

Railway applications — Methods for calculation of stopping distances, slowing distances and immobilization braking —

Part 1: General algorithms

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British Standard

ICS 45.060.01

National foreword

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The UK participation in its preparation was entrusted to Technical Committee RAE/4, Braking, which has the responsibility to:

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- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 25 May 2005

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 95 and a back cover.

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Amendments issued since publication

Amd. No.	Date	Comments

© BSI 25 May 2005

ISBN 0 580 46019 3

English version

**Railway applications - Methods for calculation of stopping
distances, slowing distances and immobilization braking - Part 1:
General algorithms**

Applications ferroviaires - Freinage - Méthodes de calcul
des distances d'arrêt et de ralentissement - Méthodes de
calcul du freinage d'immobilisation - Partie 1: Algorithmes
généraux

Bahnanwendungen - Bremsen - Verfahren zur Berechnung
der Anhalte- und Verzögerungsbremswege - Verfahren zur
Berechnung der Feststellbremsung - Teil 1: Grundlagen

This European Standard was approved by CEN on 15 March 2005.

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Foreword

This European Standard (EN 14531-1:2005) 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of an identical text or by endorsement, at the latest by October 2005, and conflicting national standards shall be withdrawn at the latest by October 2005.

This European Standard has been prepared under a mandate given to CEN/CENELEC/ETSI by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive 96/48 and Directive 2001/16.

For relationship with EU Directives, see informative Annexes ZA and ZB, which are integral parts of this European Standard.

This European Standard is one part of the European Standard as listed below:

EN 14531, Railway applications – Methods for calculation of stopping, slowing distances and immobilization braking

- Part 1: General algorithms
- Part 2: Application to single freight wagon
- Part 3: Application to mass transit (LRV's and D- and E- MU's)
- Part 4: Application to single passengers coach
- Part 5: Application to locomotive
- Part 6: Application to high speed trains

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

Introduction

This European Standard is aimed at enabling the railway industries and operators to work with a common calculation method.

It describes the fundamental algorithms and calculations for the design of brake equipment for railway vehicles.

This European Standard should be considered as a technical document which gives the physical basis for the brake calculations. It will also help the user to understand the UIC 544-1 leaflet through completion of the requirements in the UIC 544-1 leaflet.

This European Standard gives examples of freight wagon applications considered as the highest priority. It is applicable for all vehicle types. If necessary, additional application examples will be added as separate parts to the European Standard.

1 Scope

This European Standard specifies a general algorithm to be used in any type of vehicle application. It enables the calculation of the various aspects of the performance: stopping or slowing distances, dissipated energy, force calculations, immobilization braking.

Typical examples of calculations for freight wagon, coach and locomotive are given in Parts 2 to 6 of this European Standard.

NOTE This European Standard does not specify the performance requirements which can be found in the different standards specified in Clause 2.

This European Standard enables the verification that the design respects the requirements according to the railway application type.

2 Normative references

The following referenced documents are indispensable for the application of this European Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13452-1:2003, *Railway applications — Braking — Mass transit brake systems — Part 1: Performance requirements*

EN 13452-2:2004, *Railway applications — Braking — Mass transit brake systems — Part 2: Methods of test*

EN 14198:2004, *Railway applications — Braking — Requirements for the brake system of trains hauled by a locomotive*

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

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 13452-1:2004, EN 14198:2003 and EN 14478:2004 apply.

NOTE If there are inconsistencies between this European Standard and the definitions given in EN 14478, then the definitions given in EN 14478 take precedence.

3.2 Symbols and indices

For the purposes of this European Standard, the general symbols given in Table 1 and indices given in Table 2 apply.

NOTE Specific symbols are defined in the relevant clauses.

Table 1 — Symbols

Symbol	Term	Dimensions
A	area	m^2
a	deceleration	m/s^2
B	braked mass (see UIC 544-1)	kg
D	wheel diameter	m
d	diameter	m
F	force	N
F_B	braking force	N
F_g	downhill force on the train	N
f_0	available coefficient of adhesion	
g	acceleration due to gravity	m/s^2
I	rotational inertia	$\text{kg} \cdot \text{m}^2$
i	rigging ratio, calliper ratio	
m	mass	kg
n	quantity	
P	power	W
p	pressure	Pa
R	wheel radius	m
r	radius	m
s	distance	m
t	time	s
v	speed	m/s
W	energy	J
W_s	energy per square unit	J/m^2
η	efficiency	
κ	coefficient of rotating mass	
λ	brake percentage	
μ	friction coefficient	

Table 2 — General indices

Symbol	Term	Dimensions
AMG	attraction force for a magnetic brake	
a	axle	
BEC	braking force for an eddy current brake	
BED	electro-dynamic braking force	
BFR	fluid retarder	
BMG	braking force for a magnetic brake	
b	block or pad	
bog	bogie	
C	cylinder	
disc	disc	
dyn	dynamic	
e, 2	final	
eq	equivalent	
ext	external	
H	hand brake	
int	internal	
m	average, mean	
max	maximal	
min	minimal	
mot	motor	
M_unsp	unsprung mass	
MG	magnetic brake	
park	parking, immobilization	
R	reaction	
Ra	rolling resistance	
rot	rotational	
R1	return spring	
R2	regulator	
st	static	
tot	total	
tra	trailer	
veh	vehicle	

Table 2 – (concluded)

w	wheel	
weig	weighing	
wind	wind	
0, 1	initial	

NOTE In this European Standard, the wheelset is simply named "axle".

4 General algorithms

4.1 General algorithm to calculate stopping and slowing distances

This algorithm is presented in Annex A.

The content of each part and the corresponding calculations are explained in Clause 5.

This algorithm can be used either with mean values or with instantaneous values of, for example force or retardation which are integrated step by step.

4.2 General algorithm to calculate immobilisation brake

This algorithm is presented in Annex B.

The content of each part and the corresponding calculations are explained in Clause 6.

5 Stopping and slowing distances calculation

5.1 General

All the values which are used shall be justified, for example, by tests, calculations, or engineer's estimations, in accordance with the appropriate standards, for example EN 13452-2.

5.2 General characteristics

5.2.1 Train formation

The parameters to define train formation are:

- quantity of motor axles;
- quantity of trailer axles;
- quantity of braked axles for each brake equipment type.

In the cases of single wagon, coach or locomotive, the notion of train is restricted to the single wagon, the coach or the locomotive.

Brake equipment type shall be taken to mean a group of equipment whose purpose is to provide braking force.

For example, on a wagon or a coach, the friction brake equipment begins at the distributor and ends at the contact between the braked wheels and the rail.

Each brake equipment type shall be the subject of a specific calculation, and the quantity of braked axles shall be shared between the various types of brake equipment.

NOTE 1 When there are several brake equipment types, it is preferable to identify each type (for example by means of a number: type 1, type 2, ...).

When brake equipment is used on one part of the train under certain conditions and used on another part of the same train under other conditions, two different brake equipment types shall be considered.

NOTE 2 Other conditions can be for example, different brake cylinder pressures.

Then the two brake equipment types shall be separately described and separately calculated.

The total quantity of axles is the result of the summation of the quantity of braked and unbraked axles.

5.2.2 Vehicle and train characteristics

5.2.2.1 Static mass per axle, static mass

The static mass per axle is the mass, measured by weighing, of each axle in a stationary condition.

The static mass of the train is the summation of all the values of static mass per axle and includes all operating loads.

The static mass per axle is the static mass of the train divided by the quantity of axles only in the case where the operating load is equally shared by all axles.

It is indicated in tonnes [t].

When there are different brake equipment types, the static mass per axle shall be indicated for each brake equipment type.

NOTE If the train is equipped with different types of wheel, according to the definition of “brake equipment” it is recommended that each type of wheel is considered as being applicable to a specific brake equipment type.

5.2.2.2 Rotating mass per axle, rotating mass

5.2.2.2.1 General

The definition of the rotating mass is given in EN 14478.

It may be calculated using a theoretical approach or estimated on the basis of known typical values.

In the cases of single wagon or coach, in a first approach, designers may ignore the rotating masses if they also ignore the rolling resistance of the single wagon or the coach.

NOTE If the train is equipped with different types of wheel, according to the definition of brake equipment, it is recommended that each type of wheel is considered as being applicable to a specific brake equipment type.

5.2.2.2.2 Rough calculation example

When considering a disc, in the first instance, a disc can be considered as a single ring, the mass of which is concentrated on the mean swept diameter.

When considering a wheel, in the first instance, a wheel can be considered as a single wheel, the mass of which is concentrated on the worn wheel diameter.

5.2.2.2.3 Typical values

In some cases, the rotating masses are expressed by a coefficient of the static mass and this coefficient, κ is given by:

$$\kappa = \frac{M_{st} + M_{rot}}{M_{st}} \quad (1)$$

where

κ is the coefficient of the rotating mass;

M_{st} is the static mass, in tonnes;

M_{rot} is the rotating mass, in tonnes.

In the cases of single wagon, this coefficient is given for two conditions: in tare (about 5 t/axle or 6 t/axle) and laden (about 20 t/axle).

EXAMPLE 1 For non-powered axle with Ø920 mm wheel half worn, without disc,

— in tare condition: $\kappa = 1,06$

— in laden condition: $\kappa = 1,02$

EXAMPLE 2 For non-powered axle with Ø1 000 mm wheel half worn, without disc,

— in tare condition: $\kappa = 1,07$

— in laden condition: $\kappa = 1,02$

EXAMPLE 3 For non-powered axle with Ø850 mm wheel half worn, without disc,

— in tare condition: $\kappa = 1,05$

— in laden condition: $\kappa = 1,02$

5.2.2.3 Wheel diameters

The wheel diameter is assumed to be measured on the nominated line of contact with the running surface of the rail.

Unless otherwise specified, the wheel diameter used in the calculation shall be that of a new wheel which gives the lowest deceleration in the case of disc brakes.

NOTE If the train is equipped with different types of wheel, according to the definition of a brake equipment, it is recommended that each type of wheel is considered as being applicable to a specific brake equipment type.

5.2.2.4 Rolling resistance

The rolling resistance is the braking force provided by the structure of the train.

Unless otherwise specified the effect of wind forces is not taken into account.

The value of the rolling resistance may be by analogy to another existing vehicle, or based on a specific calculation.

When the values are the results of tests, the test conditions shall be similar to the expected operating conditions.

NOTE 1 In a first approach, with the single wagon or the coach, designers may ignore the rolling resistance if they also ignore the rotating masses.

The rolling resistance is represented by a formula which consists of:

- one term independent of vehicle speed;
- one term proportional to the speed, dealing with the mechanical components (train and track);
- a third term proportional to the square of the speed (aerodynamic resistance).

According to this formula the mathematical formulae, which shall be applied are the following:

- a) Calculate the instantaneous rolling resistance as a function of the speed, F_{Ra} , in newtons (N), using the following equation:

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

where

v is the instantaneous speed of the vehicle, in metres per second (m/s);

A is the characteristic coefficient of the vehicle, in newtons (N);

B is the characteristic coefficient of the vehicle, in N/(m/s);

C is the characteristic coefficient of the vehicle in N/(m/s)².

NOTE 2 The speed may be expressed in km/h and the rolling resistance in [daN] or [kN]. In this case, A , B , C are expressed in [daN], [daN/(km/h)], [daN/(km/h)²] or [kN], [kN/(km/h)], [kN/(km/h)²].

NOTE 3 Values for A , B and C may be obtained using the test method given in EN 14067-2.

- b) Calculate the average rolling resistance as a function of the initial speed F_{Ra} , in newtons (N), using the following equations.

- average rolling resistance in the case of braking to a stop:

$$F_{Ra,m} = A + \frac{2}{3} \times B \times v_0 + \frac{1}{2} \times C \times v_0^2 \quad (3)$$

where

v_0 is the speed at which braking is initiated, in metres per second (m/s);

A , B , C are the coefficients in Equation (2);

NOTE 4 The speed may be expressed in km/h and the rolling resistance in [daN] or [kN]. In this case, A , B , C are expressed in [daN], [daN/(km/h)], [daN/(km/h)²] or [kN], [kN/(km/h)], [kN/(km/h)²].

- average rolling resistance in the case of slowing braking:

$$F_{Ra,m} = A + \frac{2}{3} \times B \times \frac{v_0^2 + v_0 \times v_e + v_e^2}{v_0 + v_e} + \frac{1}{2} \times C \times (v_0^2 + v_e^2) \quad (4)$$

where

v_0 is the speed at which braking is initiated, in metres per second (m/s);

v_e is the final speed, in metres per second (m/s);

A , B , C are the coefficients in Equation (2).

NOTE 5 The speed may be expressed in km/h and the rolling resistance in [daN] or [kN]. In this case, A , B , C are expressed in [daN], [daN/(km/h)], [daN/(km/h)²] or [kN], [kN/(km/h)], [kN/(km/h)²].

NOTE 6 Examples of calculations for wagons with bogies are presented in C.1.

5.3 Brake characteristics

NOTE The following examples illustrate the application of the general algorithm. For specific applications reference should be made to the specific vehicle types covered in the following parts of this European Standard:

- Part 2: Application to a single freight wagon;
- Part 3: Application to mass transit (LRV's and D- and E-MU's);
- Part 4: Application to single passenger coach;
- Part 5: Application to locomotive;
- Part 6: Application to high speed trains.

5.3.1 Characteristics of a tread brake or a disc brake equipment type

5.3.1.1 Fixed characteristics of a tread brake equipment type

5.3.1.1.1 General characteristics

This item is composed of every component characteristic that contributes to the brake performance of equipment that uses rigging.

When a tread brake uses a block mounted on a cylinder, the equipment shall be considered as a disc brake type.

NOTE “Fixed” means “not subject to change”.

The characteristics of a classical tread brake equipment are given in Table 3:

Table 3 — Characteristics of classical tread brake equipment

Characteristic	Footnote	Symbol	Units	
a) Pressure at the brake cylinder	a	p_C	[bar]	
— tare			[bar]	
— laden			[bar]	
b) Brake piston area		A_C	[cm ²]	
c) Cylinder efficiency		η_C	[-]	
d) Total rigging ratio after cylinder		i_C	[-]	
— * tare	b		[-]	
— * laden			[-]	
e) Rigging return spring force		F_{R1}	[N]	
f) Total rigging ratio after return spring		i_{R1}	[-]	
g) Brake regulator opposing force		F_{R2}	[N]	
h) Total rigging ratio after regulator		c	i_{R2}	[-]
i) Rigging efficiency in dynamic conditions			η_{dyn}	[-]
j) Friction area of the block	A_b		[m ²]	
k) Quantity of blocks per wheel		$n_{b,w}$	[-]	
a May be a continuously variable function of the static mass per axle.				
b In many cases it is inside the cylinder. In such cases rigging ratio in d) = rigging ratio in f).				
c Currently, when the wheels are clasp braked, the rigging ratio after regulator for four axle wagons (2 bogies) is equal to 8.				

The examples given in 5.3.1.1.2 to 5.3.1.1.4 describe various types of rigging arrangements and support the calculations.

5.3.1.1.2 Conventional two axle wagon equipped with a mechanical empty load device

Conventional Two Axle Wagon equipped with a mechanical empty-load device is shown Figure 1 and Table 4.

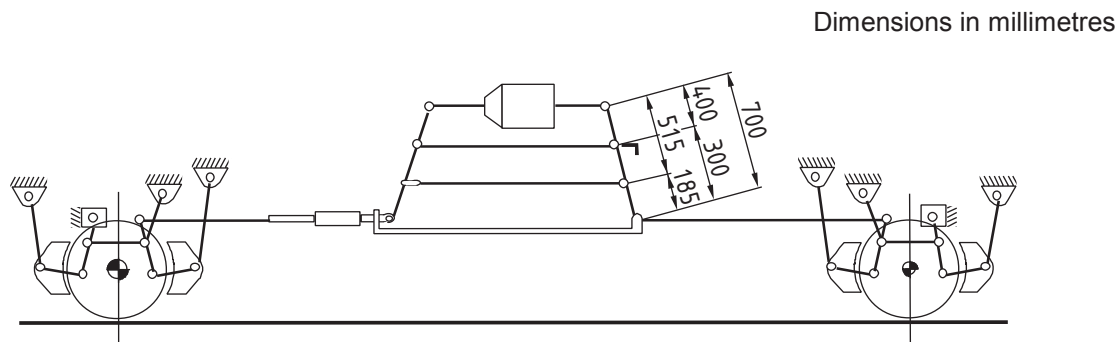


Figure 1 — Conventional two axle wagon equipped with a mechanical empty-load device

Table 4 — Conventional two axle wagon equipped with a mechanical empty-load device

Characteristic	Symbol	Unit	Value
a) Pressure at the brake cylinder	p_C		
— * tare		[bar]	= 3,8
— * laden		[bar]	= 3,8
b) Brake piston area	A_C	[cm ²]	= 706,9
c) Cylinder efficiency	η_C	[-]	= 1
d) Total rigging ratio after cylinder	i_C		
— * tare		[-]	= $(a/b) \times 4 = 5,33$
— * laden		[-]	= $(c/d) \times 4 = 11,135$
e) Rigging return spring force	F_{R1}	[N]	= 1 500
f) Total rigging ratio after return spring	i_{R1}	[-]	= same values as d)
g) Brake regulator opposing force	F_{R2}	[N]	= 2 000
h) Total rigging ratio after regulator	i_{R2}	[-]	= 4
i) Rigging efficiency in dynamic conditions	η_{dyn}	[-]	= 0,83
j) Friction area of the block	A_b	[m ²]	0,027 2
k) Quantity of blocks per wheel	$n_{b,w}$	[-]	= 2

5.3.1.1.3 Conventional two axle wagon equipped with a pneumatic empty load device

Conventional Two Axle Wagon equipped with a pneumatic empty-load device is shown in Figure 2 and Table 5.

Dimensions in millimetres

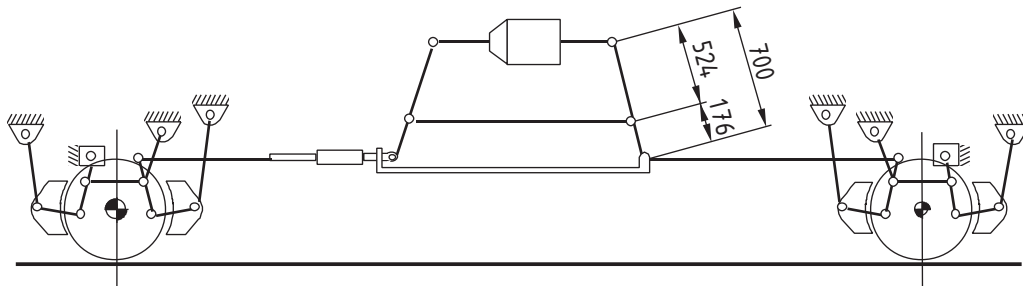


Figure 2 — Conventional two axle wagon equipped with a pneumatic empty-load device

Table 5 — Conventional two axle wagon equipped with a pneumatic empty-load device

Characteristic	Symbol	Unit	Value
a) Pressure at the brake cylinder	p_C	[bar]	
— * tare		[bar]	= 1,75
— * laden		[bar]	= 3,8
b) Brake piston area	A_C	[cm ²]	= 706,9
c) Cylinder efficiency	η_C	[-]	= 1
d) Total rigging ratio after cylinder	i_C	[-]	= $(a/b) \times 4 = 11,91$
e) Rigging return spring force	F_{R1}	[N]	= 1 500
f) Total rigging ratio after return spring	i_{R1}	[-]	= 11,91
g) Brake regulator opposing force	F_{R2}	[N]	= 2 000
h) Total rigging ratio after regulator	i_{R2}	[-]	= 4
i) Rigging efficiency in dynamic conditions	η_{dyn}	[-]	= 0,83
j) Friction area of the block	A_b	[m ²]	0,027 2
k) Quantity of blocks per wheel	$n_{b,w}$	[-]	= 2

5.3.1.1.4 Conventional two bogie wagon equipped with a pneumatic empty-load device

Conventional Two Bogie Wagon equipped with a pneumatic empty-load device is shown in Figure 3 and Table 6.

Dimensions in millimetres

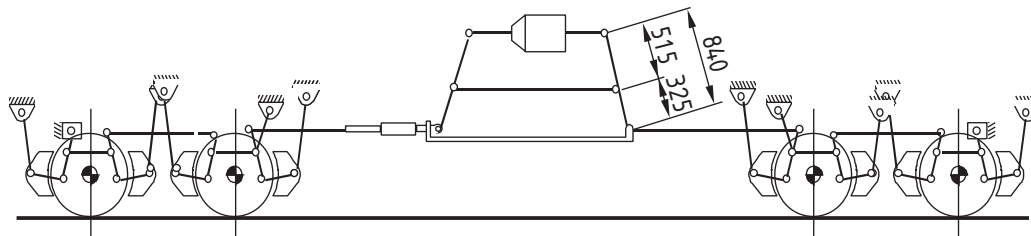


Figure 3 — Conventional two bogie wagon equipped with a pneumatic empty-load device

Table 6 — Conventional two bogie wagon equipped with a pneumatic empty-load device

Characteristic	Symbol	Unit	Value
a) Pressure at the brake cylinder	p_C	[bar]	
— * tare		[bar]	= 1,27
— * laden		[bar]	= 3,8
b) Brake piston area	A_C	[cm ²]	= 1 295,0
c) Cylinder efficiency	η_C	[-]	= 1
d) Total rigging ratio after cylinder	i_C	[-]	= $(a/b) \times 8 = 12,68$
e) Rigging return spring force	F_{R1}	[N]	= 1 500
f) Total rigging ratio after return spring	i_{R1}	[-]	= 12,68
g) Brake regulator opposing force	F_{R2}	[N]	= 2 000
h) Total rigging ratio after regulator	i_{R2}	[-]	= 8
i) Rigging efficiency in dynamic conditions	η_{dyn}	[-]	= 0,83
j) Friction area of the block	A_b	[m ²]	= 0,042 5
k) Quantity of blocks per wheel	$n_{b,w}$	[-]	= 2

5.3.1.2 Fixed characteristics of a disc brake equipment type

5.3.1.2.1 General characteristics

This item is composed of every component characteristic that contributes to the brake performance.

In general, the tread brake systems that use cylinders may be described in a similar manner.

NOTE “Fixed” means “not subject to change”.

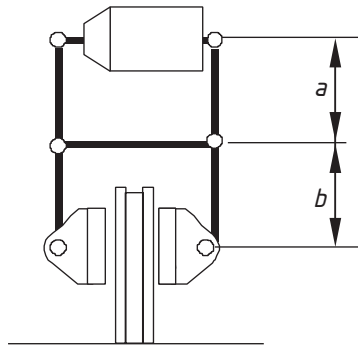
The characteristics of a conventional disc brake equipment are as given in Table 7:

Table 7 — Characteristics of conventional disc brake equipment

Characteristic	Symbol	Unit
a) Pressure at the brake cylinder ^a	p_C	[bar]
* tare		[bar]
* laden		[bar]
b) Brake piston area	A_C	[cm ²]
c) Cylinder efficiency	η_C	[-]
d) Rigging return spring force	F_{R1}	[N]
e) Brake regulator opposing force ^b	F_{R2}	[N]
f) Output cylinder force ^c	F_C	[N]
g) Rigging efficiency in dynamic conditions	η_{dyn}	[-]
h) Calliper ratio	i_C	[-]
i) Type and area of the pad per face of disc	A_b	[m ²]
j) Mean swept radius	r_s	[m]
k) Swept area (2 faces) of the disc	A_s	[m ²]
l) Quantity of discs per cylinder	$n_{disc,C}$	[-]
m) Quantity of friction faces per disc	n_s	[-]
n) Quantity of cylinders per axle	$n_{C,a}$	[-]
o) Quantity of pads per cylinder	$n_{b,C}$	[-]
^a May be as a continuously variable function of the static mass per axle. ^b Generally included in d). ^c In the case of a classic pneumatic cylinder, this is calculated from the data a), b), c), d), e) or is given by the supplier as a function of the brake cylinder pressure.		

5.3.1.2.2 Disc braked vehicle with one cylinder per disc

Disc braked vehicle with one cylinder per disc is shown in Figure 4 and Table 8.



The calliper ratio is: $i_c = 2 \times \frac{a}{b}$

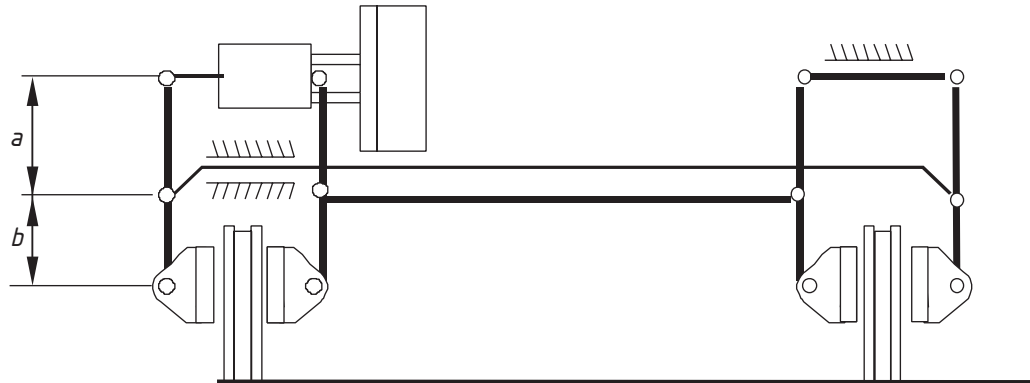
Figure 4 — Disc braked vehicle with one cylinder per disc

Table 8 — Disc braked vehicle with one cylinder per disc

Characteristic	Symbol	Unit	Value
a) Pressure at the brake cylinder	p_C	[bar]	
<i>Generally, in these applications, the pressure is varied continuously depending on the static mass per axle.</i>			
b) Brake piston area	A_C	[cm ²]	= 510,7
c) Cylinder efficiency	η_C	[-]	= 0,97
d) Rigging return spring force	F_{R1}	[N]	= 1 500
e) Brake regulator opposing force	F_{R2}	[N]	= 0
f) Output cylinder force	F_C	[N]	= <i>Has to be calculated</i>
g) Rigging efficiency in dynamic conditions	η_{dyn}	[-]	= 0,95
h) Calliper ratio	i_C	[-]	= 2 (where $a = b$)
i) Area of the pad per face of disc	A_b	[m ²]	= $0,017\ 5 \times 2$
j) Mean swept radius	r_s	[m]	= 0,235
k) Swept area of the disc	A_s	[m ²]	= $2 \times \pi \times (0,560^2 - 0,366^2)/4$ = 0,282
l) Quantity of discs per cylinder	$n_{disc,C}$	[-]	= 1
m) Quantity of friction faces per disc	n_s	[-]	= 2
n) Quantity of cylinders per axle	$n_{C,a}$	[-]	= 2
o) Quantity of pads per cylinder	$n_{b,C}$	[-]	= $n_{disc,C} \times n_s = 1 \times 2 = 2$

5.3.1.2.3 Disc braked wagon with one cylinder for two discs

Disc braked wagon with one cylinder for two discs is shown in Figure 5 and Table 9.



$$a/b = 1,167$$

Figure 5 — Disc braked wagon with one cylinder for two discs

Table 9 — Disc braked wagon with one cylinder for two discs

Characteristic	Symbol	Unit	Value
a) Pressure at the brake cylinder ^a	p_C	[bar]	
b) Brake piston area	A_C	[cm ²]	= 510,7
c) Cylinder efficiency	η_C	[-]	= 0,97
d) Rigging return spring force	F_{R1}	[N]	= 1 500
e) Brake regulator opposing force ^b	F_{R2}	[N]	= 0
f) Output cylinder force ^c	F_C	[N]	= To be calculated from a), b), c) d) and e)
g) Rigging efficiency in dynamic conditions	η_{dyn}	[-]	= 0,90
h) Calliper ratio	i_C	[-]	= $4 \times a/b = 4,668$
i) Type and area of the pad per face of disc	A_b	[m ²]	= $0,017\ 5 \times 2$
j) Mean swept radius	r_s	[m]	= 0,244
k) Swept area of the disc	A_s	[m ²]	= $2 \times \pi \times (0,560^2 - 0,366^2)/4$ = 0,282
l) Quantity of discs per cylinder	$n_{disc,C}$	[-]	= 2

m) Quantity of friction faces per disc	n_s	[-]	= 2
n) Quantity of cylinders per axle	$n_{C,a}$	[-]	= 1
o) Quantity of pads per cylinder	$n_{b,C}$	[-]	$= n_{disc,C} \times n_s = 2 \times 2 = 4$
a May be as a continuously variable function of the static mass per axle. b Generally included in d). c In the case of a classic pneumatic cylinder, this is calculated from the data a), b), c), d), e), or is given by the supplier as a function of the brake cylinder pressure.			

5.3.1.2.4 Tread braked wagon with cylinders

Tread braked wagon with cylinders is shown in Figure 6 and Table 10.



Figure 6 — Tread braked wagon with cylinders

Table 10 — Tread braked wagon with cylinders

Characteristic	Symbol	Unit	Value
a) Pressure at the brake cylinder ^a	p_C	[bar]	
b) Brake piston area	A_C	[cm ²]	= 510,7
c) Cylinder efficiency	η_C	[-]	= 0,97
d) Rigging return spring force	F_{R1}	[N]	= 1 500
e) Brake regulator opposing force ^b	F_{R2}	[N]	= 0
f) Output cylinder force ^c	F_C	[N]	= To be calculated from a), b), c), d) and e)
g) Rigging efficiency in dynamic conditions	η_{dyn}	[-]	= (4)
h) Calliper ratio	i_C	[-]	= (5)
i) Type and friction area of the block	A_b	[m ²]	= $Bg \Rightarrow 0,320 \times 0,085$
j) Quantity of cylinders per axle ^d	$n_{C,a}$	[-]	= 2
k) Quantity of blocks per cylinder ^e	$n_{b,C}$	[-]	= 1
^a May be as a continuously variable function of the static mass per axle. ^b Generally included in d). ^c In the case of a classic pneumatic cylinder, this is calculated from the data a), b), c), d), e), or is given by the supplier as a function of the brake cylinder pressure. ^d Generally there is a cylinder per block, without rigging. The efficiency is included in c). ^e Generally this is an internal device with a ratio equal to 1.			

5.3.1.3 Weighing device pressure acting on cylinder pressure or rigging amplification

On vehicles, the cylinder pressure may be continuously adapted according to the static mass.

In this case, this pressure may be expressed using the following mathematical formulae.

- a) Calculate the pressure supplied by the weighing device, p_{weig} , in bar, using the following equation:

$$p_{weig} = f(M_{st}) \quad (5)$$

where

M_{st} is the static mass, in tonnes.

- b) Calculate the brake cylinder pressure, p_C , in bar, as a function of the pressure given by the weighing device, using the following equation:

$$p_C = f(p_{weig}) \quad (6)$$

where

p_{weig} is the pressure supplied by the weighing device in bar.

- c) Calculate the rigging amplification downstream of the cylinder, i_c , as a function of the pressure given by the weighing device.

$$i_c = f(p_{\text{weig}}) \quad (7)$$

where

p_{weig} is the pressure supplied by the weighing device in bar.

NOTE 1 In this case, the cylinder pressure is not altered by the weighing device.

NOTE 2 The pilot pressure at the variable load relay valve needs to be specified.

EXAMPLE 1 Pressure supplied by the weighing device:

$$p_{\text{weig}} = \left[(M_{\text{st}} - M_{\text{unsp}}) \times \frac{g}{n_R} \right] \times i_{\text{int}} \times i_{\text{ext}} \quad (8)$$

where

p_{weig} is the pressure supplied by the weighing device in bar;

M_{st} is the static mass in tonnes;

M_{unsp} is the unsprung mass in tonnes;

(M_{unsp} is the sum of the wheel set masses + sum of the axle box masses + sum of the suspension sprung masses;

This definition is only valid in the case where the weighing device is installed in the primary suspension)

g is the acceleration due to gravity (= 9,81 m/s²);

n_R is the quantity of suspension reaction points;

i_{int} is the internal characteristic ratio (relationship between the input and output signals);

i_{ext} is the external characteristic ratio (depending on the device installation);

$i_{\text{int}} \times i_{\text{ext}}$ is the characteristic of the weighing device in bar/N.

NOTE 3 For certain weighing devices, the value is normally specified by the supplier, either graphically or in a specific calculation that takes into account the input load to the weighing device.

EXAMPLE 2 Pressure at the brake cylinder:

$$p_c = a_0 + a_1 \times p_{\text{weig}} + a_2 \times p_{\text{weig}}^2 \quad (9)$$

with

minimum of $p_c = p_{c,\text{min}} = x$ bar

maximum of $p_C = p_{C,max} = y$ bar

Generally, the final values of the coefficients “ a_0 ”, “ a_1 ” and “ a_2 ” are obtained from bench test results.

5.3.1.4 Coefficient of friction

5.3.1.4.1 General

Precision in the determination of the coefficient of friction is desirable because small variations in the coefficient of friction value may lead to significant variations in the stopping distance.

Because of this large influence, the supplier of the brake blocks and/or pads should provide information based upon test results detailing the characteristic of the coefficient of friction.

NOTE 1 Generally, the coefficient of friction value is dependent on four principal parameters: instantaneous speed, temperature, contact pressure and humidity. In some cases, it is necessary to take into account other ambient influences (for example: corrosive atmosphere).

It is impossible to describe precisely the coefficient of friction with all four parameters simultaneously. Generally, according to the friction material of the block or the pad, only two of them, being the most representative of the sensitivity of the materials are chosen.

After gaining experience of a particular friction material on specific applications, it is possible to determine an average value of the coefficient of friction dependent on only one or two parameters. For practical reasons, in these cases, it is preferred to replace the instantaneous speed with the initial speed. The average value should be calculated according to the braking distance.

NOTE 2 Cast iron blocks are not significantly dependent on the humidity. Because of a greater experience of their application it is, in a first approach for calculations, required to describe their coefficient of friction, only with respect to the initial speed. If a more precise calculation is required regard should be given to both the initial speed and block pressure.

NOTE 3 Composition blocks or pads are generally dependent on the humidity. When they are relatively hot, their behaviour generally depends on the temperature that is reached during braking. Each block or pad material may exhibit its own characteristics, and these are required for calculations, both in the dry condition and the standard wet conditions defined in the leaflets UIC 541-3 and UIC 541-4. As far as possible, it is recommended that the supplier provides characteristics versus the dissipated energy.

NOTE 4 Sintered blocks or pads exhibit a behaviour dependent on the type of sintered material. The same characteristics as defined for the composition blocks or pads are required for calculations.

5.3.1.4.2 Coefficient of friction for the UIC cast iron blocks (B_g , B_{gu})

When the UIC calculation method with “ k ” coefficient is not used (UIC 544-1), the general algorithm with a mean value of the coefficient of friction that depends on the initial speed and the block pressure may be used.

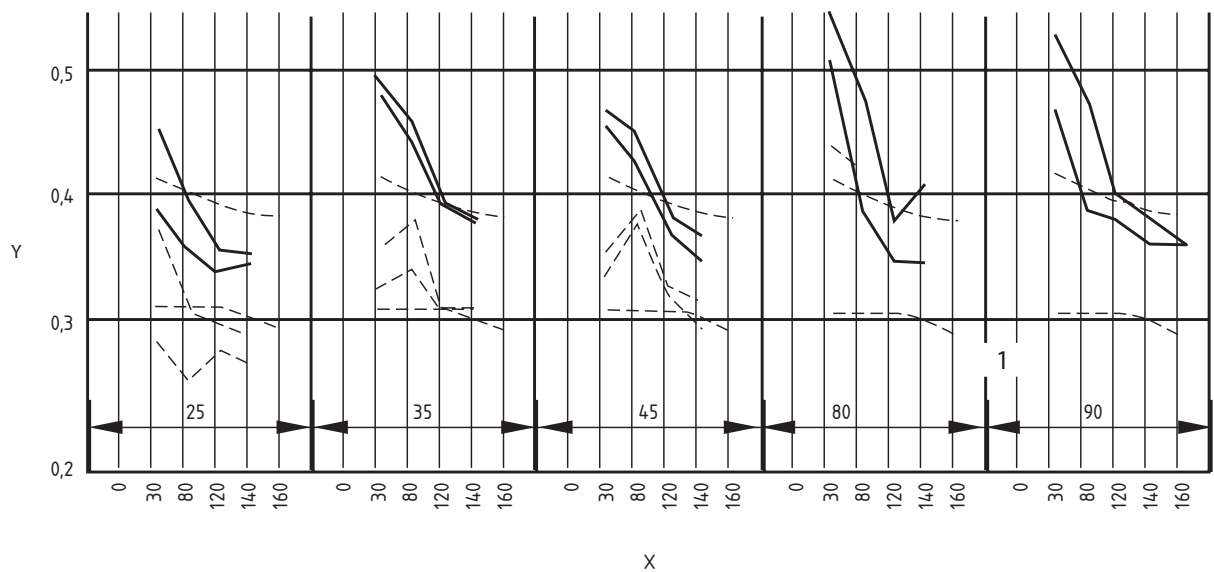
5.3.1.4.3 Coefficient of friction for composition or sintered blocks

Unless otherwise specified, the braking performance should be assured whatever the climatic conditions.

It is necessary of the operator to know the stopping distances in both the dry and wet conditions.

Experience has shown that variations in the stopping distance may occur with composition and sintered materials.

An example of characteristics that may be required for calculations is presented in Figure 7.



Key

- 1 application force per unit area (N/cm^2)
 - X initial speed (km/h)
 - Y friction coefficient
- _____ dry condition
..... wet condition

NOTE The curves represent the minimum and the maximum values of the mean coefficient of friction calculated from the initial speed to the stop.

Figure 7 — Typical characteristics of a composition or sintered pad

5.3.2 Characteristics of the other brake equipment types

5.3.2.1 Electrodynamic brake

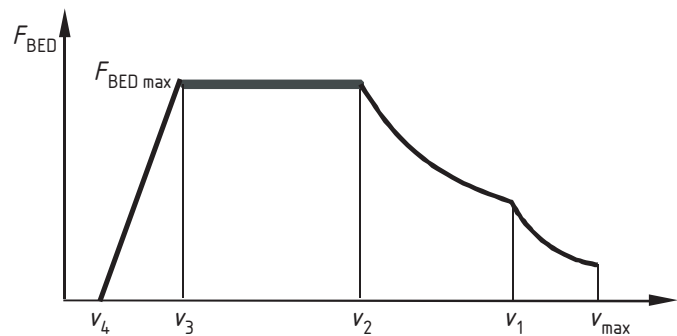


Figure 8 — Characteristic curve for electrodynamic brake force

The electrodynamic brake force can be represented by a characteristic curve as shown in Figure 8, which is composed of:

— a linear section from v_4 to v_3
$$F_{\text{BED}} = F_{\text{BED,max}} \times \frac{v - v_4}{v_3 - v_4} \quad (10)$$

— a constant section from v_3 to v_2
$$F_{\text{BED}} = F_{\text{BED,max}} \quad (11)$$

— a hyperbolic section with constant power from v_2 to v_1

$$F_{\text{BED}} = F_{\text{BED,max}} \times \frac{v_2}{v} \quad (12)$$

— a section depending on $1/v^2$ from v_1 to v_{max}

$$F_{\text{BED}} = F_{\text{BED,max}} \times \frac{v_2 \times v_1}{v^2} \quad (13)$$

where

F_{BED} is the instantaneous electro-dynamic braking force, in newtons (N);

$F_{\text{BED,max}}$ is the maximum electro-dynamic braking force, in newtons (N). This is equal to the value of the force in the constant section;

v is the instantaneous speed, in km/h;

v_1, v_2 are particular speeds, in km/h;

v_{max} is the maximum operational speed, in km/h.

If the deceleration of the train is relatively constant during the braking, the mean value of the electro-dynamic braking force from 0 to v_0 is given by the formula:

when $V_0 > V_1$

$$F_{\text{BED,m}} = F_{\text{BED,max}} \times \left[\frac{2 \times v_1 \times v_2 \times \left(\text{Log} \frac{v_0}{v_1} + 1 \right) - v_2^2 - \frac{1}{3} \times (v_3^2 + v_3 \times v_4 + v_4^2)}{v_0^2} \right] \quad (14)$$

when $v_1 > v_0 > v_2$

$$F_{\text{BED,m}} = F_{\text{BED,max}} \times \left[\frac{2 \times v_0 \times v_2 - v_2^2 - \frac{1}{3} \times (v_3^2 + v_3 \times v_4 + v_4^2)}{v_0^2} \right] \quad (15)$$

when $v_2 > v_0 > v_3$

$$F_{\text{BED},m} = F_{\text{BED},\max} \times \left[\frac{v_0^2 - \frac{1}{3} \times (v_3^2 + v_3 \times v_4 + v_4^2)}{v_0^2} \right] \quad (16)$$

when $v_3 > v_0 > v_4$

$$F_{\text{BED},m} = F_{\text{BED},\max} \times \frac{v_0 - v_4}{v_3 - v_4} \times \frac{2 \times v_0^2 - v_0 \times v_4 - v_4^2}{3 \times v_0^2} \quad (17)$$

where

$F_{\text{BED},m}$ is the mean electro-dynamic braking force, in newtons (N)

$F_{\text{BED},\max}$ is the maximum electro-dynamic braking force, in newtons (N). This is equal to the value of the force in the constant section;

v_1, v_2 are particular speeds, in km/h;

v_0 is the initial speed, in km/h;

$v_{\max}$ is the maximum operational speed, in km/h.

NOTE The last section of the curve (depending on $1/V^2$) is used with regenerative braking when the voltage needs to be limited. When this section is not used, the maximum speed $V_{\max}$ equals V_1 .

5.3.2.2 Fluid retarder

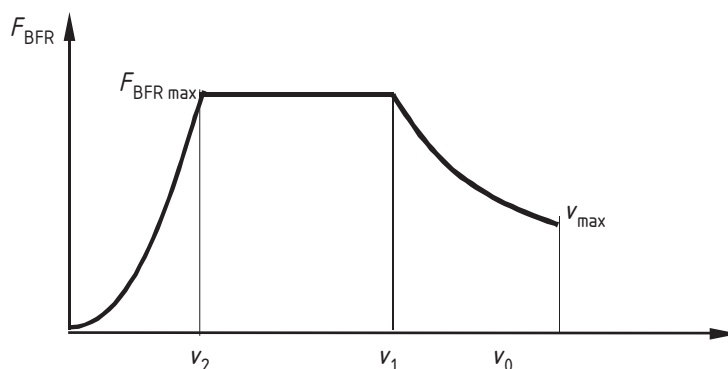


Figure 9 — Characteristic curve for fluid retarder braking force

The fluid retarder braking force can be represented by a characteristic curve, as shown in Figure 9, which is composed of:

— a parabolic section from 0 to v_2 $F_{\text{BFR}} = F_{\text{BFR},\max} \times \frac{v^2}{v_2^2}$ (18)

— a constant section from v_2 to v_1 $F_{\text{BFR}} = F_{\text{BFR},\max}$ (19)

— a hyperbolic section with constant power from v_1 to $v_{\max}$