



BSI Standards Publication

Railway applications - Braking - Brake performance

National foreword

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European foreword

This document (EN 16834:2019) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2019, and conflicting national standards shall be withdrawn at the latest by October 2019.

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

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive 2008/57/EC.

For relationship with EU Directive 2008/57/EC, see informative Annex ZA, which is an integral part of this document.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This document defines a harmonized way to assess the braking performance by test of locomotives, passenger coaches, freight wagons and self-propelled passenger trains (EMU/DMU).

The document sets out the standardized method for undertaking brake performance tests and the correction factors to be applied to the data obtained for all types of rolling stock.

This document also defines the methods to assess the brake performance in terms of stopping distance, and from this the process to determine vehicle(s) deceleration and braked weight.

It then deals with conversion of the braked weight to the braked weight percentage of a vehicle or train for operating purposes. It also sets out additional factors when determining the braked weight percentage of a train calculated from specified braked weight, depending on the formation of the train.

In Annex D there is a method for determining brake performance of freight wagons fitted with P10 cast iron or LL-blocks using limited testing (force measurement).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

EN 14198, *Railway applications — Braking — Requirements for the brake system of trains hauled by locomotives*

EN 14478, *Railway applications — Braking — Generic vocabulary*

EN 14531-1, *Railway applications — Methods for calculation of stopping and slowing distances and immobilization braking — Part 1: General algorithms utilizing mean value calculation for train sets or single vehicles*

EN 14531-2:2015, *Railway applications — Methods for calculation of stopping and slowing distances and immobilization braking — Part 2: Step by step calculations for train sets or single vehicles*

EN 15355, *Railway applications — Braking — Distributor valves and distributor-isolating devices*

EN 15595, *Railway applications — Braking — Wheel slide protection*

EN 15663, *Railway applications — Vehicle reference masses*

EN 15877-1, *Railway applications — Marking on railway vehicles — Part 1: Freight wagons*

EN 15877-2, *Railway applications — Markings of railway vehicles — Part 2: External markings on coaches, motive power units, locomotives and on track machines*

EN 16207, *Railway applications — Braking — Functional and performance criteria of Magnetic Track Brake systems for use in railway rolling stock*

EN 16452, *Railway applications — Braking — Brake blocks*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 14478, EN 14198 and the following apply.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

brake assessment speed

brake initiation speed which is decisive for determination of brake performance

Note 1 to entry: In general the initiation speed leading to the lowest braked weight.

3.2

braked weight

representative quantity for the mean braking capacity of the vehicle or train, expressed in tons, which is always expressed as a whole number

Note 1 to entry: It is displayed on the vehicle (in accordance with EN 15877-1 and EN 15877-2). Braked weight corresponds to the retardation effort and is currently expressed and designated as “B”.

3.3

braked weight percentage

quotient of braked weight and vehicle mass $\times 100$

Note 1 to entry: Also known as λ (lambda).

3.4

maximum braking load

load condition lower or equal to “design mass under exceptional payload” as defined in EN 15663 in accordance with the related vehicle standard (e.g. EN 16185-1, EN 14198)

3.5

minimum load

load condition “design mass in working order” (as defined in EN 15663)

3.6

normal load

load condition “design mass under normal payload” (as defined in EN 15663)

3.7

fully certified and exchangeable LL-block

LL-block, which fulfils all UIC requirements including exchangeability with P10 (as listed in ERA document ERA/TD/2009-02/INT)

3.8

K-block

brake block with “K”-friction materials as defined in EN 16452

3.9

EN-UIC brake

brake system as defined in EN 14198

4 Symbols and abbreviations

For the purposes of this document, the following symbols and abbreviations in Table 1 apply.

Table 1 — Symbols and abbreviations

Symbol	Description	Unit
a	deceleration	m/s ²
B	braked weight	t
C	constant for calculating the λ values	—
D	constant for calculating the λ values	—
d	diameter	mm
F	force	kN
g	acceleration due to gravity	9,81 m/s ²
i	gradient	‰
k	assessment factor for determining the braked weight	—
m	mass of the test train or test vehicle	t
r	radius	mm
s	total stopping distance (up to $v = 0$)	m
t	time	s
v	speed	km/h
λ	braked weight percentage	%
ρ	coefficient of inertia of rotating masses	—
σ_n	standard deviation of test result	m
τ	adhesion	—
μ	coefficient of friction	—
η	efficiency of brake rigging	—
ATP	Automatic Train Protection	
Bg	brake block type Bg (single block)	
Bgu	brake block type Bgu (double brake block)	
DMU	Diesel Multiple Unit	
ep-brake	electropneumatic brake	
EMU	Electric Multiple Unit	
ETCS	European Train Control System	

Symbol	Description	Unit
G	brake mode of the slow-acting brake (freight train)	
K	brake block material in accordance with EN 16452	
L	brake block material in accordance with EN 16452	
LL	brake block material in accordance with EN 16452	
Mg	magnetic track brake	
P	brake position of quick-acting brake (passenger train)	
P+E	brake position P + electrodynamic brake	
P+H	brake position P + hydrodynamic brake	
P+Mg	brake position P + magnetic track brake	
P10	material designation of the cast-iron block with a 1 % phosphorus content	
◊ _R	brake position in accordance with EN 14198	
R	brake position in accordance with EN 14198	
R+E	brake position R + electrodynamic brake	
R+H	brake position R + hydrodynamic brake	
R+Mg	brake position R + magnetic track brake	
S	train related brake performance category in accordance with EN 14198	
SS	train related brake performance category in accordance with EN 14198	
Sbb	brake accelerator	
Wb	eddy current brake	

5 Principles of determining the brake performance

5.1 General

The object of defining the brake performance of railway brakes is to characterize the braking capabilities of railway vehicles.

To determine the brake performance three methods of brake assessment can be used: stopping distance, braked weights, and deceleration. All three will determine the brake performance.

From vehicle testing, braked weight is derived from stopping distance. For freight wagons (fitted with cast iron blocks or fully certified and exchangeable LL-blocks) the braked weight may be calculated as set out in Annex D, if applicable.

Brake performance assessment is defined based on a number of standardized conditions (e.g. level track, dry rail and mean in-service vehicle condition). Brake assessment thus does not assume the worst possible vehicle condition, which can be the result of e.g. braking force tolerances, friction coefficient scatter, downgraded efficiency, or the failure of brake system components etc.

These brake performances do not contain safety margins.

For vehicle having different brake positions as described in EN 14198, there shall be an assessment for each brake position.

The brake performance marked on vehicles (EN 15877-1 and EN 15877-2) shall be derived from the performance determined by tests and/or calculation according to this document.

Links between calculation of brake performance and test are given in Table 2.

Table 2 — Links between calculation of brake performance and test

Vehicle type	Calculation	Brake performance	Validation by test
All vehicles excluding freight wagons	EN 14531-1 and/or EN 14531-2	Decelerations + response time / stopping distance ↑ ↓ Braked weights	mandatory
freight wagons	EN 14531-1 and/or EN 14531-2 or Annex D, if applicable (cast iron / certified LL-blocks)	Stopping distance ↑ ↓ Braked weights	mandatory (with exception of freight wagons, where the requirements of Annex D are met)

5.2 Brake assessment with braked weights

This method originated after the introduction of the compressed air brake. For this purpose a huge number of test runs on level track had been performed with a given passenger train with 60 wheelsets, defined brake equipment and given mass from various initial speeds.

The brake performance of this train has been ever since equivalent to $\lambda = 100\%$ and serves as reference standard deceleration so that per definition the braked weight is equivalent to the mass of the train. The results of further tests with different brake settings set up brake assessment charts providing the relations:

$$\lambda = f(v, s) \quad (1)$$

where

s stopping distance, expressed in m;

v initial speed, expressed in km/h;

λ brake weight percentage, expressed in %.

The reference train was equipped with block brakes with low-phosphorus cast-iron blocks.

A **brake assessment diagram** is used as a basis of reference for determining the brake performance of new vehicles using the passenger brake mode.

The assessment diagrams (see Figure A.1 and B.1) are applicable for an initial braking speed of up to 200 km/h.

The braked weight is expressed in tons. The quotient obtained from the sum of all the braked weights and the mass of the train multiplied by 100 gives the braked weight percentage λ of the train and relates to the stopping distance in the event of an emergency brake application.

The braked weights assigned to the individual vehicles or vehicle segments are normally to be marked on the outside of the vehicles in accordance with EN 15877-1 and EN 15877-2 when they are obtained from brake application by brake pipe only. Braked weights shall be indicated in whole numbers of tons,

with values $< 0,5$ to be rounded down and values $\geq 0,5$ to be rounded up. If the results come from tests on a train, the figures are initially rounded up or down for the smallest unit (wagon) on which a braked weight is indicated.

5.3 Brake assessment with deceleration's method

The brake performance of trains can be expressed by decelerations. This method may be applied for all speed ranges. For speeds over 200 km/h, it is mandatory.

The real train deceleration profile is approximated by a function with equivalent brake response time and one or more speed intervals of constant decelerations.

The deceleration method set out in this document is intended to describe the train deceleration in a simplified set of values and not by the individual braking functions.

6 Execution of tests

6.1 Test methods

6.1.1 General

The tests shall be performed by a competent authority.

NOTE As an example, a test institute in accordance with EN ISO/IEC 17025.

Train testing is the original method, which gives more accurate results and is always applicable. In the following cases, the train test can be replaced by single vehicle test, which leads to more restrictive results:

- for coaches with maximum speed ≤ 160 km/h;
- for coaches with only one stage of braking effort and maximum speed up to 200 km/h (special evaluations rules: see braked weight assessment 8.3);
- for freight wagons;
- for locomotives;
- for single EMU/DMUs (as defined in EN 16185-2).

6.1.2 Freight wagons and coaches

If the braked weight of freight wagons/coaches is determined by testing with a train, the following special conditions apply:

- coaches: For the purpose of the tests a 400 m long hauled train should be used comprising identical coaches with the same brake equipment;
- freight wagons: For the purpose of the tests a 500 m long hauled train should be used comprising identical freight wagons with the same brake equipment;
- in both cases the locomotive brake shall be isolated and all brake pipe accelerators and the EP assist shall be deactivated.

6.1.3 Locomotives

When determining the braked weight of the locomotive in position G, tests from 100 km/h in position P shall be undertaken with the locomotive operating on its own. For all other brake positions, the testing shall be done as set out in 6.3.

Locomotives with multiple brake control architecture shall be tested in all operating modes (e.g.: UIC brake pipe, direct ep-brake, rescue- or towing-mode, etc.).

6.1.4 EMU/DMU and high speed trainsets

The brake performance of a multiple unit is determined by dynamic tests for all existing brake positions with all brakes active. To determine the brake performance in degraded modes dynamic tests shall be performed for all relevant cases (e.g. isolated parts of air brake, ep assist, dynamic brake, magnetic track brake).

For trainsets which can be coupled together to operate in multiple units, the tests shall be conducted in the most unfavourable train configuration (considering the equivalent brake response time in Annex E) determined by the static test (i.e. generally the longest planned formation).

EMU/DMU and highspeed trainsets with multiple brake control architecture shall be tested in all operating modes (e.g.: UIC brake pipe, direct ep-brake, rescue- or towing-mode, etc.).

6.1.5 Testing of vehicles/trains with additional brake equipment

Typically additional brake equipments for service and/or emergency brake applications include: dynamic brake, eddy current brake, EP assist, magnetic track brake, brake pipe accelerators.

The testing defined in 6.1.4 shall be undertaken with all brake equipment operational.

If additional brake equipment is used in emergency brake or service brake, additional testing should be performed to determine brake performance with this equipment isolated.

If more than one additional equipment is fitted, there should be further testing to determine the contribution of each equipment.

6.2 Load conditions for tests

6.2.1 Freight wagons

For freight wagons with empty/load devices, slip tests shall be conducted:

- with minimum load (empty freight wagons), in the “empty” position;
- in the “empty” position with a load at the changeover mass. When an automatic “empty-loaded” changeover device is being used, the tests shall be carried out in the “empty” position with a load close to the changeover mass, but far enough below it to ensure that the automatic changeover device remains stable in the “empty” position;
- with normal load in the “loaded” position (EN 15663: Design mass under normal payload).

For freight wagons with self-adjusting load-proportional braking, the slip tests shall be conducted:

- with minimum load (empty freight wagons);
- in the lowest load status under which the maximum braked weight is achieved;
- at the condition at which the maximum energy is dissipated (combination of speed and load).

For S and SS freight wagons, as defined in EN 14198, the load definition leads to Table 3.

Table 3 — Load conditions for slip tests with S and SS freight wagons

Vehicle mass	Freight wagon for S-regime with empty-loaded changeover device (S1 in EN 14198)	Freight wagon for S-regime with self-adjusting load-proportional (S2 in EN 14198)	Freight wagon for SS-regime
Minimum load	x	x	x
Changeover mass	x		
14,5 t / wheelset		x	
18 t / wheelset			x
20 t / wheelset			x
22,5 t / wheelset	x	x	
x mandatory tests			
NOTE The values of the vehicle weight are typical values for UIC S-Regime or SS-Regime for tread-braked wheels.			

6.2.2 Locomotives

For locomotives only minimum load shall be tested.

6.2.3 Passenger vehicles

Load condition for passenger vehicles is specified in Table 4.

Table 4 — Load condition for testing

Vehicle type	Load status		
	Minimum load	Normal load	Maximum braking load
Coach, passenger trains, multiple unit and high speed train without load-proportional braking	X	X	(x) ^a
Coach, passenger trains, multiple unit and high speed train with load-proportional braking	X	X	x ^a
(x) Recommendation			
X Requirement			
^a If difference between normal load and maximum braking load is more than 10 % of the normal load.			

In cases where loading is not possible, alternative methods are permitted, such as simulation by isolating other brake units, as long as this introduces no significant errors into the procedure. In particular, it shall

be observed on vehicles with self-adjusting load-proportional braking that the correct brake cylinder pressures (corresponding to the load) are simulated.

Simulation is performed as follows:

The number of isolated brakes is determined such that the ratio of:

$$\frac{\sum \text{the active brake forces}}{\sum \text{the installed braked forces}} = \frac{\text{Dynamic mass of test train}}{\text{Dynamic mass of laden train}} \quad (2)$$

is generally complied with.

The simulation is only allowed for long trains (400 m excluding the locomotive) not for single vehicles, EMU/DMU and high speed train.

6.3 Speeds to be used for testing

The speed criteria specified in Table 5 shall be used for all types of brake applications to a stop, i.e. for the emergency applications for brake assessment as well as for (e.g.) service brake applications or degraded mode tests.

Combinations of speed and brake position, which are not applicable for operation, are not mandatory for testing.

Table 5 — Brake position test

TEST SPEED km/h	Emergency brake						Service brake (not necessary for braked weight assessment)
	P	P+E P+H	R	R+E R+H	R+Mg P+E+Mg	R+Wb P+E+Wb	
30	C, D, E	D, E	C, D, E	D, E	—	—	D, E
100	A, B, C, D, E	D, E	A, C, D, E	D, E	—	—	D, E
120	A, B, C, D, E	D, E	A, C, D, E	D, E	—	—	D, E
140	A, B, C, D, E	D, E	A, C, D, E	D, E	A, C, E	C, E	D, E
160	A, B, C, D, E	D, E	A, C, D, E	D, E	A, C, E	C, E	D, E
200	C, D, E	D, E	C, D, E	D, E	C, E	C, E	D, E
Maximum speed (<160) ^a	A, B, C, D, E	D, E	A, C, D, E	D, E	C, E	C, E	D, E
Maximum speed (>160) ^{a b}	B, C, D, E	D, E	C, D, E	D, E	C, E	C, E	D, E
A = single vehicle – coach or wagon B = freight train C = passenger train D = loco E = EMU/DMU and High speed train sets Freight vehicles/trains which have R brake position shall be assessed as passenger vehicles/trains.							
^a Test shall be also performed from maximum speed if not included in the Table. ^b For speed > 250 km/h, other speeds in steps not greater than 40 km/h from 200 km/h to maximum design speed shall be tested.							

6.4 Method of execution of the test

6.4.1 General

The test train or test vehicle shall be accelerated up to the speed for the intended brake application. At this speed, the traction is switched off and after that an emergency brake application is initiated on level and straight track. If there are different possibilities to initiate an emergency braking (e.g. by driver brake valve, push-button, ATP valves...) the possibility leading to the longest response time shall be chosen for tests used for brake performance assessment. The choice shall be validated by suitable tests.

For single vehicle testing the method of slip test applies. The vehicle shall be uncoupled after reaching the test speed and the emergency brake shall be applied at the same time or short time after uncoupling.

In every test the stopping distance is measured from the point at which the emergency brake application was initiated (e.g. leaving running position of brake controller or emergency button depressed) until the standstill.

The measured stopping distance includes the distance covered during the delay time and the build-up time of brake equipment.

This test method can similarly be applied for other than emergency brake applications (e.g. maximum service braking).

6.4.2 Atmospheric conditions

In order to prevent adverse atmospheric conditions from affecting the results the tests should be carried out with minimum wind and dry rails.

No test in flying snow conditions is allowed.

6.4.3 Condition of brake equipment

6.4.3.1 Wheels

For block-braked vehicles with new or reprofiled wheels, these should have been run in for at least 1 200 km.

6.4.3.2 Friction components

Before the start of the tests the friction components (brake pads/blocks) shall be bedded-in to give at least 85 % contact pattern. If the tests include brake applications in wet conditions, the leading edge of the pad/block shall be bedded-in in the direction of rotation. The bedding-in status shall be documented by means of photos of a useful selection of friction elements.

After the successful bedding-in of the brake pads the brake disc roughness is considered to be appropriate for the subsequent assessment tests.

Bedding-in may take place in service or via specific bedding-in brake applications. In the latter case, the temperature of the friction elements shall be monitored regularly in order to avoid thermal overload. The manufacturer's maximum regular temperature limits for each part of the friction pair shall not be exceeded. Between bedding-in applications, the temperature of brake disc or wheel should be allowed to cool to below 100 °C.

6.4.3.3 Magnetic track brakes

Magnetic track brakes shall be bedded-in on the rail head until a contact pattern of 60 % is achieved and prior to the assessment tests the contact surface of the magnetic track brake shall be conditioned as set out in EN 16207.

6.4.4 Number and validity of individual tests

At least four valid tests shall be carried out from which the mean value shall then be calculated. The determination of the mean value, including statistical criteria, is described in 6.7.2.

- a) The starting temperature of the wheels/brake discs shall be measured on at least four of the wheels/discs subject to the theoretically greatest load. This average temperature should be below 60 °C across the measurement points. The starting temperature shall not exceed 100 °C on any measuring point.
- b) The mean gradient over the stopping distance shall be $|i| < 3 \text{ ‰}$; the maximum gradient on the test section shall not exceed $\pm 5 \text{ ‰}$, except in cases where the routes operated by a train meet this condition in no part. The deviation from the above provision shall be documented in the test report.
- c) Tests on curve radii $< 1\,000 \text{ m}$ are not permitted.
- d) Deviation of the brake initiation speed from the target speed shall be $|v_{j,\text{meas}} - v_{j,\text{nom}}| \leq 4 \text{ km/h}$. Where the nominal initial speed is higher or equal than 200 km/h, the deviation may increase to 6 km/h. Where the nominal initial speed is lower or equal than 30 km/h, the deviation shall not exceed 2 km/h.

e) No Wheel slide protection intervention shall be allowed during dry rail testing.

In the case that any of these testing conditions for brake assessment cannot be fulfilled due to infrastructure restrictions the following measures are required for the individual unit to be assessed:

- determine the influence of those deviations;
- define a procedure for the correction of the test results;
- validate the correction procedure.

As an example the treatment of curve radii lower than 1 000 m is given in Annex J.

6.5 Test in degraded mode and degraded conditions

If applicable standards for vehicle testing do not make provision for degraded mode and degraded conditions, the following procedure is recommended to cover the degraded mode (failure) and the influence of moisture on wheel/rail adhesion. The influence of moisture on the friction coefficient of mechanical brakes is covered by the assessment method described in 7.4.1 and requires no additional dynamic tests.

a) degraded mode simulated by isolation of brakes:

- 1) one independent dynamic brake or eddy current or magnetic track brake unit to be isolated, if these depend on the current supply, all units shall be isolated;
- 2) one local brake control unit (e.g. distributor) isolated.

b) degraded conditions by:

- 1) wetting of the rail to generate low adhesion as set out in EN 15595.

6.6 Determination of brake performance for the ETCS system

To determine brake performance for ETCS, the tests defined shall be conducted.

The number of deceleration stages defined shall not exceed seven. This determination shall be undertaken before safety margins are applied, observing the following nominal conditions:

- track condition (wheel/rail contact): The nominal deceleration during emergency brake application shall take place on dry rails;
- wetness of friction components: The nominal deceleration during emergency brake application shall take place with dry friction components;
- line gradients: Line tests to determine nominal deceleration during emergency brake application shall be conducted on straight level track. Criteria of 6.4.4 apply. The deceleration shall be corrected in relation to the gradient;
- load – for passenger trains without self-adjusting load-proportional braking: The nominal deceleration during emergency brake application applies to vehicles in normal load;
- load – for passenger trains with self-adjusting load-proportional braking: For vehicles with self-adjusting load-proportional braking, the nominal deceleration during emergency brake application shall be the lowest deceleration for all loading conditions (from minimum load up to maximum braking load) and, if the lowest deceleration is achieved at various loading conditions shall be, then the highest load shall be considered the nominal load condition;

- normal / degraded mode: All foreseen braking systems in emergency brake application, initiated by ETCS, shall be used for testing. A reliability and/or availability study shall give input to additional test cases in degraded mode.
- wheel diameter: The nominal deceleration is based on the new wheel diameter;
- brake development time: The nominal brake development time is the equivalent brake response time, potentially including assistance from the electro-pneumatic brake, the pneumatic brake accelerator or an equivalent system (the used shall be based on a reliability and/or availability study).

6.7 Evaluating the test results for stopping distance

6.7.1 Correcting the stopping distances for each test

The stopping distance obtained in test shall be corrected in order to take into account the following factors:

- nominal speed in relation to the initial speed measured in the test;
- gradient of the test track.

The correction shall be made using Formula (3):

$$\frac{v_{j,nom}^2}{2 \times 3,6^2 \times s_{j,corr}} = \frac{v_{j,meas}^2}{2 \times 3,6^2 \times s_{j,meas}} - \frac{g}{\rho} \times \frac{i_m}{1000} \quad (3)$$

Conversion gives Formula (4):

$$s_{j,corr} = \frac{3,933 \times \rho \times v_{j,nom}^2}{3,933 \times \rho \times v_{j,meas}^2 - i'_m \times s_{j,meas}} \times s_{j,meas} \quad (4)$$

with

$$i'_m = i_m + W_{Bo} \quad (5)$$

where

$s_{j,corr}$	corrected stopping distance which corresponds to the nominal speed in the test, expressed in m;
$s_{j,meas}$	stopping distance measured in test, expressed in m;
$v_{j,nom}$	nominal initial speed in test, expressed in km/h;
$v_{j,meas}$	initial speed measured in test, expressed in km/h;
i_m	mean gradient over s on the test track, with the plus sign for rising gradients and the minus sign for falling gradients, expressed in ‰. For tests on trains, the gradient shall be determined with reference to the train's centre of gravity;
W_{Bo}	mean curve resistance over $s_{j,meas}$ of test track. For tests in curves of between 1 000 m and 5 000 m radius, the mean curve resistance shall be calculated using $W_{Bo} = 650/(r - 55)$ N/kN. Above 5 000 m radius, the curve resistance is negligible;

ρ coefficient of inertia of the rotating masses, which is defined in Formula (6);
 g acceleration due to gravity.

$$\rho = 1 + \frac{m_r}{m} \quad (6)$$

where

m mass of the train or test vehicle;
 m_r equivalent mass of the rotating components.

Where no exact value is available then $\rho = 1,15$ for locomotives and $\rho = 1,04$ for coaches shall be used.

6.7.2 Determining the mean stopping distance

Four or more valid tests shall be conducted in order to determine the mean value. Prior to this, all stopping distances shall be corrected in accordance with the method described in 6.7.1.

For tests with nominal initial speed higher than 30 km/h and used to determine brake performance in the sense of the present standard, the test results shall meet the requirements described hereafter.

The mean value shall be considered valid only, if the criteria of Formulae (7) and (8) are simultaneously met:

Criterion K1:

$$\frac{\text{standard deviation of test results } (\sigma_n)}{\text{mean value of test results } (\bar{s})} \leq 3,0 \% \quad (7)$$

and

Criterion K2:

$$\left| \text{extreme value } (s_e) - \text{mean value } \bar{s} \right| \leq 1,95 \times \sigma_n \quad (8)$$

with

$$\sigma_n = \sqrt{\frac{\sum |s_{j,\text{corr}} - \bar{s}|^2}{n}} \quad (9)$$

where

$s_{j,\text{corr}}$ stopping distance measured during test “j” and corrected from Formula (4), expressed in m;
 $\bar{s}$ mean stopping distance, expressed in m;
 n number of valid tests;
 σ_n standard deviation of test results;
 s_e individual stopping distance furthest from mean value.

If after the fourth test one of the two criteria is not met, an additional test shall be conducted and the criteria used again.

If criterion K2 is not met when the number of valid tests ≥ 5 , the extreme value s_e shall be discarded and the criteria reviewed again.

If, however, only K1 is not met or both criteria are not met after the extreme value is discarded, a further additional test shall be conducted.

The procedure shall be applied until K1 and K2 are met or a total of 10 tests have been performed (valid and invalid tests are counted).

The number of valid tests shall be at least 70 % of the number of all the tests performed, bearing in mind that discarded tests due to external factors (wrong test conditions 6.4.4) are not to be counted as part of the overall number of tests performed.

If after a total of 10 tests both criteria are not met, the test series shall be halted and the brake system and test conditions verified. Interruption of the tests shall be noted in the test report.

The flow chart, see Figure 1, given hereafter demonstrates the correct procedure.

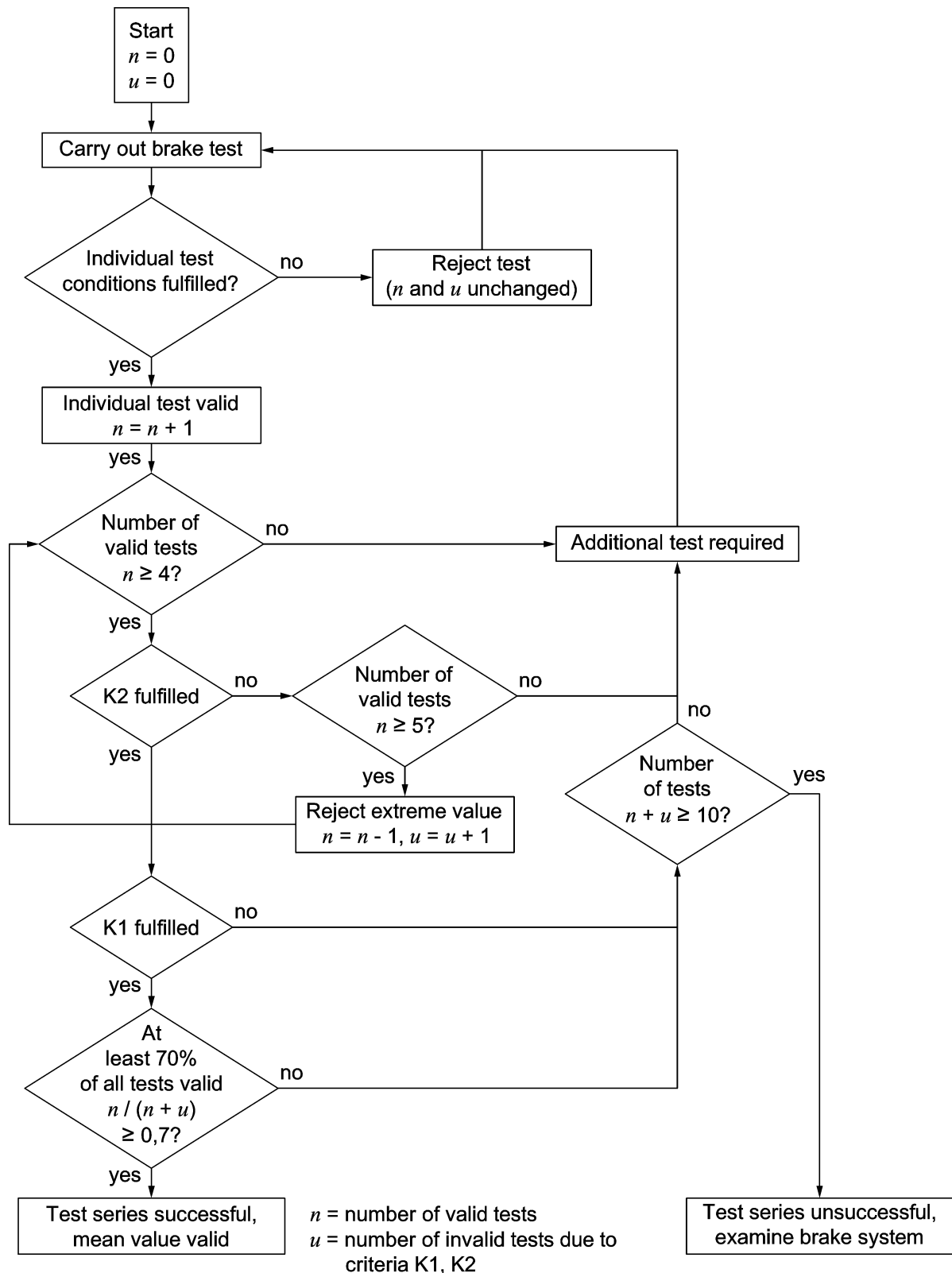


Figure 1

6.7.3 Correction of the mean stopping distance

6.7.3.1 Basic principle

The mean stopping distance $\bar{s}$ is determined as refers to the vehicle in its current condition. To determine brake performance, this result relating to the present condition of the vehicle shall be corrected to a condition generally applicable to the design series. The procedure described hereafter can only be used for brakes where the braking force is transmitted exclusively via the wheel/rail interface, i.e. excludes magnetic track brakes or eddy current brake. The following factors are considered in this context:

- Dynamic efficiency of brake rigging on test vehicle in relation to the mean value foreseen for operations. If dynamic brakes are taken into account, the correction factor in relation to brake rigging efficiency is not relevant.
- In the case of disc-braked test vehicles with average wheel diameters, in relation to the diameter of the semi-worn wheel. If dynamic brakes are taken into account, the correction factor in relation to the wheel diameter is applicable if the dynamic brake force is independent from the wheel diameter.
- In the event that the brake cylinder pressure on the test vehicle deviates from the nominal value assumed for the design series, a correction within a maximum tolerance range of $\pm 0,2$ bar ($\pm 0,1$ bar for freight wagons in tare condition) shall be applied.

Correction shall be made using the Formulae (10) and (11):

$$F_{\text{corr}} = F_{\text{test}} \times \frac{\eta_{\text{dyn}}}{\eta_{\text{dyn,test}}} \times \frac{d_{\text{test}}}{d_{\text{m}}} \times \left(\frac{p_{\text{nom}} - p_{\text{Feder}}}{p_{\text{test}} - p_{\text{Feder}}} \right) \quad (10)$$

and

$$\bar{s}_{\text{corr}} = t_e \times v_{\text{nom}} + \frac{F_{\text{test}} + W_{\text{m}}}{F_{\text{corr}} + W_{\text{m}}} \times (\bar{s} - v_{\text{nom}} \times t_e) \quad (11)$$

where

$\bar{s}_{\text{corr}}$	corrected mean stopping distance, expressed in m;
$\bar{s}$	mean stopping distance during test, expressed in m;
t_e	equivalent response time, expressed in s;
v_{nom}	nominal initial speed during test, expressed in km/h;
d_{test}	mean wheel diameter on test vehicles, expressed in mm;
d_{m}	diameter of semi-worn wheel, expressed in mm; for block brakes $d_{\text{m}} = d_{\text{test}}$;
p_{nom}	nominal brake cylinder pressure, expressed in bar;
p_{test}	actual brake cylinder pressure during the test, expressed in bar;
p_{Feder}	equivalent pressure to compensate the force of the retainer spring, expressed in bar;
F_{corr}	corrected brake force (average over stopping distance), expressed in kN;
F_{test}	mean brake force during test, expressed in kN;
η_{dyn}	mean efficiency of brake rigging between two scheduled maintenance activities;
$\eta_{\text{dyn,test}}$	efficiency of brake rigging during test;
W_{m}	mean value of resistance forward movement, expressed in kN.

Response time t_e is defined in Annex E.

In order to ensure that new vehicles also deliver the determined braking force, the factor $\frac{\eta_{\text{dyn}}}{\eta_{\text{dyn,test}}} \times \frac{d_{\text{test}}}{d_m}$ shall be restricted to values ≤ 1 when performing corrections for tests on new vehicles.

6.7.3.2 Advice for determining the values included in the correction

6.7.3.2.1 General

The specifications in this chapter are valid for homogenous friction brake systems (regarding the parameters efficiency, wheel diameter, brake cylinder pressure).

In other cases, such as inhomogenous systems or when using dynamic brakes, the correction calculation shall take account of the individual brake design and its contribution to the overall brake force.

6.7.3.2.2 Average brake force F_{test}

The mean brake force during the test can be calculated from the mean stopping distance $\bar{s}$ using Formula (12).

$$F_{\text{test}} = m \times \rho \times \frac{v_{\text{nom}}^2}{2(\bar{s} - v_{\text{nom}} \times t_e)} - W_m \quad (12)$$

where

m	mass of the test vehicle, expressed in t;
t_e	equivalent response time, expressed in s;
ρ	coefficient of inertia of the rotating masses
v_{nom}	nominal initial speed during test, expressed in m/s;
$\bar{s}$	mean stopping distance during test, expressed in m;
W_m	mean value of resistance to foreword movement, expressed in kN.

6.7.3.2.3 Mean dynamic efficiency η_{dyn} in operation

The following rules apply for the assumption of the dynamic efficiency in the mean operating condition:

- for standard brake rigging of tread brakes in accordance with EN 14531-1, $\eta_{\text{dyn}} = 0,83$ shall be assumed;
- for brake rigging with a more direct transmission of brake force from one cylinder to more than one brake disc or wheel the assumed value shall be limited to $\eta_{\text{dyn}} = 0,91$;
- for brake callipers or block brake units, which only affect one brake disc or wheel at a time, the assumed value shall be limited to $\eta_{\text{dyn}} = 0,95$.

When selecting a value higher than 0,91, an expert assessment is necessary which demonstrates that the efficiency loss which occurs between two maintenance visits will not lead to a value lower than the selected one.

6.7.3.2.4 Dynamic efficiency during test $\eta_{\text{dyn,test}}$

The following options may be used to determine this value:

- determination from measurement of dynamic block/pad forces;
- determination of static efficiency and calculation using Formula (13):

$$\eta_{\text{dyn,test}} = \frac{1 + \eta_{\text{stat,test}}}{2} \quad (13)$$

where

$\eta_{\text{stat,test}}$ static efficiency of brake rigging in the tests.

This is only permitted where $\eta_{\text{dyn,test}} > 0,6$.

- For new vehicles with standard brake rigging in accordance with EN 14531 (all parts), the use of $\eta_{\text{dyn,test}} = 0,91$ is permitted;
- for new vehicles with brake callipers or block brake units, the efficiency from the manufacturer's dynamic component testing may be used, or the dynamic efficiency to be set equal to the static efficiency.

For block-braked wagons and standard brake rigging in the sense indicated above, the maximum value to be used for the dynamic efficiency during testing is $\eta_{\text{dyn,test}} = 0,91$.

When taking measurements, the efficiency is in general to be determined on at least 2 axles of different design types.

6.7.3.2.5 Resistance to forward movement W_m

The resistance to forward movement averaged over the stopping distance can be calculated with Formula (14), following EN 14531-1 (identified as resistance to forward movement, F_{Ra} , see Formula (15)).

With $v_{\text{end}} = 0$ km/h:

$$W_m = \bar{F}_{\text{Ra}} = A + \frac{2}{3} \times B \times v_0 + \frac{1}{2} \times C \times v_0^2 \quad (14)$$

where

- v_0 initial speed, expressed in m/s;
- v_{end} final speed, expressed in m/s;
- A, B, C the same vehicle-specific coefficients, which in accordance with EN 14531-1 also valid for the calculation of the instantaneous resistance to forward movement W depending on the instantaneous speed:

$$F_{\text{Ra}} = A + B \times v + C \times v^2 \quad (15)$$

6.7.3.3 Additional correction for slip test

During slip tests, the actual filling time shall be corrected in relation to the nominal value in accordance with Formula (16):

$$\bar{s}_{\text{corr},2} = \left(\frac{t_n}{2} - \frac{t_s}{2} \right) \times v_{\text{nom}} + \bar{s}_{\text{corr}} \quad (16)$$

where

- $\bar{s}_{\text{corr},2}$ mean stopping distance corrected to standard filling time, expressed in m;
- $\bar{s}_{\text{corr}}$ mean stopping distance corrected in accordance with 6.7.1, expressed in m;
- t_n nominal brake build up time (4 s for standard UIC brake in accordance with EN 15355), expressed in s;
- t_s mean measured brake build up time, expressed in s;
- v_{nom} nominal initial speed during test, expressed in m/s.

6.8 Parking and holding brake testing

Friction components shall be bedded in to give at least 85 % coverage (of the friction surface).

A static type test shall be conducted to determine the ability of the parking brake to hold the unit, at the required load:

This test could be done by measuring the force required to move a train or unit (of defined load) against the parking brakes on level track (e.g. by winching or traction source). This method shall be used if calculation of braked weight is needed. During this test the braked wheel shall still rotate and not slide.

Or it can be done by one of the following methods:

- placing a train or unit with a known load on a known gradient;
- placing a train or unit with a known load on a known gradient with a number of the parking brakes isolated to simulate the required condition.

Similarly, this method may also be used for the assessment of the holding brake.

NOTE For application of the handbrake the maximum application force F_k on the wheel of the handbrake is $F_k = 500 \text{ N}$.

7 Assessment for deceleration method

7.1 General

Operating on lines with a **signalling system based on permanent control of speed** means that the brake performance of the trains running on these lines shall be known as determined by decelerations over the entire range of permissible speeds.

This applies **in particular when operating at speeds of > 200 km/h**, which is a speed range in which brake performance is not defined in terms of braked weight percentage.

7.2 Physical principles

The brake performance shall be expressed by the equivalent brake response time t_e and the decelerations a_{bi} which are constant for each step, with fully developed (95 %) braking force for the various speed ranges, e.g. the 3 speed ranges in Figure 2. The stopping distance shall then be calculated by applying Formulae (17) and (18).