedal applies during standstill, deceleration values for brake pedal applies during driving.

NOTE 4 For vehicle configurations differing from those assumptions, the relation between brake pressure and deceleration is determined individually.

Figure 3 illustrates the corresponding cumulative distributions from Table 4.



Key

X cumulative number of load cycles in counts

g deceleration level in g

1 total cumulative brake operations

2 cumulative brake operations while driving

3 cumulative brake operations during standstill

Figure 3 — Cumulative distribution per class

6.4 Temperature distributions

6.4.1 Global environmental temperature distribution T_{env}

The distribution of the environmental temperatures, as shown in Table 5, uses the following principles:

— global coverage of typical, low and high-temperature profiles;

— weighting according to human population density, cities with less than 1 000 inhabitants are not considered;

— extreme temperature events, which do not occur regularly within 10 years, are not covered.

Table 5 — Distribution of environmental temperature

T_{env} [°C]	Probability [%]
– 40	0,5
– 30	2
– 20	5
– 10	5
0	7,5
10	15
20	25
30	25
40	14
50	1
Sum	**100**

6.4.2 Temperature distribution at installation location T_{inst}

Table 6 provides the estimated probability distribution as a function of the temperature at the installation location T_{inst}.

The temperature at installation location T_{inst} reflects the superposition of the environmental temperature T_{env} outside the vehicle with the temperature increase dT at the installation location in a combustion engine compartment during vehicle operation.

The dT in electric vehicles is lower and therefore is assumed to be covered by this specification. Use Formula (1) to determine the temperature distribution at the installation location.

$$T_{inst} = T_{env} + \Delta T \quad (1)$$

where

T_{inst} is the temperature at the installation location of the brake actuation and modulation systems;

T_{env} is the distribution of worldwide environmental temperature outside the vehicle (vehicle independent, see 6.4.1);

ΔT is the temperature increase by vehicle usage at installation location (vehicle dependent, typical vehicle resulting distribution for T given in Clause 6).

At environmental temperatures of -40 °C, no increase of T_{inst} by vehicle usage is assumed due to the airflow's high cooling capability.

Moderate and high environmental temperatures lead to a ΔT of up to 55 K.

Specific temperature effects may be considered when the brake system components directly interact (have thermal conductivity) through a mechanical connection.

EXAMPLE Direct cooling effect by the connection of an actuator to the passenger compartment.

Table 6 — Distribution of temperature at the installation location

T_{inst} [°C]	Probability [%]
– 40	0,5
– 20	2,5
20	28
60	40
80	26
105	3
Sum	**100**

6.4.3 Exceptional high temperatures at the installation location

Higher ΔT can occur as a combination of exceptional events and devices' proximity with significantly increased temperatures.

EXAMPLE Stopover after long steep uphill driving at low speed with fully laden trailer and vehicle.

NOTE 1 This occurs only in rare vehicle configurations.

To also cover such exceptional situations, Figure 4 shows representative manoeuvres, including 120 °C.

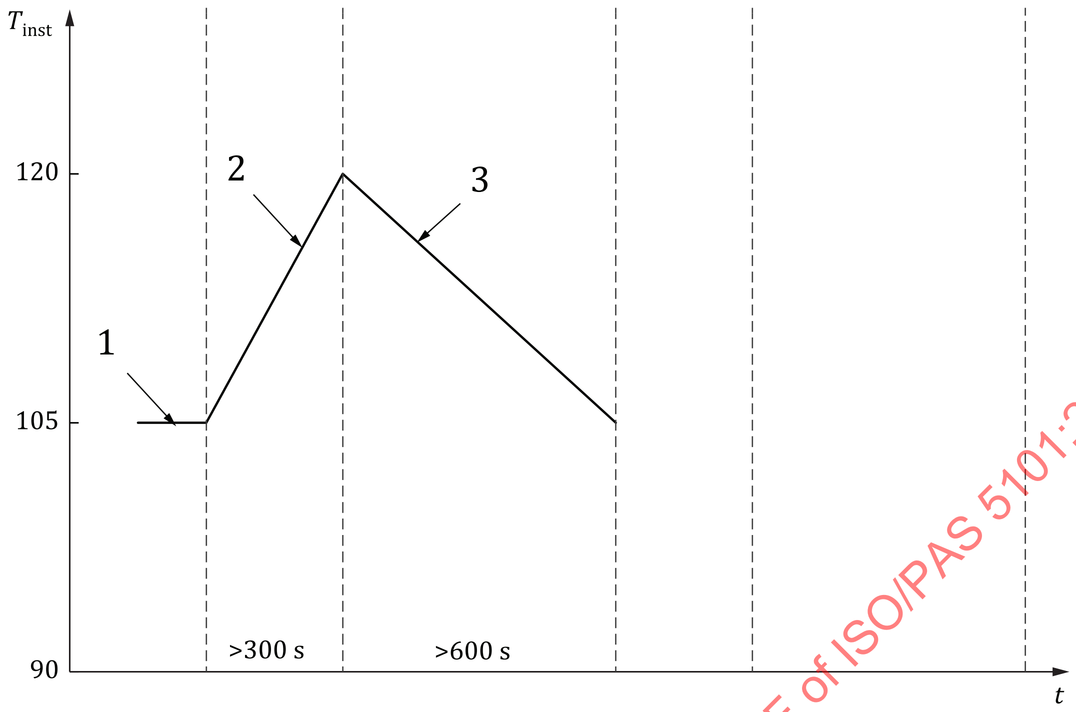
Phase 1 defines the starting condition. The braking system is heated thoroughly until 105 °C to ensure all system components start with this initial temperature.

Phase 2 represents the heat-up phase. During this time, with a minimum of 300 s, T_{inst} shall increase to 120 °C with a constant temperature gradient.

Phase 3 represents the application and cool-down phase. During this time frame of at least 600 s, apply 10 actuations at 0,15 g and 10 actuations at 0,35 g deceleration requests. These actuations are applied by input from the brake pedal or as a fully automatic brake operation, whichever mode induces the system's higher load. The pressure cycle shall follow the ACC-16 and ACC-35 profiles. Distribute the brake applications, including the corresponding pause times, evenly over time. The installation temperature of the braking system shall decrease to 105 °C with a constant temperature gradient.

Repeat this procedure a total of 15 times to simulate one occurrence of this situation once every year over a vehicle lifetime.

Due to the rare occurrence, any combination with other conservative assumptions (e.g. extreme frequency of use) is not expected.



Key

T_{inst} temperature at the installation location in °C

t elapsed time [s]

1 conditions for start

2 heat-up phase

3 application and cool-down phase

Figure 4 — Representative manoeuvre for extreme temperatures at the installation location

NOTE 2 The temperature gradients in phase 2 and phase 3 allow the braking system to reach the temperature it is expected to be subjected to in its installation location.

6.4.4 Function specific occurrence and distributions over temperature ranges

Table 7 shows neglectable occurrences of T_{inst} /manoeuvre combinations as indicated by "-". Expected occurrences of T_{inst} /manoeuvre combinations are indicated by "x". Table 7 only lists manoeuvres that typically would not occur at all indicated temperature ranges.

The total required number of specified events for a function should not be reduced.

NOTE The manoeuvres shown in Table 7 are described in Clause 7.

Table 7 — T_{inst} dependent occurrence of manoeuvres

Function	Manoeuvre	T_{inst} < −20 °C	−20 °C ≤ T_{inst} ≤ 80 °C	T_{inst} > 80 °C
Cold Start	Cold Start 1	x	x	-
	Cold Start 2	x	x	-
ABS	ABS 1	x	x	-
	ABS 4	x	x	-
	ABS 5 L	x	x	-
	ABS 5 R	x	x	-
	ABS 7	x	x	-

Table 7 *(continued)*

Function	Manoeuvre	T_{inst} < –20 °C	–20 °C ≤ T_{inst} ≤ 80 °C	T_{inst} > 80 °C
HRB	HRB 1	-	x	x
	HRB 2	-	x	x
Fading	Fading 1	-	x	x
	Fading 2	-	x	x
TCS ORD	TCS ORD 1a	-	x	x
	TCS ORD 1b	-	x	x
	TCS ORD 2a	-	x	x
	TCS ORD 2b	-	x	x
	TCS ORD 3a	-	x	x
	TCS ORD 3b	-	x	x
BDW	BDW	-	x	x

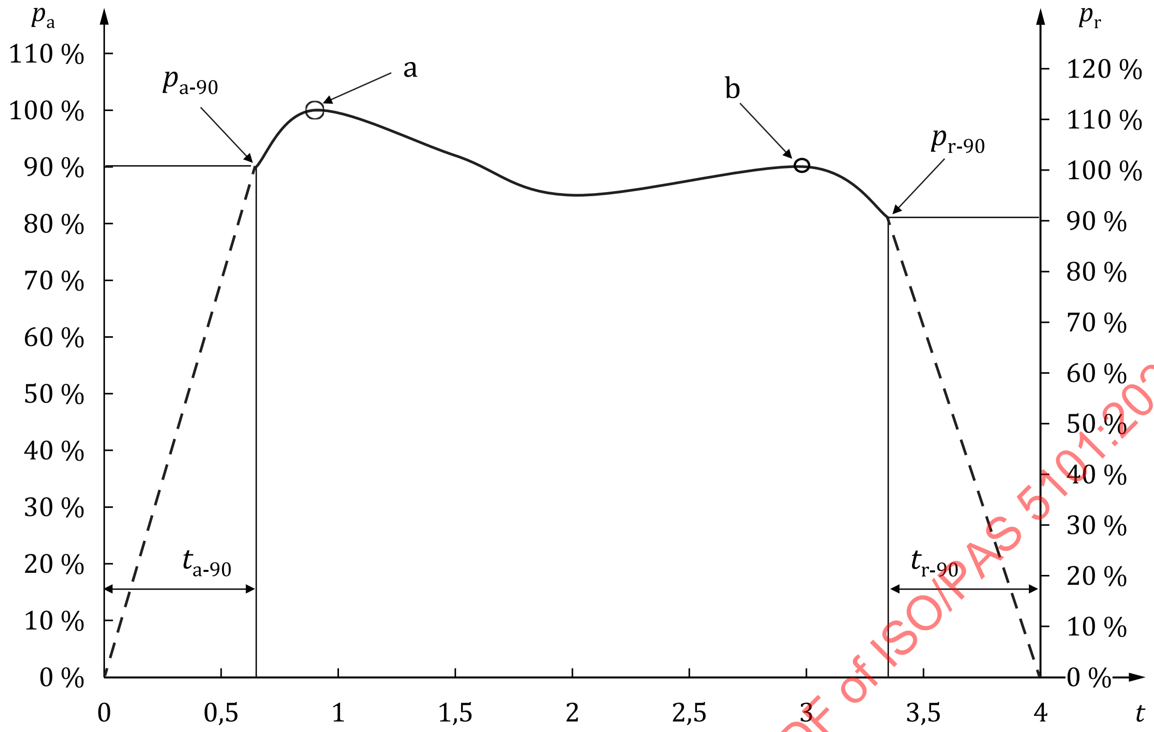
Manoeuvres with a calculated occurrence of less than one activation in a temperature class can be omitted. Manoeuvres with an occurrence of fewer than 10 activations in a temperature class can be carried out by load equivalent manoeuvres at the same temperature. The loss of accuracy is negligible.

6.5 Brake pedal application profile

6.5.1 Parameters for brake pedal apply and release time

6.5.1.1 General

A typical apply and release time of 650 ms is assumed independent of the brake event's target pressure. The typical application time is from the onset of brake pedal application until pressure reaches 90 % of the first local maxima ($t_{a\text{-}90}$). The typical release time is from the time pressure reduces to 90 % of the last local maxima until the pressure is fully released ($t_{r\text{-}90}$), see Figure 5.



Key

t time

p_a brake pressure during brake pedal apply

p_r brake pressure during brake pedal release

t_{a-90} time from p_{a-0} until p_{a-90} is reached

t_{r-90} time from p_{r-90} until p_{r-0}

[a] Target brake pressure of brake pedal apply.

[b] Brake pressure level at beginning of brake pedal release.

NOTE The profile illustrates a typical manoeuvre, but not the actual gradient during the apply and releases times, nor results from field data. During the onset of the application or during the end of the release time, the gradient can be nonlinear due to the actual driver demand, system sizing, and the system response at low pressure.

Figure 5 — Example for interpretation of apply and release times

When defining representative pressure profiles for the brake systems function, manufacturers should consider the typical apply and release times. According to the manufacturer's specific trigger logic, apply the applicable gradients (rate of change) for functions intended to support the driver during panic braking or emergencies.

6.5.1.2 Background

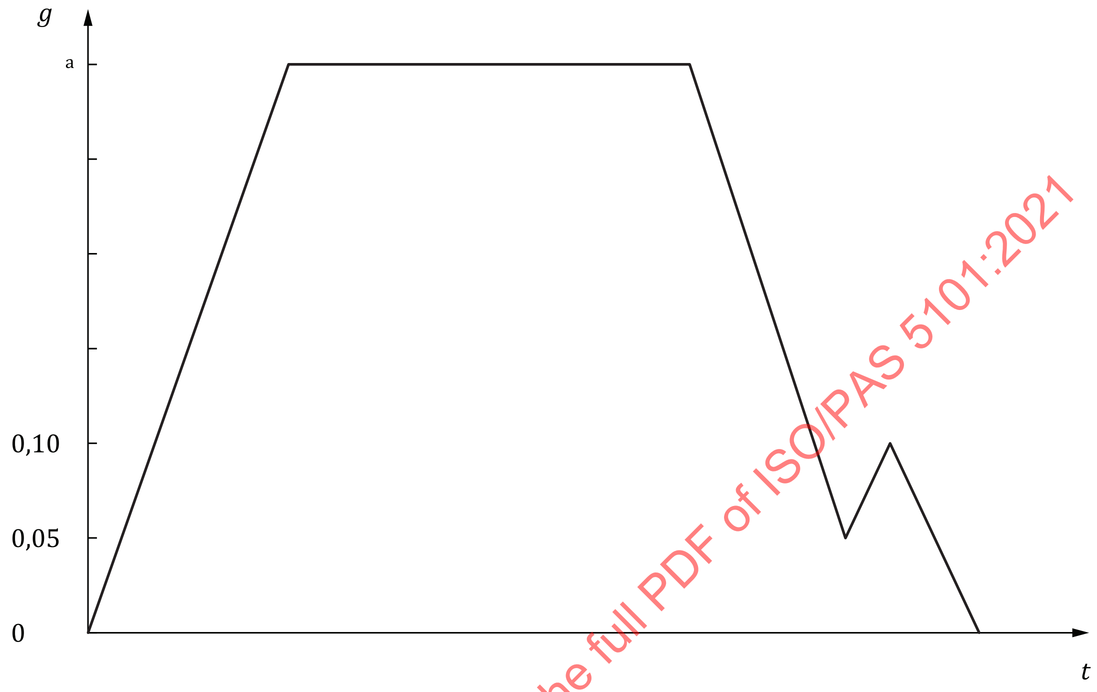
The analysis represents field data from more than 570 000 brake events to define typical apply and release times. The analysis discarded events identified as panic actions before averaging the apply and release times.

6.5.2 Modulation of deceleration during brake events

6.5.2.1 General

Modulation of deceleration during a brake event represents expected driver behaviour. Analysis of field data indicates one modulation event per brake event on average. The average modulated volume is 30 % of the volume at the maximum pressure of each event. The field data also indicates that most modulation events occur at the end of a brake event and low deceleration.

A suitable representation of this modulation can be implemented by adding a 0,05 g modulation on every brake release step, as shown in Figure 6.



Key

a Max.

Figure 6 — Example of brake event with modulated brake pedal release

6.5.2.2 Background

Field data representing 660 000 brake events was analysed. Modulation of deceleration is more frequent during brake events leading to a standstill than during brake events not leading to a standstill. The driver tends to avoid the stopping jerk by partly releasing the brake pedal and – when a standstill is achieved – pushing the brake pedal again to ensure a safe standstill. Brake events leading to standstill commonly include multiple modulations. On the other hand, a significant fraction of brake events not leading to a standstill does not show any modulation. One modulation per action is the average for events leading to a standstill and not leading to a standstill.

7 Braking system usage

7.1 Base brake function

The load of the base brake function highly depends on the specific braking system configuration.

Therefore, generic manoeuvres cannot be given. Relevant manoeuvres and frequencies can be determined based on the lifetime specifications (see 6.2) and the brake pedal application profile (see 6.5).

7.2 Dynamic stability functions

7.2.1 Electronic brake force distribution (EBD)

EBD is dependent on a variety of vehicle-specific characteristics and software parameters. Therefore, a generic number or calculation rule cannot be given here. Instead, the following procedure is recommended to gather the missing information regarding the EBD activation frequency:

Evaluate the minimum deceleration at which the EBD intervention occurs for the typically laden vehicle on a surface with dry asphalt ($\mu \sim 1$). Determine the deceleration using vehicle test or simulation.

Determine the frequency of brake operations equal or higher to this deceleration using Table 4, column frequency per class while driving. Use this number as the number for vehicle-specific EBD activations over a lifetime.

NOTE Based on experience, 50 % of the EBD cycles occur as pressure hold at the rear axle, the other 50 % as brake pressure release at the rear axle followed by a pressure increase.

7.2.2 Antilock braking system (ABS)

7.2.2.1 Description of function

ABS prevents the wheels from locking and supports the stability and steerability of the vehicle.

7.2.2.2 Manoeuvre description and expected occurrence

Table 8 describes the expected occurrence and manoeuvre parameters for the function of ABS.

Table 8 — Overview of manoeuvres for ABS

Name	Frequency	μ	p_{MC} [kPa]	Brake pedal force [N]	Speed [km/h]	Control time [s]	Use case
ABS 1	10 300	0,20	3 000	75	50	1	road disturbances, snow, ice
ABS 2	1 950	0,35	6 000	150	50	1	snow, gravel
ABS 3	500	0,2 – 1,4	10 000	250	70	2	rough road
ABS 4	50	1/0,2/1	13 000	500	100	4	double μ-jump
ABS 5a	25	0,8/0,15	13 000	500	80	4	μ-split
ABS 5b	25	0,15/0,8	13 000	500	80	4	μ-split
ABS 6	200	1,00	18 000	1 200	80	2	emergency stop on high-μ
ABS 7	50	0,20	22 000	1 800	70	4	emergency stop on low μ
Total	**13 100**						

NOTE 1 The total control time of the manoeuvres sums up to 3,96 h.

For modulation systems, use master cylinder pressure (p_{MC}) as the manoeuvre parameter.

The values of the brake pedal force characteristics are derived from the p_{MC}, applying the characteristic from a passenger car.

The manoeuvre parameter brake pedal force shall be used for actuation and integrated brake systems instead of p_{MC}.

NOTE 2 The high-pressure events cover 99 % of field data from different vehicle types (passenger cars, vans and light commercial vehicles with pressure to brake pedal force characteristics corresponding to 27 500 kPa at 1 800 N).

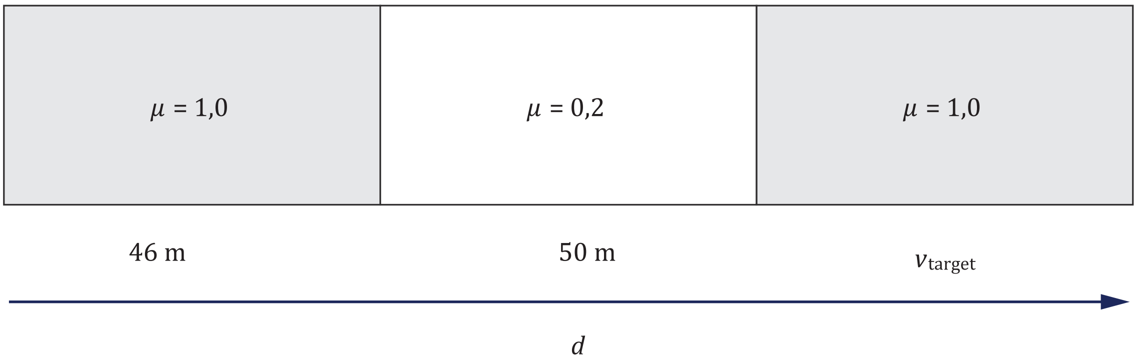
The wheel brake pressure modulation shall be according to the control strategy of the brake system considered.

As illustrated in Table 9 for the ABS 3 manoeuvre, the front right wheel experiences the same adhesion level as the front left wheel, plus an offset of 150 ms. The rear wheels experience the same adhesion levels as the corresponding front wheels with a 300 ms offset.

Table 9 — Pattern of the coefficient of adhesion level for the ABS 3 manoeuvre for all four wheels

Front left wheel		Front right wheel		Rear left wheel		Rear right wheel	
Time [s]	μ	Time [s]	μ	Time [s]	μ	Time [s]	μ
0,00	0,8	0,00	0,8	0,00	0,8	0,00	0,8
0,10	0,6	0,25	0,6	0,40	0,6	0,55	0,6
0,20	1,0	0,35	1,0	0,50	1,0	0,65	1,0
0,30	0,8	0,45	0,8	0,60	0,8	0,75	0,8
0,40	0,8	0,55	0,8	0,70	0,8	0,85	0,8
0,50	0,2	0,65	0,2	0,80	0,2	0,95	0,2
0,60	1,4	0,75	1,4	0,90	1,4	1,05	1,4
0,70	0,8	0,85	0,8	1,00	0,8	1,15	0,8
0,80	0,8	0,95	0,8	1,10	0,8	1,25	0,8
0,90	1,0	1,05	1,0	1,20	1,0	1,35	1,0
1,00	0,4	1,15	0,4	1,30	0,4	1,45	0,4
1,10	1,2	1,25	1,2	1,40	1,2	1,55	1,2
1,20	0,7	1,35	0,7	1,50	0,7	1,65	0,7
1,30	0,8	1,45	0,8	1,60	0,8	1,75	0,8
1,40	0,8	1,55	0,8	1,70	0,8	1,85	0,8
1,50	0,9	1,65	0,9	1,80	0,9	1,95	0,9
1,60	0,6	1,75	0,6	1,90	0,6	2,05	0,6
1,70	1,0	1,85	1,0	2,00	1,0	2,15	1,0
1,80	0,8	1,95	0,8	2,10	0,8	2,25	0,8
1,90	0,8	2,05	0,8	2,20	0,8	2,35	0,8
2,00	0,7	2,15	0,7	2,30	0,7	2,45	0,7
2,20	0,8	2,35	0,8	2,50	0,8	2,65	0,8
2,65	0,8	2,65	0,8	2,65	0,8	2,65	0,8

The manoeuvre ABS 4 describes sudden changes in coefficients of adhesion to represent changing road surfaces. These changes in coefficients of adhesion are detailed in Figure 7.



Key

μ coefficient of adhesion

d distance in metres

v_{target} target speed at end of manoeuvre ABS 4

Figure 7 — Pattern of the μ-level for the ABS 4 manoeuvre

The manoeuvre ABS 5 relates to different coefficients of adhesion (0,8 and 0,15) at the wheels on the left-hand side and right-hand side of the vehicle.

7.2.2.3 Rationale and additional information

During rough road driving, the coefficient of adhesion and the normal force vary over time. The manoeuvre ABS 3 only varies the coefficient of adhesion as a combination of both effects.

Other functions can also trigger ABS-cycling; see Clause 8 for corresponding substitution methods.

7.2.3 Traction control (TCS)

7.2.3.1 Description of function

The traction control function modulates the pressure of the individual wheel brakes to avoid slipping of wheels when accelerating on surfaces with a low coefficient of adhesion.

7.2.3.2 Manoeuvre description and expected occurrence

This document defines five types of manoeuvres to represent the load of the traction control functionality. Table 10 describes these manoeuvres and their expected occurrence.

NOTE 1 For this function, driving situations are specified instead of pressure versus time because these depend, for example, on control strategy, vehicle characteristics and parametrization of the function.

Table 10 — Manoeuvre definition and frequency

Driving manoeuvre	Road surface left/right μ-split	Accelerator pedal position (driver request) [%]	v_{min} - v_{max} [km/h]	Frequency	Control time for each drive-off [s]
TCS 1a	0,2/0,9	40	2 – 5	9 000	approximately 1,5
TCS 1b	0,9/0,2	40	2 – 5	9 000	approximately 1,5
TCS 2a	0,25/0,35	45	2 – 22	5 050	approximately 3,0
TCS 2b	0,35/0,25	45	2 – 22	5 050	approximately 3,0
TCS 3a	0,2/0,9	60	2 – 15	1 000	approximately 2,7

Table 10 *(continued)*

Driving manoeuvre	Road surface left/right μ-split	Accelerator pedal position (driver request) [%]	v_{min} - v_{max} [km/h]	Frequency	Control time for each drive-off [s]
TCS 3b	0,9/0,2	60	2 – 15	1 000	approximately 2,7
TCS 4a	0,2/0,9	100	2 – 70	100	approximately 10,0
TCS 4b	0,9/0,2	100	2 – 70	100	approximately 10,0
TCS 5a	0,2/0,9	100	2 – 40	50	approximately 6,0
TCS 5b	0,9/0,2	100	2 - 40	50	approximately 6,0
Total				**30 400**	

NOTE 2 The total control time of the manoeuvres sums up to 18,14 h.

NOTE 3 Symmetrical interventions can often be avoided by engine torque reductions. The residual symmetrical interventions are covered by left/right manoeuvres.

All manoeuvres describe different coefficients of adhesion at the wheels on the left-hand side and right-hand side of the vehicle.

Manoeuvre 5 is performed with a brake friction coefficient reduced by 30 % to simulate fading conditions.

NOTE 4 The manoeuvre definitions do not explicitly specify a road slope; the engine torque values cover road slopes.

7.2.3.3 Rationale and additional information

The five manoeuvres cover different road surface conditions such as low-μ on both sides of the vehicle (manoeuvre 2) and different μ-levels on either side of the vehicle (μ-split). Manoeuvres with μ-split are intended to be carried out symmetrically, i.e. with low-μ on the left side of the vehicle in 50 % of all cases and low-μ on the right side of the vehicle in 50 % of all cases.

NOTE This clause covers front wheel drive, rear wheel drive and all-wheel drive.

7.2.3.4 Traction control for off-road (TCS ORD)

7.2.3.4.1 Description of function

Some vehicles are used off-road beyond the realm of standard traction control. More and stronger TCS activations are expected in heavier terrain because the surface can consist of many bumps and holes.

This document considers regular passenger cars, light commercial vehicle and sport utility vehicles.

7.2.3.4.2 Manoeuvre description and expected occurrence

Table 11 describes the expected frequency over lifetime and manoeuvre parameters for the TCS ORD function.

NOTE 1 For this function, driving situations are specified instead of pressure versus time because these depend, for example, on control strategy, vehicle characteristics and parametrization of the function.

NOTE 2 The total control time of the manoeuvres sums up to 0,68 h.

Table 11 — Manoeuvre definition and frequency

Driving manoeuvre	*μ*	Slope [%]	Initial speed [km/h]	Frequency	Control time for each drive-off [s]
TCS ORD 1a	0,2-1,0	25	0	15	approximately 10
TCS ORD 1b	0,2-1,0	25	0	15	approximately 10
TCS ORD 2a	0,2-1,0	15	0	80	approximately 5
TCS ORD 2b	0,2-1,0	15	0	80	approximately 5
TCS ORD 3a	0,2-1,0	15	5	340	approximately 2
TCS ORD 3b	0,2-1,0	15	5	340	approximately 2
Total				**870**	

All manoeuvres describe different patterns of coefficients of adhesion at the wheels on the left-hand side and right-hand side of the vehicle.

These patterns of coefficients of adhesion are described in Table 12 and Figure 8 for the TCS ORD 1a manoeuvre and in Table 13 and Figure 9 for TCS ORD 2a and TCS ORD 3a manoeuvres.

The patterns of coefficients of adhesion in the manoeuvres with the indices "b" are the same as for the indices "a", whereas their sequence over distance is switched.

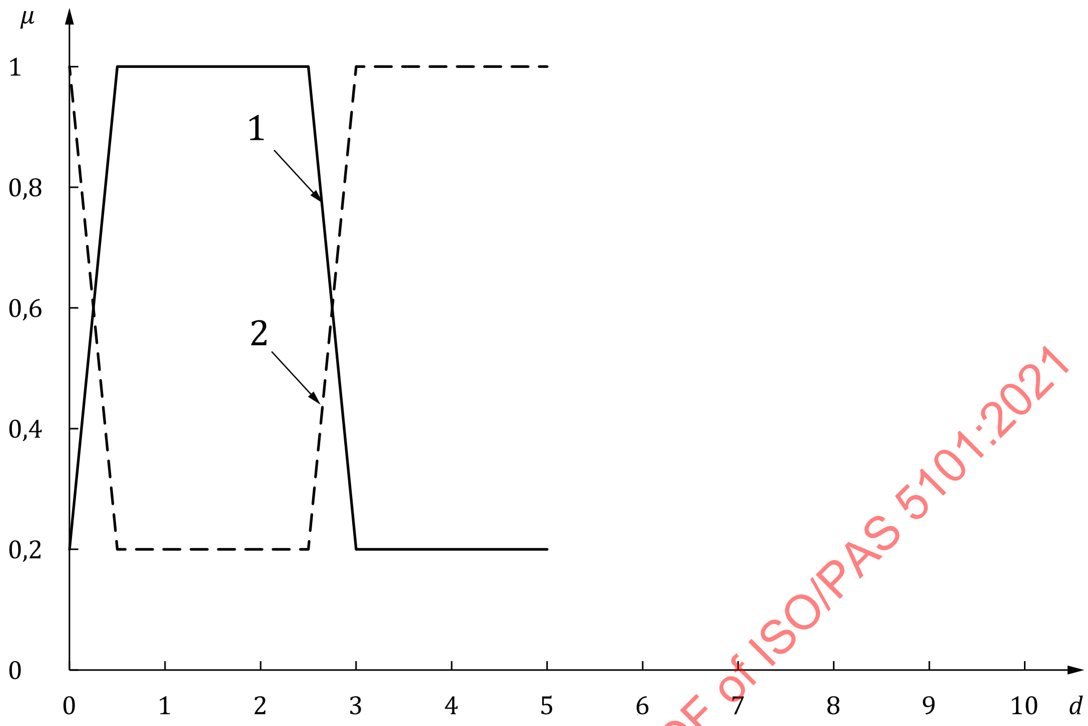
— TCS ORD manoeuvre 1 is rare due to its long duration (10 s), representing a very steep grade (25 %).

— TCS ORD manoeuvre 2 is common with a medium duration (5 s), representing a steep grade (15 %).

— TCS ORD manoeuvre 3 is very common with a short (2 s), representing a steep grade (15 %).

Table 12 — TCS ORD 1a: Pattern of coefficient of adhesion

Distance [m]	*μ* left side	*μ* right side
0,0-0,5	0,2-1,0	1,0-0,2
0,5-2,5	1,0	0,2
2,5-3,0	1,0-0,2	0,2-1,0
3,0-5,0	0,2	1,0



Key

μ coefficient of adhesion

d distance in metres

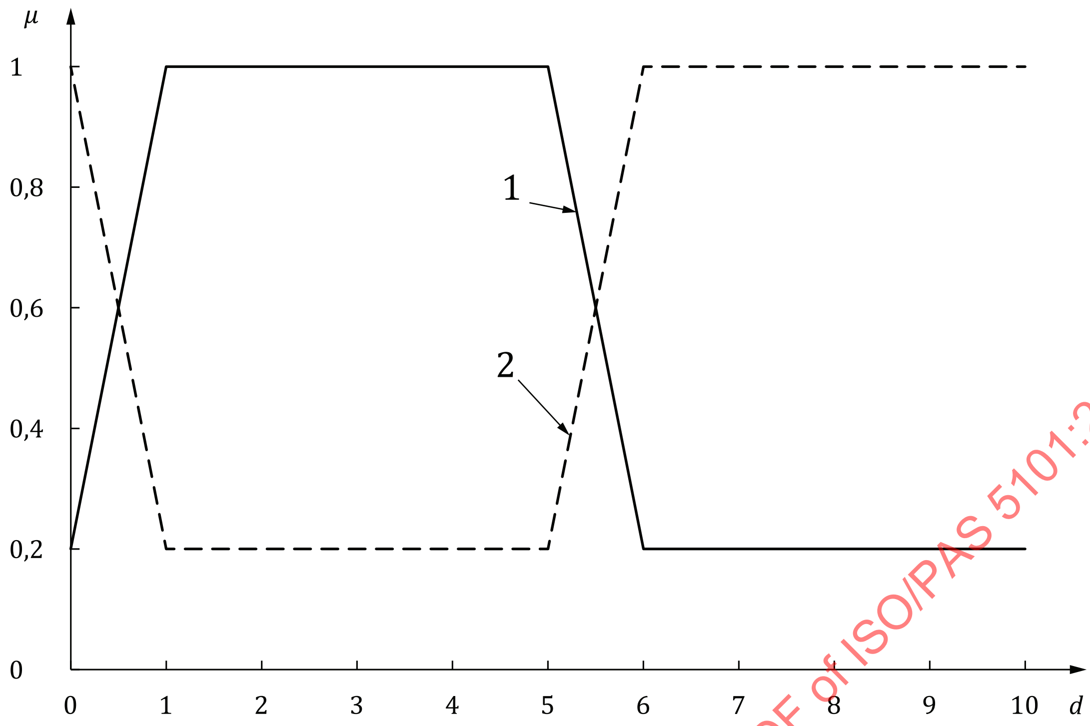
1 left wheel

2 right wheel

Figure 8 — Road surface adhesion as a function of driven distance

Table 13 — TCS ORD 2a and 3a: Pattern of coefficient of adhesion

Distance [m]	***μ* left side**	***μ* right side**
0,0-1,0	0,2-1,0	1,0-0,2
1,0-5,0	1,0	0,2
5,0-6,0	1,0-0,2	0,2-1,0
6,0-10,0	0,2	1,0



Key

μ coefficient of adhesion

d distance in metres

1 left wheel

2 right wheel

Figure 9 — Road surface adhesion as a function of driven distance

7.2.3.4.3 Rationale and additional information

Manoeuvres with μ-split are intended to be carried out symmetrically, i.e. with low-μ on the left side of the vehicle in 50 % of all cases and low-μ on the right side of the vehicle in 50 % of all cases.

7.2.4 Electronic stability control (ESC)

7.2.4.1 Description of functions

The function ESC modulates the wheel brake pressure to improve vehicle stability and keep the vehicle on track in critical driving situations. The pressure modulation generates a stabilizing yaw torque on the vehicle.

7.2.4.2 Manoeuvre description and expected occurrence

Five manoeuvres with two different coefficients of adhesion (0,4 and 1,0) have been defined according to Table 14 to represent the field load of the ESC functionality. All manoeuvres start at 90 km/h. Appropriate steering angle profiles trigger ESC according to Figures 10 – 12.

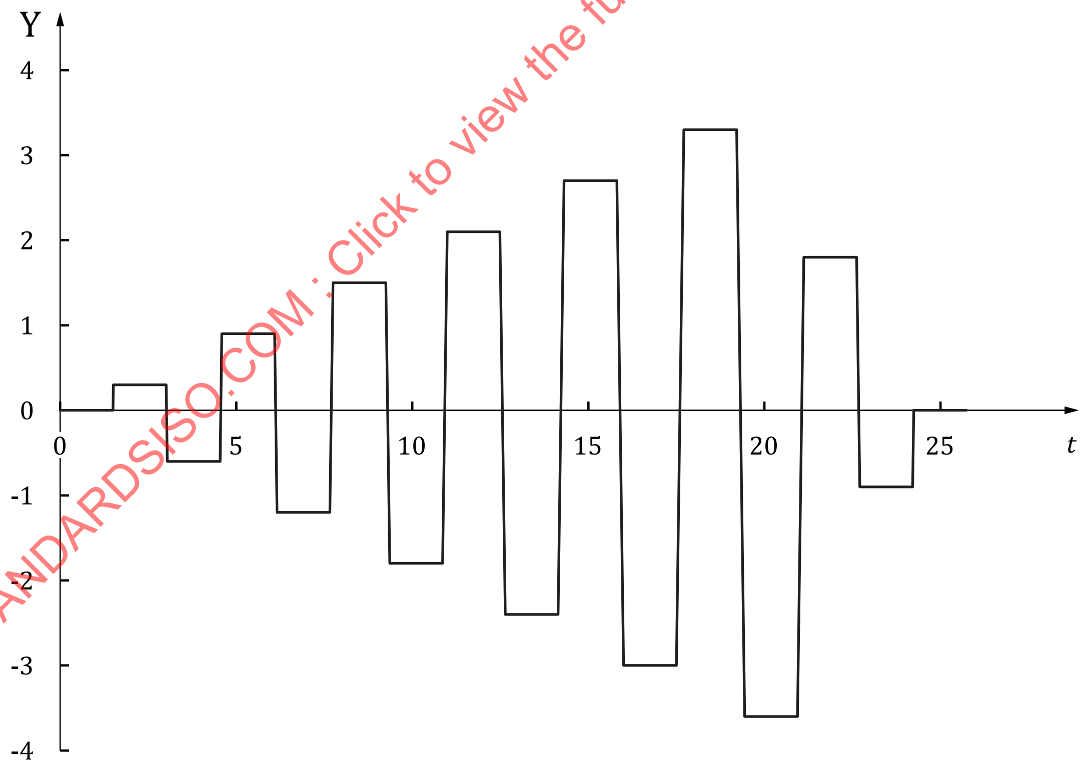
Table 14 — Overview of manoeuvres for ESC

Manoeuvre	μ	Frequency	p_{MC} [kPa]	Control time [s]	Description
ESC 1	0,4	600	0	7,0	Slalom
ESC 2a	1,0	200	2 000	0,5	Lane change left with brake intervention
ESC 2b	1,0	200	2 000	0,5	Lane change right with brake intervention
ESC 3a	1,0	20	3 000	0,5	Lane change left with brake intervention
ESC 3b	1,0	20	3 000	0,5	Lane change right with brake intervention
Total		**1 040**			

NOTE 1 The total control time of the manoeuvres sums up to 1,3 h.

NOTE 2 For this function, driving situations are specified instead of pressure versus time because these depend, for example, on control strategy, vehicle characteristics and parametrization of the function.

Figures 10 – 12 and Tables 15 – 17 show the profiles for the steering angle.



Key

Y steering angle [°]

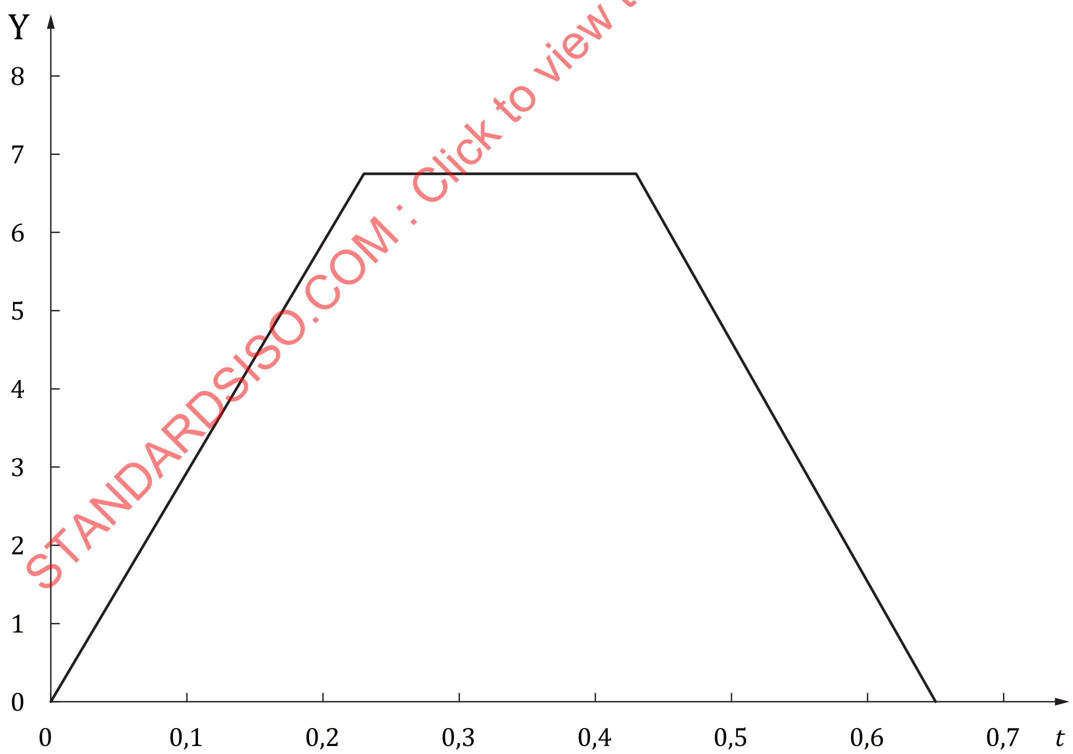
t elapsed time [s]

Figure 10 — Steering angle profile for ESC 1

Table 15 — Steering angles for ESC 1

Steering angle [°]
0,0
0,3
- 0,6
0,9
- 1,2
1,5
- 1,8
2,1
- 2,4
2,7
- 3,0
3,3
- 3,6
1,8
- 0,9
0,0

The rate of change of the steering angle is 30°/s. At each level, the steering angle remains constant for a period of 1,5 s. Table 15 defines the steering angle values for the ESC 1 profile.



Key

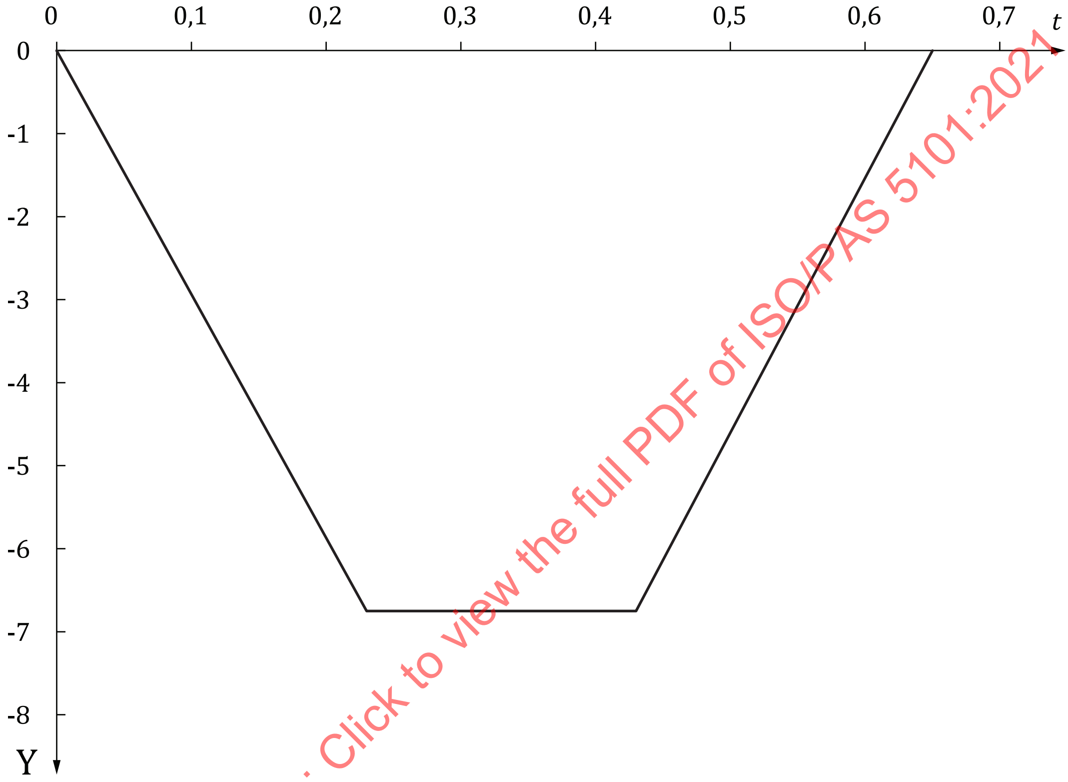
Y steering angle [°]

t elapsed time [s]

Figure 11 — Steering angle profile for ESC 2a and ESC 3a

Table 16 — Steering angles for ESC 2a and 3a

Time [s]	Steering angle [°]
0,00	0,0
0,23	6,75
0,43	6,75
0,65	0,00



Key

Y steering angle [°]

t elapsed time [s]

Figure 12 — Steering angle profile for ESC 2b and ESC 3b

Table 17 — Steering angles for ESC 2b and ESC 3b

Time [s]	Steering angle [°]
0,00	0,0
0,23	- 6,75
0,43	- 6,75
0,65	0,00

7.2.4.3 Rationale and additional information

The first manoeuvre, ESC 1, represents slalom driving with low surface friction.

NOTE Slalom driving is not a typical real-world driving situation, but it is an efficient way of stimulating multiple ESC interventions.

The manoeuvres ESC 2a – ESC 3b represent lane-change manoeuvres on dry-road surface friction levels while the driver applies the brake pedal.

7.2.5 Trailer sway control (TSC)

7.2.5.1 Description of function

The function trailer sway control actuates the braking system to improve the stability of the vehicle and trailer combination during critical driving situations. TSC intervenes via short pressure increases alternating at the left and right front wheel synchronously to the vehicle and trailer combination oscillation.

7.2.5.2 Manoeuvre description and expected occurrence

The manoeuvres described in Figures 10–12 and Tables 15–17 also apply to trailer sway control. The frequencies expressed in Table 14 cover the expected occurrence of TSC.

7.2.5.3 Rationale and additional information

The expected occurrence of the TSC function is rare and occurs with 0 activations in the 95th percentile. Thus, the specifications for the ESC functions in 7.2.4.2. cover the expected occurrences.

NOTE For this function, driving situations are specified instead of pressure versus time because these depend, for example, on control strategy, vehicle characteristics and parametrization of the function.

7.2.6 Roll-over mitigation functions

7.2.6.1 Description of functions

The roll-over-function helps to avoid the roll-over of a vehicle in a situation of high lateral acceleration. This function is typically used on vehicles with a high centre of gravity. This document differentiates between "soft" and "strong" roll-over interventions.

During a "soft" roll-over intervention, the vehicle velocity is reduced to avoid reaching situations in which roll-over is imminent as a preventive intervention.

Through a "strong" roll-over intervention, lateral tyre forces are reduced in a controlled manner by increasing the brake pressure to avoid a roll-over. This intervention is curative and is used when roll-over seems imminent.

7.2.6.2 Expected occurrence

Table 18 shows the expected frequencies of “soft" and "strong" roll-over interventions.

Table 18 — Specification of roll-over function

Manoeuvre	μ	Frequency	Control time [s]	Description
Roll-over "soft"	1,0	15	1,0	Preventive intervention
Roll-over "strong"	1,0	0[a]	1,0	Curative intervention
Total		**15**		

[a] The 95th percentile shows no occurrence of roll-over strong intervention. Use in the field is expected to be very infrequent. Nevertheless, the system should be designed that single roll-over strong activations do not lead to relevant damage on any component.

Use an even split between left and right turns. The duration of a roll-over intervention is, on average, 1 s.

7.2.6.3 Rational and additional information

The shown values are taken from the 95th percentile light commercial vehicle and van category vehicle usage. These cars usually have a high centre of gravity. Passenger cars have a lower centre of gravity and are therefore expected to have fewer activations.

NOTE For this function, driving situations are specified instead of pressure versus time because these depend, for example, on control strategy, vehicle characteristics and parametrization of the function.

7.3 Brake torque optimizing functions

7.3.1 Brake booster support functions

7.3.1.1 Description of functions

The brake booster support functions extend the brake booster's capability when it cannot provide the requested brake force amplification. The structure of the brake booster support functions is as follows:

a) the over-boost function activates when the brake booster reaches its amplification limit (insufficient brake booster performance);

b) the failed boost function activates when the brake force amplification is not functioning;

c) the cold start function (for vacuum-based actuation systems only) activates when a (temporary) insufficient vacuum supply occurs after engine cold starts; when a vacuum-based actuation system provides the brake force amplification.

NOTE 1 Brake booster support functions are typically present in braking systems consisting of separate brake actuation and brake modulation units.

NOTE 2 The function cold start is usually activated immediately after ignition in a cold start situation.

The applicability of relevant influencing parameters as given in 7.3.1.2.2 should be checked for the vehicle considered.

The basis for the manoeuvre descriptions in 7.3.1.2.1 are:

— an amplification rate of 5:1;

— a brake pressure of 10 000 kPa corresponding to 1 *g* deceleration with typically laden vehicle;

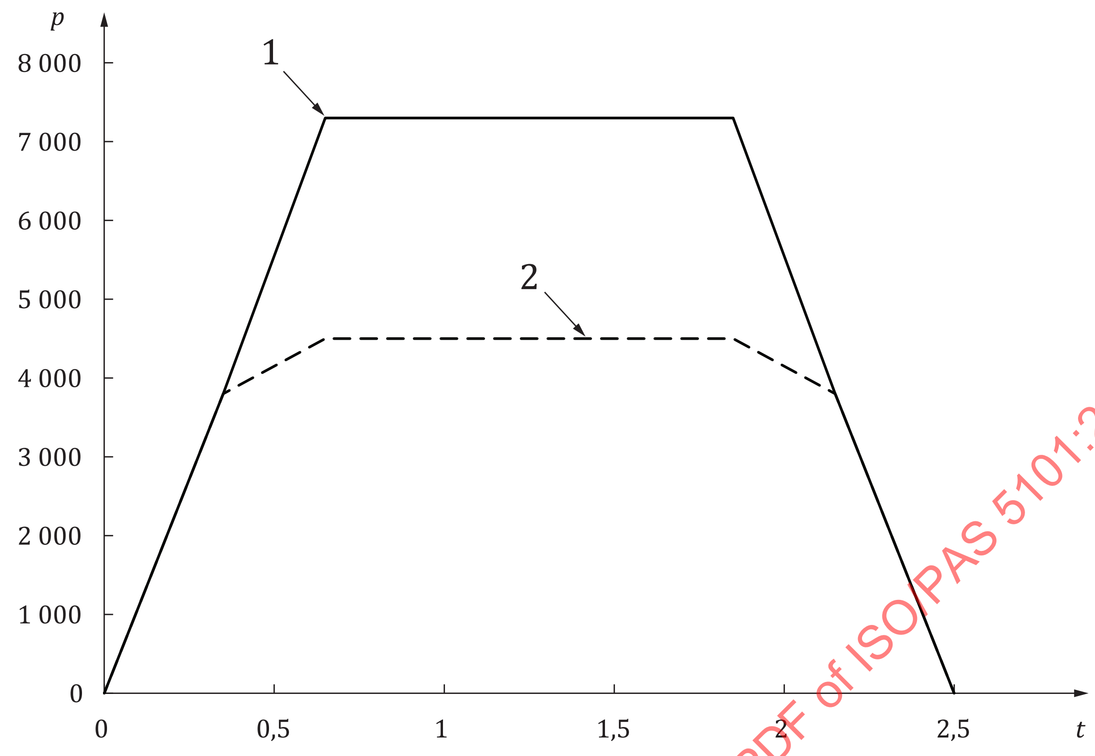
— time needed to reach target pressure is 650 ms.

NOTE 3 With an amplification rate of 5:1, an increase in master cylinder pressure of 1 000 kPa, increases the brake pressure by 5 000 kPa. As a result, during active brake booster support functions, the modulation system amplifies the master cylinder pressure above the effective runout level by a factor of five.

7.3.1.2 Over-boost

7.3.1.2.1 Manoeuvre description and expected occurrence

Figures 13–16 and Tables 19–22 show the manoeuvres to represent the over-boost functionality load.



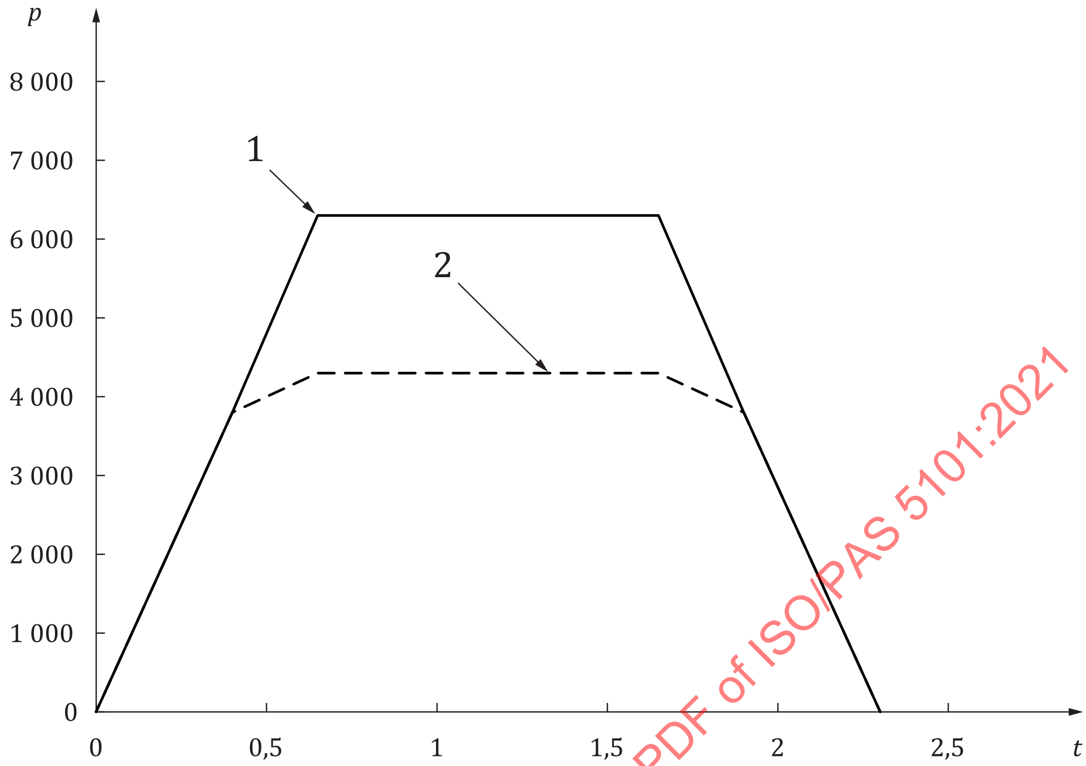
Key

p brake pressure [kPa]
t elapsed time [s]
1 brake pressure
2 master cylinder pressure

Figure 13 — Manoeuvre over-boost 1

Table 19 — Pressures for manoeuvre over-boost 1

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]
0	0	0
0,35	3 800	3 800
0,65	4 500	7 300
1,85	4 500	7 300
2,15	3 800	3 800
2,5	0	0



Key

p brake pressure [kPa]

t elapsed time [s]

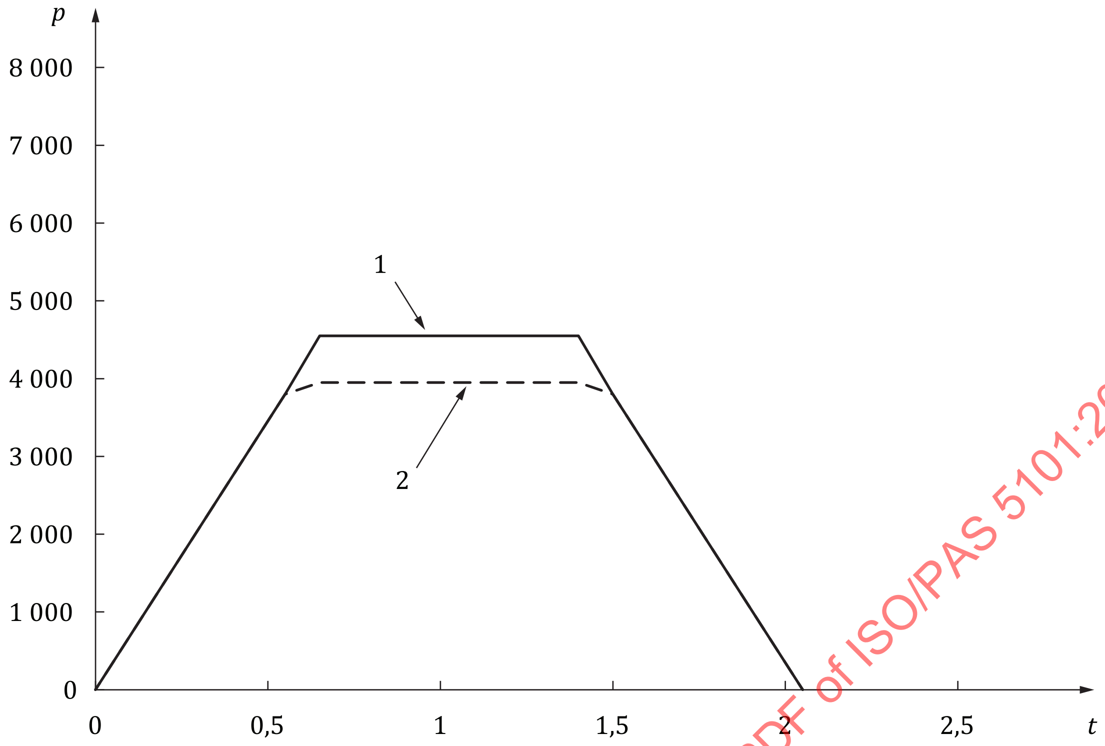
1 brake pressure

2 master cylinder pressure

Figure 14 — Manoeuvre over-boost 2

Table 20 — Pressures for manoeuvre over-boost 2

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]
0	0	0
0,4	3 800	3 800
0,65	4 300	6 300
1,65	4 300	6 300
1,9	3 800	3 800
2,3	0	0



Key

p brake pressure [kPa]

t elapsed time [s]

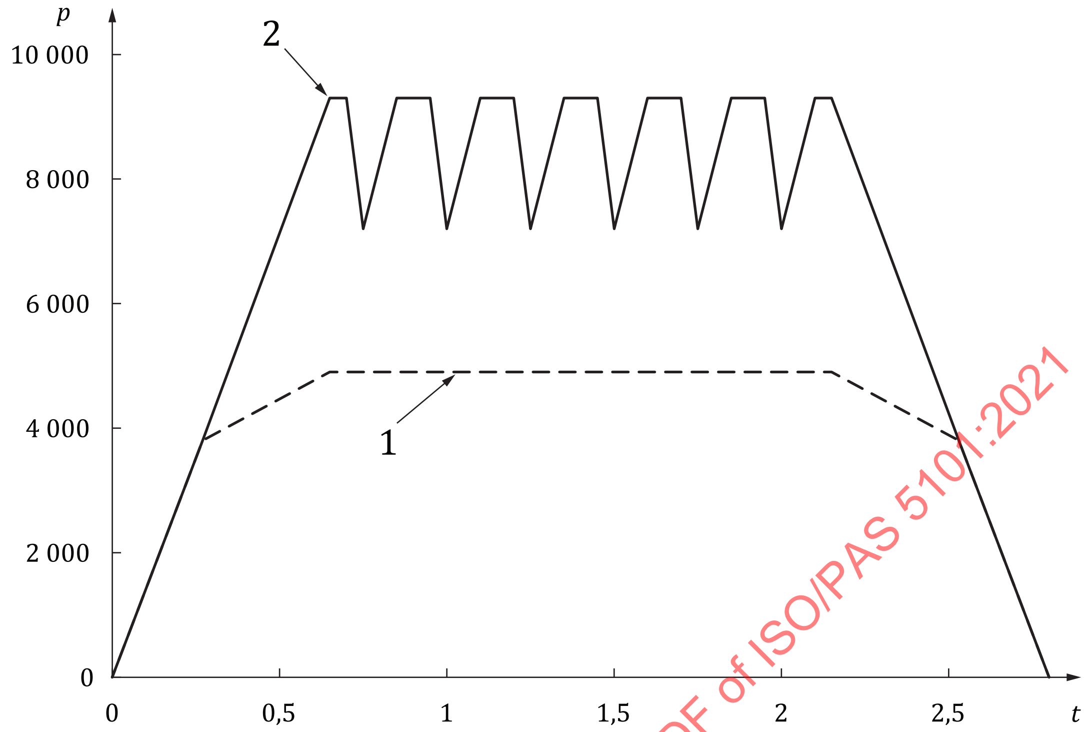
1 brake pressure

2 master cylinder pressure

Figure 15 — Manoeuvre over-boost 3

Table 21 — Pressures for manoeuvre over-boost 3

Time [s]	p_{MC} [kPa]	**Brake pressure** [kPa]
0	0	0
0,55	3 800	3 800
0,65	3 950	4 550
1,4	3 950	4 550
1,5	3 800	3 800
2,05	0	0



Key

p brake pressure [kPa]

t elapsed time [s]

1 brake pressure

2 master cylinder pressure

NOTE The ABS pressure modulation is displayed simplified.

Figure 16 — Manoeuvre over-boost ABS

Table 22 — Pressures for manoeuvre over-boost ABS

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]
0	0	0
0,25	3 800	3 800
0,65	4 900	9 300
2,15	4 900	9 300
2,55	3 800	3 800
2,8	0	0

Table 23 describes the expected occurrence (number of cycles) of these manoeuvres related to the nominal runout pressure.

Table 23 — Manoeuvre occurrence for over-boost at 6 000 kPa nominal runout pressure

Manoeuvre	Frequency
Over-Boost 1	600
Over-Boost 2	2 500
Over-Boost 3	13 000
Over-Boost ABS	600
Total	**16 700**

7.3.1.2.2 Rationale and additional information

This document provides the expected over boost cycles for vehicles equipped with a vacuum-based actuation system equal to or higher than 6 000 kPa nominal runout pressure.

Additionally, electromechanical actuations with a nominal runout pressure higher or equal to 3 500 kPa are covered in Tables 19–22, as no reduction of the nominal runout pressure is expected for electromechanical brake boosters.

For a detailed calculation of the expected amount of over-boost cycles, e.g. vehicles equipped with an actuation with lower runout pressure, the following steps are needed.

a) Step 1: calculate the effective runout pressure based on the nominal runout pressure.

   1) Reduction of runout pressure by altitude

      — The performance of vacuum-based actuation systems depends on the pressure difference, which can be reached in the vacuum chamber. With increasing altitude, the air pressure reduces, and therefore the performance of the vacuum-based actuation reduces as well. As 95 percent of the global population resides below 1 500 m, the air pressure at this level is used as conservative assumption.

      — The resulting effective runout pressure can be calculated by considering the reduced pressure difference at this altitude.

      — For a nominal runout pressure of 6 000 kPa, the resulting runout pressure at this altitude is about 4 500 kPa.

   2) Reduction of runout pressure during typical brake pedal applications

      — The nominal runout pressure is defined for slow brake pedal movements, much slower than the typical brake pedal applications.

      — A typical brake pedal application leads to a reduction of the pressure difference in the vacuum chamber. Therefore, consider an additional reduction of 700 kPa for vacuum-based actuation systems to get the final effective runout pressure.

During typical brake pedal application at an altitude of 1 500 m, a vacuum-based actuation system with a nominal runout pressure of 6 000 kPa results in an effective runout pressure of 3 800 kPa.

b) Step 2: clustering of partial brake operations and definition of representative manoeuvres.

   1) The specific over-boost deceleration is the level above the effective runout pressure;

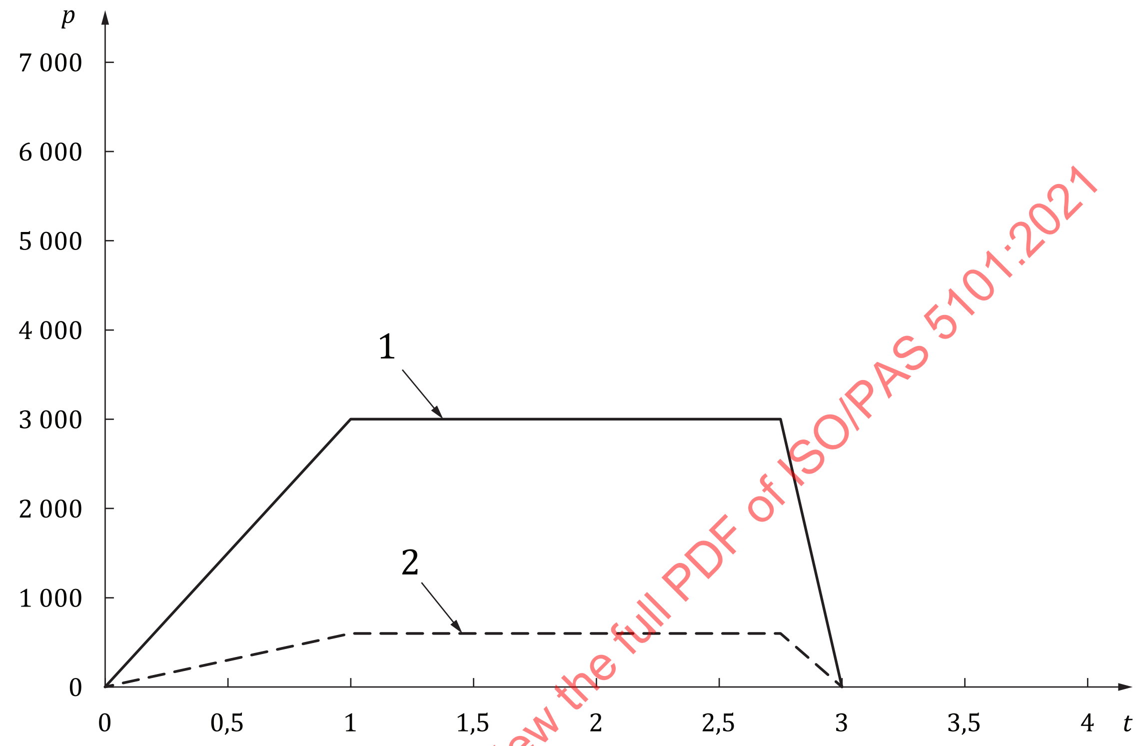
   2) The area can be divided into, e.g. four clusters of deceleration levels;

   3) The weighted mean deceleration level of each cluster, based on Table 4, defines the maximum deceleration during the representative manoeuvres for this cluster.

7.3.1.3 Failed boost

7.3.1.3.1 Manoeuvre description and expected occurrence

Figure 17 and Figure 18 and Table 24 and Table 25 describe the two manoeuvres for failed boost.



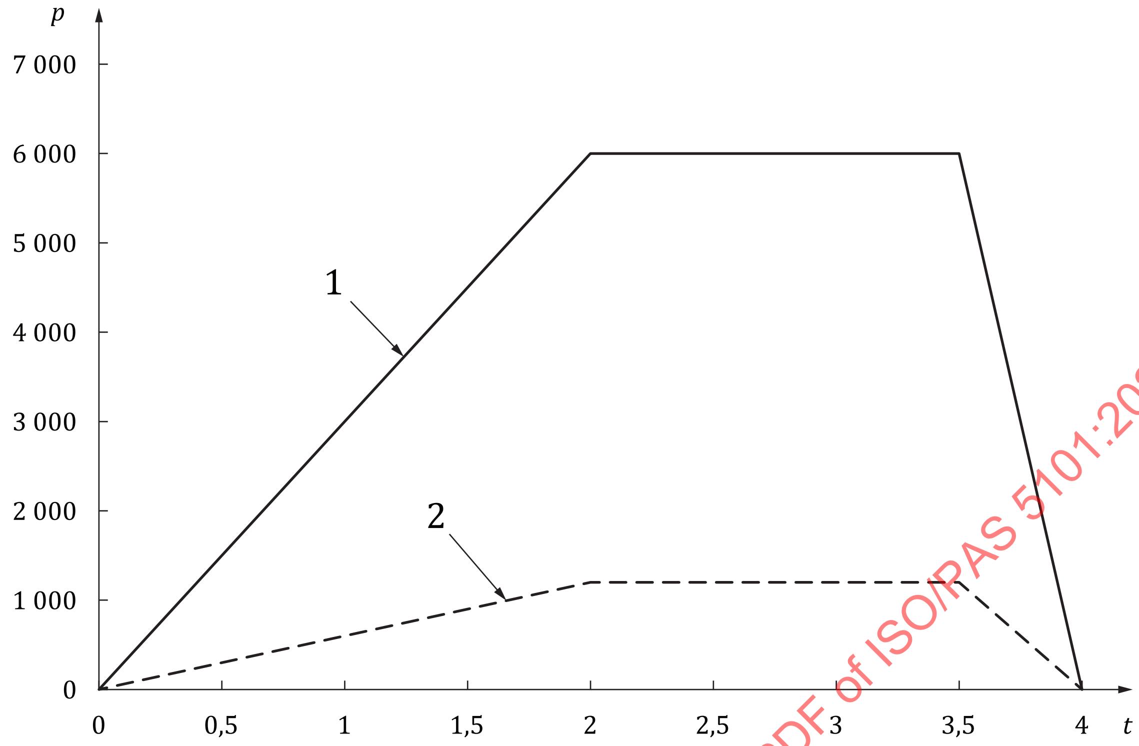
Key

p brake pressure [kPa]
t elapsed time [s]
1 brake pressure
2 master cylinder pressure

Figure 17 — Manoeuvre failed boost 1

Table 24 — Pressures for manoeuvre failed boost 1

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]	Brake pressure gradient [kPa/s]
0,00	0	0	0
1,00	600	3 000	3 000
2,75	600	3 000	0
3,00	0	0	- 12 000



Key

p brake pressure [kPa]
t elapsed time [s]
1 brake pressure
2 master cylinder pressure

Figure 18 — Manoeuvre failed boost 2

Table 25 — Pressures for manoeuvre failed boost 2

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]	Brake pressure gradient [kPa/s]
0,00	0	0	0
2,00	1 200	6 000	3 000
3,50	1 200	6 000	0
4,00	0	0	- 12 000

Table 26 describes the expected occurrence of these manoeuvres.

Table 26 — Overview of manoeuvres for failed boost support

Manoeuvre	Frequency	Maximum p_{MC} [kPa]	Maximum p_{brake} [kPa]	Build-up gradient $\Delta p_{brake}/\Delta t$ [kPa/s]	Decrease gradient $\Delta p_{brake}/\Delta t$ [kPa/s]
Failed Boost	2 000	600	3 000	3 000	–12 000
Failed Boost	1 000	1 200	6 000	3 000	–12 000
Total	**3 000**				

7.3.1.3.2 Rationale and additional information

Due to the very low failure probability of a brake force amplification, the function shows 0 activations in the 95th percentile. Furthermore, the driver usually receives a warning when the brake booster fails and repairs or replaces the brake booster. So, 3 000 activations is a conservative expectation of the number of activations. The number is based on the assumption that it is equivalent to:

— 3 000 km of driving with 1 braking event per km (motorway driving) or;

— 600 km of driving with 5 brake operations per km (city driving).

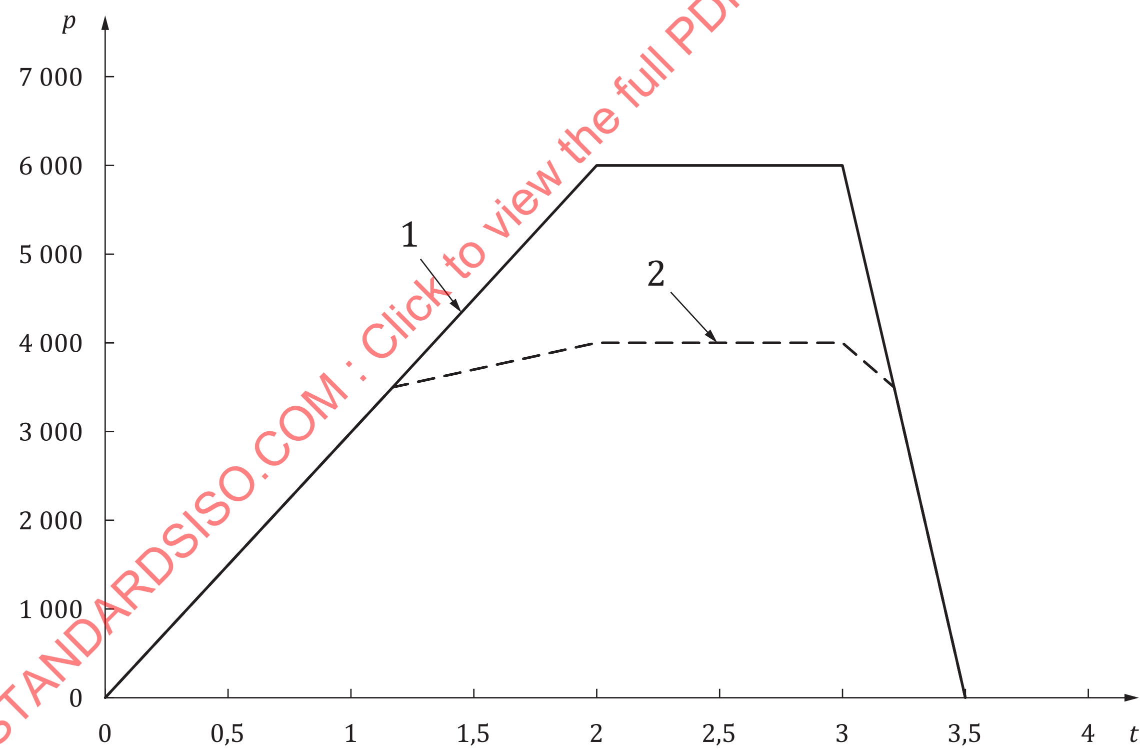
Due to the rare occurrence, any combination with other conservative assumptions (e.g. extreme frequency of use) is not expected.

The higher frequency of 3 000 kPa manoeuvres relative to the number of 6 000 kPa manoeuvres reflects that low-pressure brake operations occur significantly more frequent than high-pressure brake operations. A typical boost ratio of failed boost support is 5:1.

7.3.1.4 Cold start function

7.3.1.4.1 Manoeuvre description and expected occurrence

Figures 19 and 20 and Table 27 and Table 28 describe the two manoeuvres for the cold start function.



Key

p brake pressure [kPa]

t elapsed time [s]

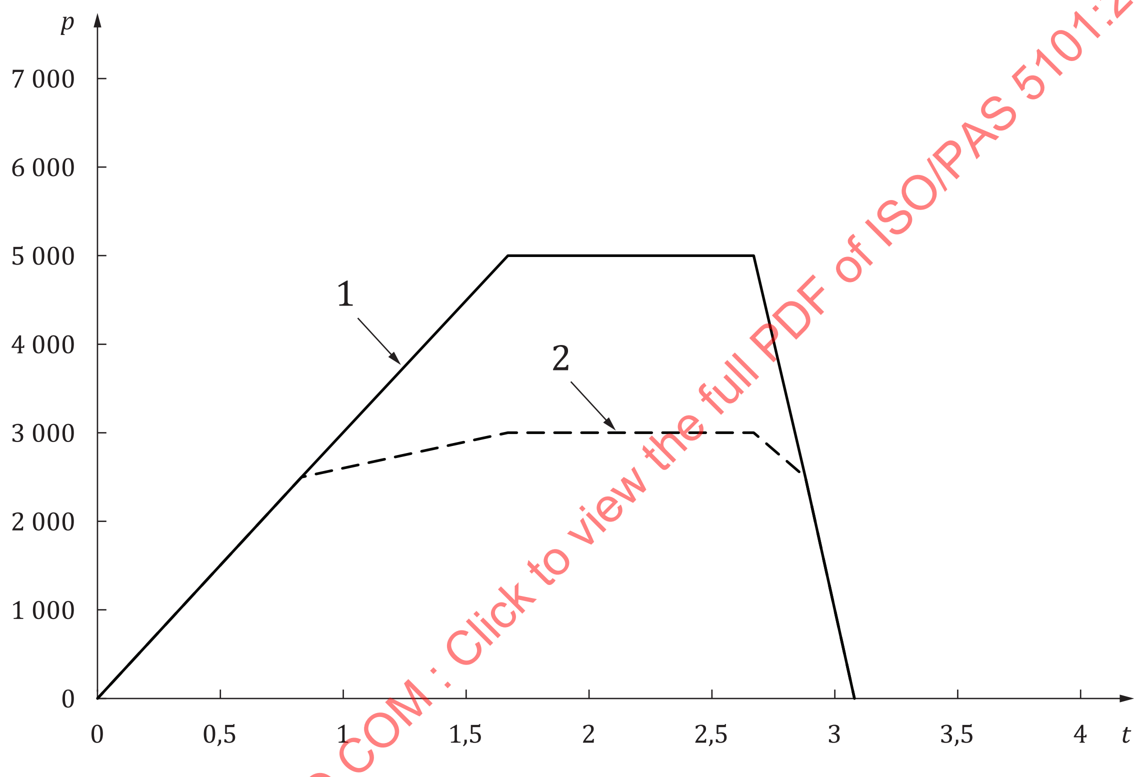
1 brake pressure

2 master cylinder pressure

Figure 19 — Manoeuvre cold start 1

Table 27 — Pressures for manoeuvre cold start 1

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]	Brake pressure gradient [kPa/s]
0,00	0	0	0
1,17	3 500	3 500	3 000
2,00	4 000	6 000	3 000
3,00	4 000	6 000	0
3,21	3 500	3 500	– 12 000
3,50	0	0	– 12 000



Key

p brake pressure [kPa]
t elapsed time [s]
1 brake pressure
2 master cylinder pressure

Figure 20 — Manoeuvre cold start 2

Table 28 — Pressures for manoeuvre cold start 2

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]	Brake pressure gradient [kPa/s]
0,00	0	0	0
0,83	2 500	2 500	3 000
1,67	3 000	5 000	3 000
2,67	3 000	5 000	0

Table 28 *(continued)*

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]	Brake pressure gradient [kPa/s]
2,88	2 500	2 500	– 12 000
3,08	0	0	– 12 000

Table 29 describes the expected occurrence of these manoeuvres.

Table 29 — Overview of manoeuvres for cold start support

Manoeuvre	Frequency	Effective p_{runout} [kPa]	Maximum p_{MC} [kPa]	Maximum p_{brake} [kPa]	Build-up gradient $\Delta p_{brake}/\Delta t$ [kPa/s]	Decrease gradient $\Delta p_{brake}/\Delta t$ [kPa/s]
Cold Start 1	600	3 500	4 000	6 000	3 000	– 12 000
Cold Start 2	2 100	2 500	3 000	5 000	3 000	– 12 000
Total	**2 700**					

7.3.1.4.2 Rationale and additional information

Cold start support during vehicle standstill is not considered in the described manoeuvres and expected occurrence. Supposing it is necessary to activate the function at a standstill, in that case the manoeuvres should be adapted accordingly, and the occurrence should be derived using Table 4's column 'Frequency per class during standstill'.

Cold start can occur four times per day maximum, taking into account engine cool-down times. For the described lifetime of 15 years, that ends up in approximately 20 000 cold start events. Per cold start, a maximum of five brake operations is expected, which equates to 100 000 brake operations over the vehicle lifetime.

NOTE After a cold start, the vehicle speed is low, so that on average, no more than 1 km driving takes place during the cold-start phase (1,6 million brake operations for 300 000 km leads to approximately 5,3 brake operations per km).

The vacuum supply (i.e. the pressure difference between engine manifold pressure and atmospheric pressure) during the cold-start phase, among other things, depends on the engine applied and the temperature. At the beginning of the cold-start phase, a typical vacuum supply level is –30 kPa when the vehicle is stationary and –25 kPa during a dynamic brake application. Typically, the effective runout pressure is 3 000 kPa. Two manoeuvres – one with a runout pressure of 2 500 kPa and one with a runout pressure of 3 500 kPa – are specified with an expected similar occurrence (50 000 each) to cover the deviations in starting pressures for cold start support. These conditions also reflect the vacuum level recovery during the cold-start phase.

Calculation:

a) 50 000 brake operations during cold start occur when the runout pressure is 3 500 kPa, which is equivalent to 0,35 *g*. The probability that cold-start support is needed for these brake operations is 1,04 % because only 16 687 brake operations of the total 1,6 million brake operations while driving are at 0,35 *g* or above (see Table 4). Therefore, the number of cycles of manoeuvre cold start 1 is 1,04 % × 50 000 = 520, rounded up to 600;

b) 50 000 of all brake operations during cold start happen when the runout pressure is 2 500 kPa which is equivalent to 0,25 *g*. The probability that cold-start support is needed for these brake operations is 4,14 % because only 66 297 brake operations of the total 1,6 million brake operations while driving are at 0,25 *g* or above (see Table 4). Therefore, the number of cycles of manoeuvre cold start 2 is 4,14 % × 50 000 = 2 070, rounded up to 2 100;

c) the target pressure in manoeuvre cold start 1 corresponds to the average deceleration of all brake operations with deceleration at 0,35 *g* or above;

d) the target pressure in manoeuvre cold start 2 corresponds to the average deceleration of all brake operations with deceleration at 0,25 *g*;

e) the pressure-build gradient of 3 000 kPa/s corresponds to the empirical rule that drivers typically build up the target brake pressure within one second regardless of the target level;

f) the pressure-release gradient is set to –12 000 kPa/s. This gradient leads to a faster pressure decrease than observed in real-life driving situations.

7.3.2 Hydraulic brake assist (HBA)

7.3.2.1 Description of function

Hydraulic brake assist helps the driver build up brake pressure in emergencies. HBA detects a fast brake pedal application above a threshold and interprets this as an emergency.

7.3.2.2 Manoeuvre description and expected occurrence

Table 30 describes the expected occurrence and manoeuvre parameters for the function HBA.

Table 30 — Overview of manoeuvres for hydraulic brake assist

Manoeuvre	μ	Frequency	p_{MC} [kPa]	Control time [s]	Use case
HBA 1	1,0	340	5 000	2,2	
HBA 2	0,9	50	5 000 to 10 000	1,5	The driver takes over after 0,6s; HBA stops
HBA 3	1,0	50	6 000 to 1 500	3,0	The driver reduces brake request; ABS ends after 1,5 s
HBA 4	1,2	10	8 000	5,0	
HBA 5	1,0	10	13 500	4,0	Fading: brake friction coefficient reduced by 50 %; brake pressure increased to 20 000 kPa
Total		**460**			

NOTE The total control time of the manoeuvres sums up to 0,268 h.

7.3.2.3 Rationale and additional information

Subclause 7.3.2 follows the brake pressure gradient distribution and vehicle velocity distribution, taking into account the maximal (highest possible) sensitive HBA application threshold. It also assumes the HBA function is only available for vehicle velocity above 15 km/h.

NOTE 15 km/h is considered the lowest reasonable threshold for HBA velocity.

HBA brake operations typically lead to ABS brake operations; see Clause 8 for the corresponding substitution methods.

7.3.3 Hydraulic rear-brake boost (HRB)

7.3.3.1 Description of function

Hydraulic rear-brake boost helps the driver to build up brake pressure in the rear brakes in emergencies. The typical use case is that the driver presses the brake (pedal) sufficiently hard to trigger ABS at the front wheels but not sufficiently hard to trigger ABS at the rear wheels. The function interprets this as being due to insufficient brake pedal apply by the driver, hence increasing the brake force in the rear brakes.

7.3.3.2 Manoeuvre description and expected occurrence

Table 31 describes the expected occurrence and manoeuvre parameters for the function HRB.

Table 31 — Overview of manoeuvres for HRB

Manoeuvre	μ	Frequency	p_{MC} [kPa]	p_{brake} [kPa]	Control time [s]	Use case
HRB 1	0,8	200	7 000	10 000	2,0	Wet road
HRB 2	1,0	50	13 500	20 000	4,0	e.g. high load on rear axle
Total		**250**				

NOTE The total control time of the manoeuvres sums up to 0,16 h.

7.3.3.3 Rationale and additional information

Hydraulic rear-brake boost only occurs during ABS brake operations; see Clause 8 for the corresponding substitution methods.

7.3.4 Fading support

7.3.4.1 Description of function

Fading support helps the driver build up braking force in fading situations. Fading can occur due to repeated, hard, or prolonged brake operations, usually at high speeds. This kind of operation heats the brake pads and disc, tending to decrease the brake friction coefficient.

7.3.4.1.1 Manoeuvre description and expected occurrence

Table 32 describes the expected occurrence and manoeuvre parameters for the function fading support.

Table 32 — Overview of manoeuvres for fading support

Manoeuvre	μ	Frequency	p_{MC} [kPa]	p_{brake} [kPa]	Control time [s]	Use case
Fading 1	1,0	60	10 000	16 000	2,0	brake friction coefficient reduced by 30 %
Fading 2	1,0	10	13 500	20 000	4,0	brake friction coefficient reduced by 50 %
Total		**70**				

NOTE The total control time of the manoeuvres sums up to 0,044 h.

7.3.4.2 Rationale and additional information

Typical use cases for fading are a long down-hill drive of a vehicle not using the engine braking capability and with a trailer without brakes of its own or repeated strong braking at high velocity.

Fading support events usually occur in combination with ABS brake operations; see Clause 8 for corresponding substitution methods.

7.3.5 Brake preconditioning

7.3.5.1 Prefill functions

7.3.5.1.1 General

The brake prefill function builds up a low brake pressure (which does not lead to a noticeable deceleration change) to reduce the pressure build-up time in emergencies.

Various sensors can trigger these prefill activations.

In this document, prefill activations triggered by a radar sensor and accelerator pedal is covered. It is not expected that these different activation types influence each other.

7.3.5.1.2 Prefill trigger by environmental sensor

The brake prefill is triggered if environmental sensors detect an object that needs the vehicle to decelerate to avoid a collision.

According to field data, the 95th percentile value corresponds to 6 000 activations.

Note Field data are based on vehicles equipped with radar sensor.

7.3.5.1.3 Prefill trigger by accelerator pedal

If the driver releases the accelerator pedal very fast, this high release gradient can trigger a prefill.

According to field data, the 95th percentile value corresponds to 3 000 activations.

7.3.5.2 Brake disc wiping (BDW)

7.3.5.2.1 Description of function

Brake disc wiping is a function to remove moisture from the brake disc to increase the brake friction coefficient. Typically, the trigger is a rain sensor signal or the activation of the windscreen wiper. The electronic brake system periodically builds up a low pressure to remove moisture pre-emptively for any following braking event.

7.3.5.2.2 Expected occurrence

The frequency of the brake disc wiping activations can be adjusted to the vehicle needs. Feasible adjustments are either by the elapsed time or the driven distance between two activations.

A standard adjustment is, e.g. a brake disc wiping trigger every 180 s (3 min) or every 3 000 m (3 km).

Table 33 and Table 34 shows the expected frequency of brake disc wiping activations over the lifetime for several adjustments.

Table 33 — Brake disc wiping activations (time-related)

Elapsed time between activations [s]	Expected activations
30	83 140
60	33 650
120	10 610
180	4 860
300	1 470
480	400
600	200
720	110

Table 34 — Brake disc wiping activations (distance-related)

Driven distance between activations [m]	Expected activations
500	110 640
1 000	50 100
2 000	20 190
3 000	11 300
5 000	4 900
8 000	1 920
10 000	1 180
12 000	750

NOTE This document does not provide a brake disc wiping manoeuvre pressure profile since it depends on the specific implementation.

7.3.5.2.3 Rationale and additional information

An active brake disc wiping function is assumed during 800 h of driving or 60 000 km of driven distance. Every event pressurizing the brake, either by the driver or any other function (e.g. adaptive cruise control), resets the brake disc wiping trigger and reduces the number of brake disc wiping events over a lifetime. The longer the elapsed time or the longer the driven distance between two brake disc wiping events is adjusted, the more likely brake disc wiping events get skipped by a driver action or an autonomous manoeuvre.

In the combination of adaptive cruise control and brake disc wiping, see Clause 8 for corresponding substitution methods.

NOTE For vehicles using an electric powertrain or an alternator to cover some braking events, it is possible that a brake disc wiping trigger reset due to a driver action or an autonomous manoeuvre is not applicable. For such braking events, the friction brakes are typically not actuated; therefore, moisture is not removed from the brake disc.

7.3.5.2.3.1 Probability for moisture

According to SAE J903, 1,5 million windscreen wiping cycles occur over a vehicle lifetime. Assuming a frequency of 15 to 20 windscreen wiping cycles per minute indicates roughly 1 600 h of windscreen wiping, representing 20 % of the vehicle lifetime in terms of operating time (total 8 000 h). In terms of distance driven, 20 % represents 60 000 km (total 300 000 km).

7.3.5.2.3.2 Reduction of the duration or driven distance with moisture

The brake disc wiping function typically is active only at a vehicle velocity above 50 km/h. The average vehicle spends more than 50 % of its operating time below this velocity, reducing the active BDW function to 800 h over a lifetime. For a distance-triggered brake disc wiping function, the reduction effect is lower. The time spent at higher velocity leads to disproportionately higher distances driven than the time spent at a lower velocity. Therefore, no further reduction applies to the driven distance.

7.3.5.2.3.3 Reduction of the number of events due to braking between BDW events

Frequent braking substitutes brake disc wiping activations by frequently resetting the brake disc wiping trigger. The estimation of this effect relies on 250 000 km worth of historical driving data as shown in Table 35 and Table 36.

Table 35 — Reduction of BDW events due to brake operations (time related)

Driving duration with moisture [h]	Reduction due to vehicle speed [h]	Elapsed time between activations [s]	Potential operations	Reduction due to braking [%]	Remaining activations
1 600	800	30	96 000	13,4	83 140
		60	48 000	29,9	33 650
		120	24 000	55,8	10 610
		180	16 000	69,6	4 860
		300	9 600	84,7	1 470
		480	6 000	93,4	400
		600	4 800	95,8	200
		720	4 000	97,2	110

Table 36 — Reduction of BDW events due to brake operations (distance related)

Driven distance with moisture [km]	Driven distance between activations [m]	Potential operations	Reduction due to braking [%]	Remaining activations
60 000	500	120 000	7,8	110 640
	1 000	60 000	16,5	50 100
	2 000	30 000	32,7	20 190
	3 000	20 000	43,5	11 300
	5 000	12 000	59,2	4 900
	8 000	7 500	74,4	1 920
	10 000	6 000	80,4	1 180
	12 000	5 000	85,0	750

7.4 Assistance functions

7.4.1 Standstill management

7.4.1.1 Hill start assist

7.4.1.1.1 Purpose and description of the function

Hill start assist maintains the driver's brake pressure demand and allows the driver to release the brake pedal after achieving a standstill.

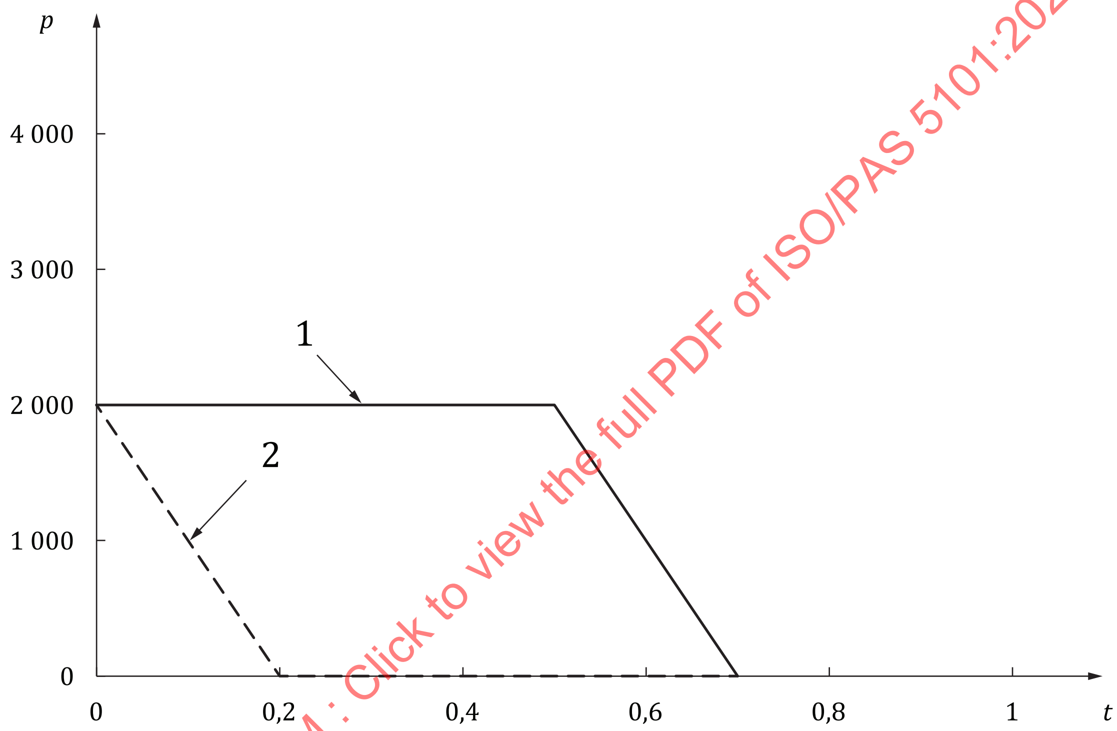
The function starts when the driver releases the brake pedal and typically ends with the accelerator pedal's actuation by the driver or after a defined duration, e.g. 2 s.

Hill start assist is only activated in case of a standstill at certain uphill slope levels according to the manufacturer's specification.

7.4.1.1.2 Manoeuvre description and expected occurrence

The manoeuvres for standstill described in Figures 21 – 23 and Tables 37 – 39 are applied for hill start assist and hold (see 7.4.1.2) and represent expected use cases of these functions.

NOTE The pressure build-up is not part of the described manoeuvres.



Key

p brake pressure [kPa]

t elapsed time [s]

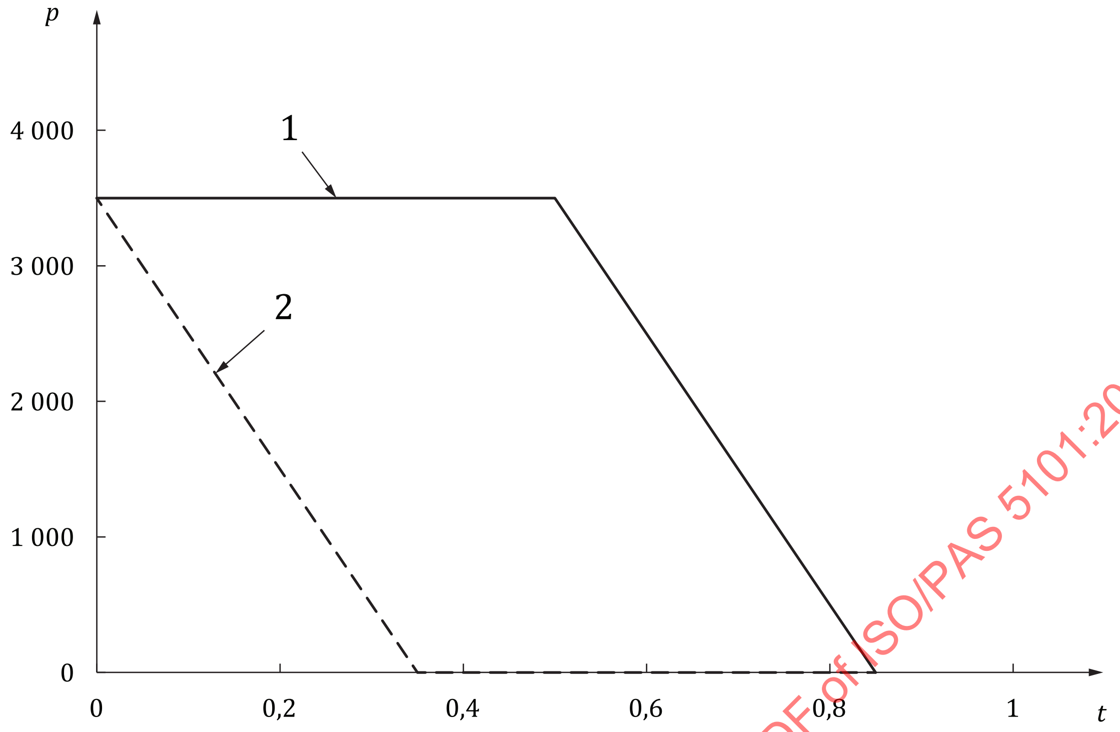
1 brake pressure

2 master cylinder pressure

Figure 21 — Standstill 1

Table 37 — Pressures for manoeuvre standstill 1

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]	Brake pressure gradient [kPa/s]
0,00	2 000	2 000	0
0,20	0	2 000	0
0,50	0	2 000	0
0,70	0	0	– 10 000



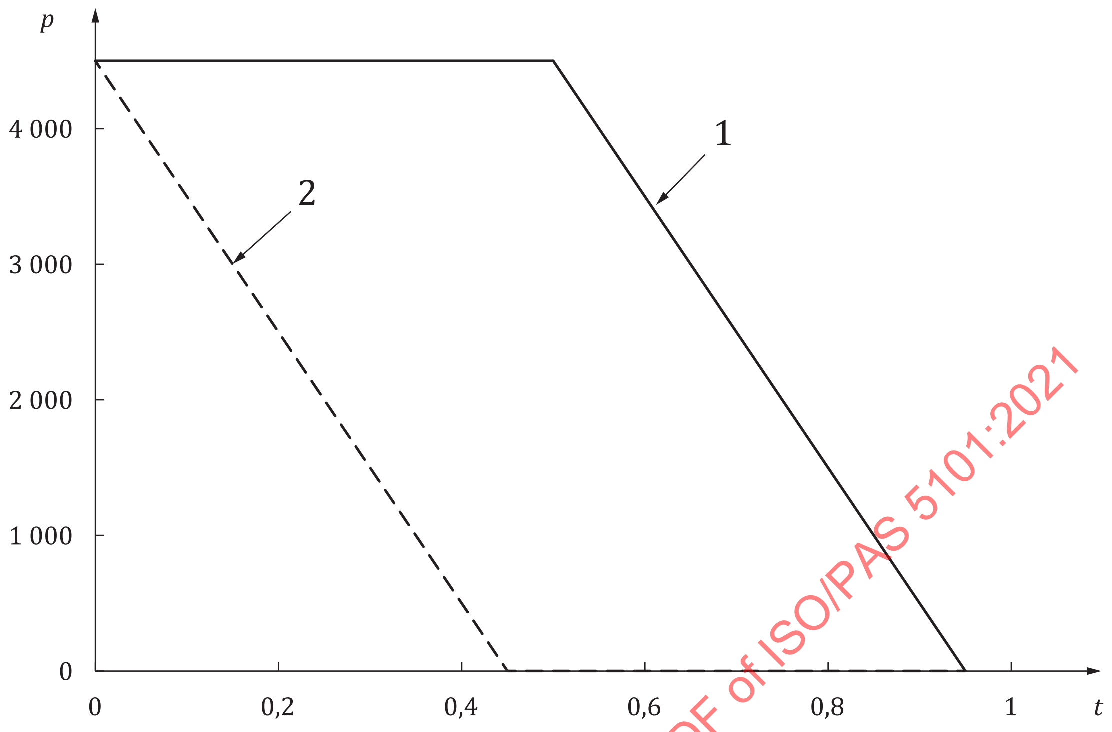
Key

p brake pressure [kPa]
t elapsed time [s]
1 brake pressure
2 master cylinder pressure

Figure 22 — Standstill 2

Table 38 — Pressures for manoeuvre standstill 2

Time [s]	p_{MC} [kPa]	Brake pressure [kPa]	Brake pressure gradient [kPa/s]
0,00	3 500	3 500	0
0,35	0	3 500	0
0,50	0	3 500	0
0,85	0	0	– 10 000



Key

p brake pressure [kPa]
t elapsed time [s]
1 brake pressure
2 master cylinder pressure

Figure 23 — Standstill 3

Table 39 — Pressures for manoeuvre standstill 3

Time [s]	**p_{MC} [kPa]**	**Brake pressure [kPa]**	**Brake pressure gradient [kPa/s]**
0,00	4 500	4 500	0
0,45	0	4 500	0
0,50	0	4 500	0
0,95	0	0	– 10 000

Table 40 describes the expected occurrence of these manoeuvres.

Table 40 — Overview of manoeuvre occurrence for hill start assist

Manoeuvre	**Frequency**	**p_{brake} [kPa]**	**Control time [s]**	**Slope [%]**
Standstill 1	211 200	2 000	0,70	≤ 5
Standstill 2	26 400	3 500	0,85	5 < slope ≤ 15
Standstill 3	2 400	4 500	0,95	> 15
Total	**240 000**			

7.4.1.1.3 Rationale and additional information

The number of standstill events over a lifetime is 480 000 (per 6.2.3). As hill start assist is only used to end an uphill standstill event, it is cut in half to 240 000.

The pressure required to maintain the standstill vehicle depends on the slope (see Table 1 for the distribution of standstill events at different slope angles). The maximum pressure levels needed in the three slope ranges indicated in Table 40 are 2 000 kPa, 3 500 kPa and 4 500 kPa. These pressure levels contain safety margins to account for slope measurement error changes, changes of load distribution during the stop or dynamics of vehicle and trailer combinations among others.

The manufacturer shall verify the adequacy of the given manoeuvres for the braking system. In case the manoeuvres are not appropriate, the base assumptions, according to Clause 6, should be applied.

7.4.1.2 Hold

7.4.1.2.1 Description of function

Hold allows the driver to release the brake pedal after standstill and maintains the driver's built-up brake pressure. The function starts when the driver releases the brake pedal and typically ends with the accelerator pedal's actuation.

The function can be activated independently from an uphill or downhill slope and thus, from the hill start assist function described in 7.4.1.1.

7.4.1.2.2 Manoeuvre description and expected occurrence

The manoeuvres are described in Figures 21 – 23 and represent expected use cases of the function.

NOTE The pressure build-up is not part of the described manoeuvres.

Table 41 describes the expected occurrence of these manoeuvres.

Table 41 — Overview of manoeuvre occurrence for hold

Manoeuvre	Frequency	p_{brake} [kPa]	Control time [s]	Slope [%]
Standstill 1	316 800	2 000	0,70	≤ 5
Standstill 2	39 600	3 500	0,85	5 < slope ≤ 15
Standstill 3	3 600	4 500	0,95	> 15
Total	**360 000**			

7.4.1.2.3 Rationale and additional information

The standstill duration in the described manoeuvres is shorter than the standstill duration as given in Clause 6. The expectation is that the reduced duration of the manoeuvre is sufficient. The hill start assist function's duration has negligible effects on the braking system's hydraulic unit's lifetime load.

Due to internal leakage, the pressure in the hydraulic system may drop during hold. The pressure drop may be compensated with different strategies to avoid unintended vehicle roll-off. Hence, this compensation's frequency depends on various parameters; an absolute amount of compensation manoeuvres cannot be provided in this document. The parameters are:

— excess pressure applied by the driver (pressure reserve before vehicles starts rolling) at the start of the hold function;

— internal leak rate (depends on the hardware and the brake fluid’s viscosity);

— detection possibilities of the pressure drop (pressure sensor available or only roll off detection);

— pressure control strategy during hold and;

— maximum hold time of the hold function.

7.4.2 Hill descent control

7.4.2.1 Description of function

Hill descent control is a cruise control functionality for downhill driving at low speeds, typically designed for off-road conditions. HDC enables the driver to perform slow, controlled descents on steep inclines by reducing the vehicle speed with the active braking actuator(s).

Typically, the hill descent function can be activated or deactivated by pressing a button on the dashboard. If necessary, the driver can vary the target speed, which has a default value of 10 km/h, by applying the brake pedal, accelerator pedal, or the adaptive cruise control buttons.

This document considers regular passenger cars, light commercial vehicle and sport utility vehicles.

7.4.2.2 Manoeuvres and expected occurrence

Table 42 describes the expected frequency over lifetime and manoeuvre parameters for the hill descent control function. The manoeuvre consists of four pressure modulations (initiation, first slope adaption, second slope adaption and the switch off).

Table 42 — Overview of manoeuvres for hill descent control

Manoeuvre	μ	Frequency	p_{MC} [kPa]	Slope [%]	Control time [s]	Use case
HDC 1	1,0	200	0	10–15	7,0	Speed control v_{target} 10 [km/h]
HDC 2	1,0	100	0	15–30	7,0	Speed control v_{target} 10 [km/h]
Total		**300**				

NOTE The total control time of the manoeuvres sums up to 0,58 h.

Table 43 and Table 44 show the patterns of downhill slopes for the manoeuvres HDC 1 and HDC 2.

Table 43 — HDC 1: Pattern of downhill slope

Time [s]	Slope [%]
0 - 2,33	10
2,33 - 4,66	15
4,66 - 7,0	10

Table 44 — HDC 2: Pattern of downhill slope

Time [s]	Slope [%]
0 - 2,33	15
2,33 - 4,66	30
4,66 - 7,0	15

7.4.2.3 Rationale and additional information

If the wheel slip becomes excessive during a hill descent control intervention, the ABS controller activates automatically. If the wheels are on different ground surfaces or any wheel loses contact with the ground, the brake torque is redistributed to the wheels with a higher coefficient of adhesion. Regarding the activation frequency, the anticipated total control time for the hill descent control function constitutes significantly less than 1 % of the aggregate control time of ABS-related functions. The manoeuvres cover a range of slopes, from 10 % to 30 %. The probability of slopes above 30 % is also significantly less than 1 %.

The impact of the vehicle speed to the pressure control is negligible.

7.4.3 Adaptive cruise control (ACC)

7.4.3.1 Description of function

The function adaptive cruise control actuates the braking system to adjust the distance to vehicles in front.

Typically, ACC is active at velocities at or above 30 km/h. An extended variant of ACC (ACC stop-and-go) can also operate at velocities below 30 km/h and can decelerate down to a standstill.

There are two additional functionalities for standstill situations caused by ACC stop-and-go: "soft stop" and "hold". "soft stop" reduces vehicle pitching before stopping. "hold" prevents the vehicle from moving unintentionally after the vehicle has come to a standstill.

7.4.3.2 Manoeuvres and expected occurrence

Figures 24, 25 and 27 and Tables 45, 46 and 48 describe the manoeuvres for ACC. For ACC stop-and-go (including the functionalities "soft stop" and "hold"), the manoeuvre described in Figure 26 and Table 47 also applies.