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Railway applications — Railway braking — Country specific applications for ISO 20138-1

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Foreword

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

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 269, *Railway applications,* Subcommittee SC 2, *Rolling stock*.

This second edition cancels and replaces the first edition (ISO/TR 22131:2018), which has been technically revised.

The main change is: the symbols and terms in Clause 6 have been revised.

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.

Railway applications — Railway braking — Country specific applications for ISO 20138-1

1 Scope

This document provides additional information to assist the understanding and the use of ISO 20138-1. The calculations in this document follow the same principles but they are slightly different.

This document contains country specific calculation approaches currently in use and represents the state of knowledge including for calculating:

— stopping and slowing distances;

— equivalent response time;

— brake performance;

— brake ratio.

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.

ISO 20138-1:2018, *Railway applications — Calculation of braking performance (stopping, slowing and stationary braking) — Part 1: General algorithms utilizing mean value calculation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20138-1 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/

4 Slowing or stopping distance calculation using a method implemented in France

4.1 General

This calculation is based on the alternative method of equivalent response time calculation, as used in the French railway requirements, in particular, for trains operating in "G" position.

4.2 Symbols and abbreviations

For the purpose of Clause 4, the terms, symbols and abbreviations defined in Table 1 apply.

Table 1 — Symbols and abbreviations

Symbol or abbreviation	Description	Unit
1	Point when the brake force, deceleration or pressure has been substantially achieved, typically 95 %	—
a_e	Equivalent deceleration (on level track, without considering gradient effect)	m/s^2
g	Standard acceleration of gravity	m/s^2
"G" position	Distributor valve and distributor isolating devices (as defined in EN 15355[9])	—
i	Gradient of the track (positive rising/negative falling)	—
s_{grad}	Stopping/slowing distance on a gradient	m
s_{tests}	Stopping distances measured during the tests	m
t_a	Delay time	s
t_{ab}	Build-up time	s
t_e	Equivalent response time	s
$2{\cdot}t_e$	Equivalent response time multiplied by 2	s
v_0	Initial speed	m/s
v_{fin}	Final speed (= 0 in the case of a stopping distance)	m/s
X	Time	s
Y	Factor of nominal braking force, deceleration or pressure	—

4.3 Slowing or stopping distance calculation

4.3.1 French model for "G" position

This model provides a high level of accuracy for the calculation of stopping distances of trains with long build up time (e.g. "G" position). It is currently used by the infrastructure managers in order to evaluate the conformance of a train with the train control system and the length of the signalling sections.

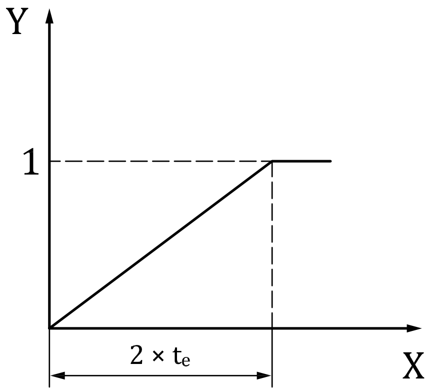
For this French model of slowing or stopping distance calculation, Figure 1 can be used for trains operating in "G" position for brake systems with retarding forces acting on rail contact point.

The model uses a linear development of the effort from 0 to 1 during a time of $2 \cdot t_e$.

The equivalent response time, t_e, can be calculated as set out in Formula (1):

$$t_e = t_a + \frac{t_{ab}}{2} \tag{1}$$

where t_a and t_{ab} are in accordance with ISO 20138-1:2018, 5.5.2.



Key

X time, in s

Y factor of nominal braking force, deceleration or pressure

1 point when the full brake force, deceleration or pressure has been achieved, typically 95 % of maximum value

t_e equivalent response time, in s

Figure 1 — Model based on a linear development of the effort from 0 to 1 during a time of 2 · t_e

The stopping (v_{fin} = 0) or slowing distance can be calculated as set out in Formula (2):

$$s_{grad} = v_0 \cdot t_e \cdot \frac{a_e}{a_e + g \cdot i} + \frac{v_0^2 - v_{fin}^2}{2 \cdot (a_e + g \cdot i)} - \frac{a_e \cdot t_e^2 \cdot (a_e + 4 \cdot g \cdot i)}{6 \cdot (a_e + g \cdot i)} \quad (2)$$

NOTE 1 The equivalent deceleration, a_e, does not take the effect of the gradient into account.

Formula (2) is valid for calculating the stopping/slowing distance with a fully established brake, provided that the condition in Formula (3) is fulfilled:

$$v_0 - v_{fin} \geq (a_e + 2 \cdot i) \cdot t_e \quad (3)$$

where

s_{grad} is the stopping/slowing distance on a gradient, in m;

v_0 is the initial speed, in m/s;

t_e is the equivalent response time, in s;

a_e is the equivalent deceleration (on level track, without considering gradient effect), in m/s^2;

g is the standard acceleration of gravity, in m/s^2;

i is the gradient of the track (positive rising/negative falling);

v_{fin} is the final speed (= 0 in the case of a stopping distance), in m/s.

NOTE 2 The stopping/slowing distance as calculated by applying Formula (2) is shorter than calculated according to the method described in ISO 20138-1:2018, 5.7.4.

4.3.2 Calculation using ISO 20138-1:2018, 5.7.5.1 step model

ISO 20138-1:2018, 5.7.5.1 gives Formula (4) for calculations on level track (i = 0) or with gradient. It uses the model for theoretical response time $t_e = t_a + \frac{t_{ab}}{2}$ as “step” model.

$$s_{grad} = v_0 \cdot t_e - \frac{1}{2}\frac{m_{st}}{m_{dyn}} \cdot g \cdot i \cdot t_e^2 + \frac{\left(v_0 - \frac{m_{st}}{m_{dyn}} \cdot g \cdot i \cdot t_e\right)^2 - v_{fin}^2}{2a_e} \quad (4)$$

With train resistance and dynamic mass which compensate each other and v_{fin} = 0, the formula is simplified as Formula (5):

$$s_{grad} = v_0 \cdot t_e - \frac{g \cdot i \cdot t_e^2}{2} + \frac{(v_0 - g \cdot i \cdot t_e)^2}{2a_e} \quad (5)$$

where

s_{grad} is the stopping/slowing distance on a gradient, in m;

v_0 is the initial speed, in m/s;

t_e is the equivalent response time, in s;

m_{st} is the static mass, in kg;

m_{dyn} is the dynamic mass, in kg;

g is the standard acceleration of gravity, in m/s^2;

i is the gradient of the track (positive rising/negative falling);

a_e is the equivalent deceleration (on level track, without considering gradient effect), in m/s^2;

v_{fin} is the final speed (= 0 in the case of a stopping distance), in m/s.

4.4 Example of calculation

4.4.1 Test results

This example is based on a long train of 1 000 m in “G” position.

As a reference for further comparison, the tests realized on the tracks have provided the following results for the stopping distances s_{tests}:

Stopping distance on level track	824 m
Stopping distance on a down gradient of 5 ‰	885 m
Stopping distance on an up gradient of 5 ‰	776 m

The equivalent response time, t_e (delay time + 1/2 brake build-up time), derived from the results of the tests is 15,5 s.

The equivalent deceleration without including the effect of the gradient, a_e, derived from the results of the tests is 0,89 m/s^2.

4.4.2 Comparison of calculation models with test results

The stopping distances, s_{tests}, calculated using Formula (5) (simplified ISO 20138-1 “step model”) are given in Table 2.

Table 2 — Stopping distances calculated using step model

	v_0 km/h	g m/s²	i mm/m	t_e s	a_e m/s²	s_{grad} m	s_{tests} m	s_{grad} vs s_{tests} difference %
Level track	100	9,81	0	15,5	0,89	864,0	824	5 %
Up gradient	100	9,81	5	15,5	0,89	834,7	776	8 %
Down gradient	100	9,81	−5	15,5	0,89	894,0	885	1 %

The stopping distances, s_{tests}, calculated using Formula (2) (French alternative method) are given in Table 3.

Table 3 — Stopping distances calculated using French alternative method

	v_0	g	i	t_e	a_e	**Condition:** $v_0 \geq (a_e + 2\,g \cdot i)\,t_e$		s_{grad}	s_{tests}	s_{grad} vs s_{tests} difference
						v_0	$(a_e + 2\,g \cdot i)\,t_e$			
	km/h	m/s²	mm/m	s	m/s²	m/s	m/s	m	m	%
Level track	100	9,81	0	15,5	0,89	27,8	>13,8	828,4	824	<1
Up gradient	100	9,81	5	15,5	0,89	27,8	>15,3	777,7	776	0
Down gradient	100	9,81	−5	15,5	0,89	27,8	>12,3	885,0	885	0

The values in Table 3 demonstrate the following.

— The stopping distances calculated with the French alternative method are shorter than the ones of the simplified “step model” of ISO 20138-1.

— The stopping distances calculated with the French alternative method are more accurate and closer to the test results on the track.

5 Calculation of braking performance implemented in Japan

5.1 General

In Japan, the fundamental law is the Railway Operation Act.[3] In addition, the Technical Regulatory Standards on Japanese Railway are published by the Ministry of Land, Infrastructure and Transport and Tourism (MILT). The technical regulation consists of ministerial ordinances and approved model specifications. Explanatory documents which complement the ministerial ordinances and approved model specifications and help users to interpret these correctly have also been published. These documents are generally used as standards as well as Japanese Industrial Standards (JIS)[4][7][8] and Japan Association of Rolling Stock Industries standards (JRIS),[5][6] etc. in Japan.

5.2 Brake ratio for a single vehicle

The brake ratio is used to compare the capability of single vehicles and is used for design assessment.

The braking force for a single vehicle can be calculated as set out in Formula (6):

$$F_{tot} = n_{cyl} \cdot A_{tot} \cdot p_c \cdot i_{tot} \cdot \eta_{tot} \tag{6}$$

where

F_{tot} is the braking force, in kN;

n_{cyl} is the number of brake cylinders;

A_{tot} is the area of a cylinder, in m^2;

p_c is the brake cylinder pressure, in kPa;

i_{tot} is the total rigging ratio;

η_{tot} is the mechanical efficiency.

The brake ratio for a single vehicle can be calculated as set out in Formula (7):

$$\theta = \frac{F_{tot}}{M_{tot} \cdot g} \cdot C \cdot 100 \quad (7)$$

with

$$C = \frac{\mu_A}{\mu_C} \quad (8)$$

where

θ is the brake ratio for a single vehicle, in %;

F_{tot} is the braking force, in kN;

M_{tot} is the operational mass of the vehicle plus load, in t;

g is the standard acceleration of gravity, in m/s^2;

C is the ratio of friction coefficients;

μ_A is the friction coefficient of applied brake block;

μ_C is the friction coefficient of cast iron block (assumed to be 0,15).

NOTE The friction coefficient of applied brake block, μ_A, and the acceptance criteria of the brake ratio are outside the scope of this document.

5.3 Example for brake ratio calculation

In case of a vehicle with a tread brake unit per wheel, as shown in Figure 2, input data are shown in Table 4.

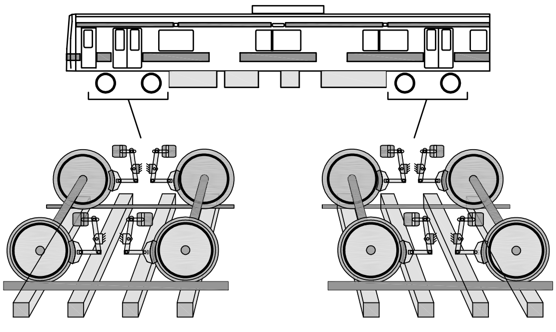


Figure 2 — Vehicle with a tread brake unit per wheel

Table 4 — Input data

Description	Symbol	Example value	Unit
Diameter of brake cylinder	d_{cyl}	0,152	m
Standard acceleration of gravity	g	9,807	m/s²
Total rigging ratio	i_{tot}	3,6	—
Operational mass	m_{op}	31,4	t
Mass per person	m_p	55	kg/person
Number of brake cylinders	n_{cyl}	8	—
Passenger capacity	n_p	153	—
Brake cylinder pressure	p_c	303	kPa
Mechanical efficiency (including counter force)	η_{tot}	1,0	—
Friction coefficient of applied brake block (composite brake block)	μ_A	0,3	—

The braking force of a vehicle can be calculated as set out in Formula (6):

$$F_{tot} = [(0{,}152\,m)^2 \cdot \pi / 4] \cdot 8 \cdot 303 \cdot 3{,}6 \cdot 1{,}0$$

$$F_{tot} = 158{,}4\ \text{kN}$$

The mass of a loaded vehicle can be calculated as set out in Formula (9):

$$M_{tot} = m_{op} + n_p \cdot m_p \tag{9}$$

$$M_{tot} = 31{,}4 + 153 \cdot \left(\frac{55}{1\,000}\right)$$

$$M_{tot} = 39{,}82\ \text{t}$$

The ratio of friction coefficients, C, using composite brake blocks can be calculated as set out in Formula (8):

$$C = \frac{0{,}3}{0{,}15} = 2{,}0$$

In the end, the brake ratio for a loaded vehicle can be calculated as set out in Formula (7):

$$\theta = \frac{158{,}4}{39{,}82\,\text{t} \cdot 9{,}807} \cdot 2{,}0 \cdot 100$$

$$\theta = 81\ \%$$

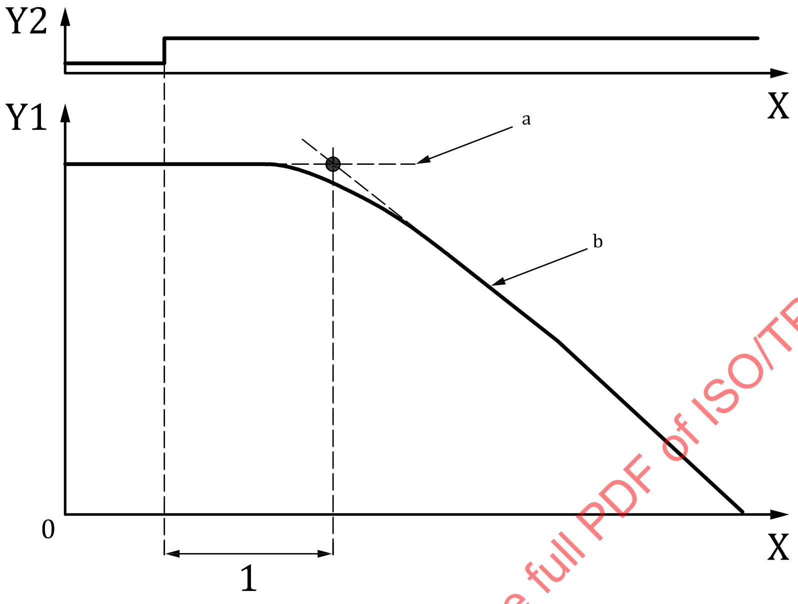
5.4 Equivalent response time

5.4.1 General

In Japan, an equivalent response time is determined as below.

5.4.2 Case 1: Determination based on train speed

The equivalent response time is determined based on train speed. In this case, the brake command and speed are measured. In the time series chart shown in Figure 3, the horizontal line is extended from the speed at the starting point of the braking. Moreover, another line is extended from around the speed at which the deceleration is almost constant. The equivalent response time is decided as the time between the start of braking and cross point of two extended lines.



Key

X time, in s

Y1 speed

Y2 brake command

1 equivalent response time

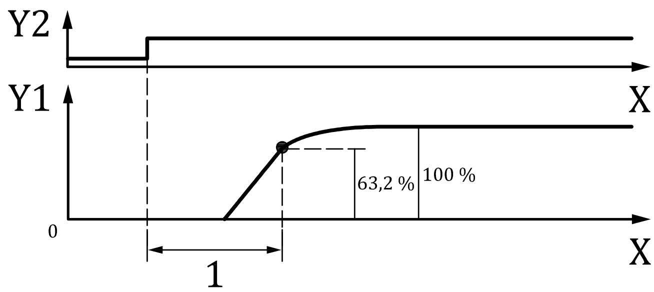
[a] Extend the horizontal line from the starting point of the braking.

[b] Deceleration is almost constant.

Figure 3 — Equivalent response time in case 1 "based on train speed"

5.4.3 Case 2: Determination based on BC pressure response

The equivalent response time is determined based on BC pressure response as shown in Figure 4. In this case, it is the time when the brake cylinder pressure reaches about 60 % to 70 % (typically 63,2 %) of set point from the starting point of braking.



Key

X time, in s

Y1 brake cylinder pressure

Y2 brake command

1 equivalent response time

Figure 4 — Equivalent response time in case 2 "BC pressure response"

6 Stopping or slowing distance calculation methods for some particular rolling stock in China

6.1 General

The following text is based on Reference [2].

Until now, some traditional calculation methods have been used for conventional predefined units, for example, long trains hauled by locomotive. The numerical parameters given in this traditional method are based on test data and experience and are used for the vehicle design.

6.2 Symbols and abbreviations

The symbols and abbreviations used in Clause 6 are detailed in Table 5.

Table 5 — Symbols

Description	Symbol	Unit
Total braking force of train	B	kN
Dynamic brake force	B_d	kN
Train unit brake ratio	b	N/kN
Coefficient independent of speed	C_1	N/kN
Coefficient dependent on speed	C_2	N/kN
Coefficient dependent on squared speed	C_3	N/kN
Diameter of brake cylinder	d_z	mm
Hauled mass	G	t
Standard acceleration of gravity	g	m/s^2
Gradient (positive rising/negative falling)	i	‰
Calculation gradient	i_j	‰
Single brake block force/braking force	K	kN
Brake pad force of each brake pad	K'	kN
Conversion brake block force of train	K_h	kN
Conversion brake block force of locomotive	K'_h	kN
Conversion brake block force of vehicle	K''_h	kN
Total distance along the curve including the transition curve lengths	L_r	m
Equivalent constant curve length	l_r	m
Transition length	l_{yz1}, l_{yz2}	m
Train overall length	l_1	m
Number of vehicles	n	—
Number of brake blocks	n_k	—
Number of brake cylinders	n_z	—
Mass of locomotive	P	t
Cylinder pressure	p_z	kPa
Brake pipe pressure	p_1	kPa
Curve radius	R	m
Wheel radius	R_c	mm
Brake pipe pressure drop	r	kPa
Mean swept radius of the brake pad on the disc face	r_m	mm
Effective braking distance	s_e	m

Table 5 *(continued)*

Description	Symbol	Unit
Free running distance	s_k	m
Stopping/slowing distance	s_z	m
Effective braking time	t_e	s
Free running time	t_k	s
Braking time	t_z	s
Running speed	v	km/h
Initial speed	v_0	km/h
Particular speeds	$v_1 \dots v_2$	km/h
Angle of constant curve sector	α	°
Service brake coefficient	β_c	—
Rigging ratio	γ_z	—
Rigging efficiency	η_z	—
Conversion braking ratio of train	ϑ_h	
Train conversion brake ratio for service brake	ϑ_{hc}	
Coefficient of adhesion	μ_z	—
Circumference rate	π	—
Conversion friction coefficient	φ_h	—
Friction coefficient of each type of brake block	φ_k	—
Additional curve resistance	ω_r	N/kN
Basic running resistance for a train	ω_0	N/kN
Basic running resistance for a single vehicle	ω'_0	N/kN

6.3 Train resistance retarding forces

6.3.1 Basic running resistance

The basic running resistance for a single vehicle, ω_0', can be calculated as set out in Formula (10).

$$\omega_0' = C_1 + C_2 \cdot v + C_3 \cdot v^2 \qquad (10)$$

where

ω_0' is the basic running resistance for a single vehicle, in N/kN;

C_1 is the coefficient independent of speed, in N/kN;

C_2 is the coefficient dependent on speed, in N/kN × h/km;

C_3 is the coefficient dependent on squared speed, in N/kN × h^2/km^2;

v is the running speed, in km/h.

Table 6 sets out the characteristic coefficients, C_1, C_2 and C_3, for specific Chinese vehicles.

Table 6 — Characteristic coefficients for specific Chinese vehicles

Vehicle type	Characteristic coefficient		
	C_1	C_2	C_3
Electric locomotives			
SS_1, SS_3 and SS_4	2,25	0,019 0	0,000 320
SS_7	1,40	0,003 8	0,000 348
SS_8	1,02	0,003 5	0,000 426
6K	1,02	0,003 5	0,000 426
8G	2,55	0,008 3	0,000 212
Diesel locomotives			
DF	2,93	0,007 3	0,000 27
DF_2	2,98	0,020 2	0,000 33
DF_4 (for freight wagon, for passenger coach)	2,28	0,029 3	0,000 178
DF_4B (for freight wagon, for passenger coach)			
DF_4C (for freight wagon)			
DF_5	1,31	0,016 7	0,000 391
DF_7D	2,28	0,029 3	0,000 178
DF_8	2,40	0,002 2	0,000 391
DF_{11}	0,86	0,005 4	0,000 218
DFH_3	1,96	0,010 5	0,000 549
Steam locomotives			
JS	0,74	0,016 8	0,000 700
QJ	0,70	0,024 3	0,000 673
Passenger coaches			
21, 22 (v_{max} = 120 km/h)	1,66	0,007 5	0,000 155
25B, 25G (v_{max} = 140 km/h)	1,82	0,010 0	0,000 145
Single deck passenger coach (v_{max} = 160 km/h)	1,61	0,004 0	0,000 187
Double deck passenger coach (v_{max} = 160 km/h)	1,24	0,003 5	0,000 157
Freight wagons			
Rolling bearing wagon (loaded)[a]	0,92	0,004 8	0,000 125
Sliding bearing wagon (loaded)	1,07	0,001 1	0,000 236
Oil tank wagon trainset (loaded)[b]	0,53	0,012 1	0,000 080
Empty wagon (fit for all types of wagon)	2,23	0,005 3	0,000 675

[a] Coefficients are used when oil tank wagon is coupled with other freight wagons.

[b] If a train consists of one or several oil tank wagons (not an oil tank wagon trainset), then the basic running resistance for a single oil tank wagon is calculated as rolling bearing wagon.

The basic running resistance of train, ω_0, is calculated as set out in Formula (11).

$$\omega_0 = \frac{P \cdot \omega_0' + G \cdot \omega_0'}{P + G} \quad (11)$$

where

ω_0 is the basic running resistance for a train, in N/kN;

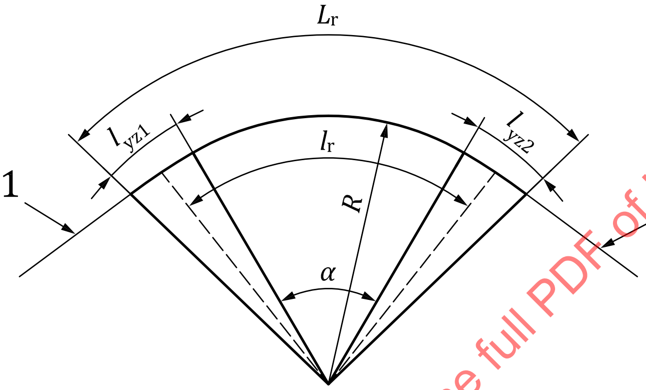
P is the mass of locomotive, in t;

ω_0' is the basic running resistance for a single vehicle, in N/kN;

G is the hauled mass, in t.

6.3.2 Curve resistance

The curve resistance depends on curve length and radius as shown in Figure 5. The dimensions of the curve-geometry are given by railway map.



Key

L_r total distance along the curve including the transition curve lengths, in m

l_r equivalent constant curve length, in m

l_{yz1}, l_{yz2} transition length, in m

R curve radius, in m

α angle of constant curve sector, in °

1 track centre line

Figure 5 — Curve lengths

The curve resistance of locomotive and train ω_r can be calculated as set out in Formulae (12), (13) and (14).

a) Train overall length lower than or equal to equivalent constant curve length, l_r.

$$\omega_r = \frac{600}{R} \tag{12}$$

b) Train overall length greater than equivalent constant curve length, l_r.

$$\omega_r = \frac{10,5 \cdot \alpha}{l_1} \tag{13}$$

or

$$\omega_r = \frac{600}{R} \cdot \frac{l_r}{l_1} \tag{14}$$

The equivalent constant curve length, l_r, can be calculated as set out in Formula (15).

$$l_r = L_r - \frac{1}{2} \cdot \left(l_{yz1} + l_{yz2}\right) \quad (15)$$

where

ω_r is the additional curve resistance, in N/kN;

R is the curve radius, in m;

α is the angle of constant curve sector, in °;

l_1 is the train overall length, in m;

l_r is the equivalent constant curve length, in m;

L_r is the total distance along the curve including the transition curve lengths, in m;

l_{yz1}, l_{yz2} is the transition length, in m.

6.4 Train braking force

6.4.1 Total braking force of train

The total braking force of train, B, is the sum of single brake block forces, K, applied to the brake blocks multiplied by friction coefficient.

a) The total braking force can be calculated using real brake block force as set out in Formula (16).

$$B = \sum (K \cdot \varphi_k) \quad (16)$$

where

B is the total braking force of train, in kN;

K is the single brake block force, in kN;

φ_k is the friction coefficient of each type of brake block.

b) The total braking force is calculated using conversion brake block force and conversion friction coefficient.

In order to simplify the total braking force calculation process, the conversion calculation method can be used. The total braking force can be also calculated as set out in Formula (17).

$$B = \sum (\varphi_h \cdot \sum K_h) \quad (17)$$

where

B is the total braking force of train, in kN;

φ_h is the conversion friction coefficient;

K_h is the conversion brake block force of train, in kN.

6.4.2 Real friction coefficient

The real friction coefficient of each type of brake block, φ_k, and brake pad can be calculated as set out in Formulae (18) to (21):

— medium phosphorous cast iron brake block:

$$\varphi_k = 0{,}64 \frac{K+100}{5K+100} \cdot \frac{3{,}6v+100}{14v+100} + 0{,}000\,7(110 - v_0) \quad (18)$$

— high phosphorous cast iron brake block:

$$\varphi_k = 0{,}82 \frac{K+100}{7K+100} \cdot \frac{17v+100}{60v+100} + 0{,}001\,2(120 - v_0) \quad (19)$$

— low friction coefficient composite brake block:

$$\varphi_k = 0{,}25 \frac{K+500}{6K+100} \cdot \frac{4v+150}{10v+150} + 0{,}000\,6(100 - v_0) \quad (20)$$

— high friction coefficient composite brake block:

$$\varphi_k = 0{,}41 \frac{K+200}{4K+200} \cdot \frac{v+150}{2v+150} \quad (21)$$

where

φ_k is the friction coefficient of each type of brake block;

K is the single brake block force, in kN;

v is the running speed, in km/h;

v_0 is the initial speed, in km/h.

6.4.3 Conversion friction coefficient

For medium phosphorous cast iron brake block, high phosphorous cast iron brake block and low friction coefficient composite brake block, the conversion friction coefficient, φ_h, is defined with the real friction coefficient using the single brake block force, K = 25 kN.

The conversion friction coefficient, φ_h, can be calculated as set out in Formulae (22) to (26):

— medium phosphorous cast iron brake block:

$$\varphi_h = 0{,}356 \frac{3{,}6v+100}{14v+100} + 0{,}000\,7(110 - v_0) \quad (22)$$

— high phosphorous cast iron brake block:

$$\varphi_h = 0{,}372 \frac{17v+100}{60v+100} + 0{,}001\,2(120 - v_0) \quad (23)$$

— low friction coefficient composite brake block:

$$\varphi_h = 0{,}202 \frac{4v+150}{10v+150} + 0{,}000\,6(100 - v_0) \quad (24)$$

— for high friction coefficient composite brake block, the conversion friction coefficient, φ_h, is defined with the real friction coefficient by the single brake block force, K = 20 kN:

$$\varphi_h = 0{,}322 \frac{v+150}{2v+150} \tag{25}$$

— for composite brake pad, the conversion friction coefficient, φ_h, is defined with the real friction coefficient by the brake pad force, K' = 20 kN, which is converted to K at wheel tread:

$$\varphi_h = 0{,}358 \frac{v+150}{2v+150} \tag{26}$$

The conversion friction coefficient for medium phosphorous cast iron [see Formula (22)] can be used:

— for trains equipped with disc brake and tread brake units up to a speed of 160 km/h;

— for trains consisting of wagons equipped with brake blocks of a mix of medium phosphorous cast iron, high phosphorous cast iron and/or low friction composite brake blocks.

6.4.4 Real brake block force

6.4.4.1 Single brake block force for tread brake

The single brake block force, K, per brake block of locomotive and vehicle can be calculated as set out in Formula (27).

$$K = \frac{\frac{\pi}{4} d_z^2 \cdot p_z \cdot \eta_z \cdot \gamma_z \cdot n_z}{n_k \cdot 10^6} \tag{27}$$

where

K is the single brake block force, in kN;

d_z is the diameter of brake cylinder, in mm;

p_z is the cylinder pressure, in kPa;

η_z is the rigging efficiency;

γ_z is the rigging ratio;

n_z is the number of brake cylinders;

n_k is the number of brake blocks.

6.4.4.2 Brake pad force for disc brake

The brake pad force of each brake pad, K', of locomotive and vehicle can be calculated as set out in Formula (28).

$$K' = \frac{\pi}{4} d_z^2 \cdot p_z \cdot \eta_z \cdot \gamma_z \cdot n_z \cdot 10^{-6} \tag{28}$$

where

K' is the brake pad force of each brake pad, in kN;

d_z is the diameter of brake cylinder, in mm;

p_z is the cylinder pressure, in kPa;

η_z is the rigging efficiency;

γ_z is the rigging ratio;

n_z is the number of brake cylinders.

NOTE This formula does not account for resistance from the spring within the brake cylinder, which otherwise would result in a variation of the rigging efficiency with cylinder pressure.

The single brake block force/braking force, K, is converted from brake disc to wheel tread can be calculated as set out in Formula (29).

$$K = \frac{r_m}{R_c} \cdot K' \quad (29)$$

where

K is the single brake block force/ or equivalent brake block force which is converted to wheel tread from the single brake pad (braking force), in kN;

r_m is the mean swept radius of brake pad on the disc face, in mm;

R_c is the wheel radius, in mm;

K' is the brake pad force of each brake pad, in kN.

6.4.5 Nominal values of rigging efficiency

Table 7 sets out the nominal values of rigging efficiency η_z.

Table 7 — Nominal values of rigging efficiency

Vehicle type	Brake equipment type	Rigging efficiency η_z
Locomotive	Tread brake	0,85
Passenger coach	Tread brake	0,85
Passenger coach	Disc brake	
Passenger coach	Tread brake unit	0,90
Freight wagon	Tread brake	0,85

6.4.6 Emergency brake cylinder pressure

Table 8 sets out the emergency brake cylinder pressure for different brake types.

Table 8 — Emergency brake cylinder pressure

Brake type	Load case	Brake pipe pressure p_1 kPa	
		500	600
		Emergency brake cylinder pressure kPa	
K_1 and K_2	—	360	420
GK	Loaded	360	420
	Empty	190	420
120	Loaded	350	410
	Empty	190	190
103	Loaded	360	420
	Empty	190	230
104, L3, GL3 (closed supplementary reservoir)		—	420
Distributor valve for locomotive		450	450

6.4.7 Conversion brake block force

The conversion brake block force of train, K_h, is calculated as set out from Formulae (30) to (33):

— medium phosphorous cast iron brake block:

$$K_h = 1{,}8\frac{K+100}{5K+100}\cdot K \tag{30}$$

— high phosphorous cast iron brake block:

$$K_h = 2{,}2\frac{K+100}{7K+100}\cdot K \tag{31}$$

— low friction coefficient composite brake block:

$$K_h = 1{,}24\frac{K+500}{6K+500}\cdot K \tag{32}$$

— high friction coefficient composite brake block:

$$K_h = 1{,}273\frac{K+200}{4K+200}\cdot K \tag{33}$$

The conversion brake block force of train, K_h, is calculated as set out in Formula (34):

$$K_h = 1{,}145\frac{K+200}{4K+200}\cdot K \tag{34}$$

where

K_h is the conversion brake block force of train, in kN;

K is the single brake block force/braking force, in kN.

The conversion brake block force for different types of locomotives and vehicles have been defined in Table 9.

6.4.8 Conversion braking ratio

The conversion braking ratio of train, ϑ_h, is calculated as set out in Formula (35):

$$\vartheta_h = \frac{\sum K'_h + \sum K''_h}{(P+G)\cdot g} \tag{35}$$

where

ϑ_h is the conversion braking ratio of train;

K'_h is the conversion brake block force of locomotive, in kN;

K''_h is the conversion brake block force of vehicle, in kN;

P is the mass of locomotive, in t;

G is the hauled mass, in t;

g is the standard acceleration of gravity, in m/s^2.

Table 9 — Conversion brake force for locomotive and vehicle

Type of locomotive and vehicle			Brake pipe pressure p_1	
			500 kPa	600 kPa
Freight wagon	Marking load (payload) 50 t and above (include the thermal vehicle[a] with a load of 40 t), equipped with GK, 120 or 103 brake	Load position	250 kN	280 kN
		Empty position	160 kN	160 kN
	Marking load (payload) 50 t and above, equipped with K2 brake		160 kN	190 kN
	Marking load (payload) 40 t and (include the thermal vehicle[a] with a load level between 25 t and 40 t), equipped with K2 brake		140 kN	170 kN
	Marking load (payload) 30 t, equipped with K2 brake		120 kN	140 kN
	Guard's van	Four axles	90 kN	110 kN
		Two axles	50 kN	60 kN
Passenger coach	L_3, GL_3 (closed supplementary reservoir), 104		—	330 kN
	104 brake, equipped with disc brake unit (without tread brake unit)	Single deck passenger coach	—	210 kN
	104 brake, equipped with disc brake unit (with tread brake unit)	Double deck passenger coach	—	200 kN
		Single deck passenger coach	—	160 kN
	Equipped with disc brake unit (with tread brake unit), 104 brake (no distinction between single deck coach and double deck coach)		—	—
Locomotive	Electrical locomotive	SS1, SS3	700 kN	700 kN
		SS4 (equipped with high friction coefficiency brake block)	400 kN	400 kN
		SS7	840 kN	840 kN
		8G	520 kN	520 kN
		6K	920 kN	920 kN
		SS8 (equipped with powder metallurgy brake block)	280 kN	280 kN
	Diesel locomotive	DF, DFH3	550 kN	550 kN
		DF4 (for freight wagon and passenger coach), DF4B (for freight wagon and passenger coach), DF4C (for freight wagon) DF8, DF11	650 kN	650 kN
		ND5 (equipped with high friction coefficiency brake block)	420 kN	420 kN
		ND2	700 kN	700 kN
		DF7D (equipped with low friction coefficiency brake block)	720 kN	720 kN
	Steam locomotive	QJ	650 kN	650 kN
		JS	600 kN	600 kN

[a] Freezer/refrigerated vehicle.

NOTE This table does not indicate the brake block type medium phosphorous cast iron.

When service brake is applied, the train conversion brake ratio for service brake, ϑ_{hc}, is calculated as set out in Formula (36):

$$\vartheta_{hc} = \vartheta_h \cdot \beta_c \quad (36)$$

where

ϑ_{hc} is the train conversion brake ratio for service brake;

ϑ_h is the conversion braking ratio of train;

β_c is the service brake coefficient.

The service brake coefficient values are presented in Table 10.

Table 10 — Service brake coefficient

Vehicle type	**Brake pipe pressure** p_1 kPa	**Brake pipe pressure drop** r kPa												
		50	60	70	80	90	100	110	120	130	140	150	160	170
		Service brake coefficient β_c												
Passenger coach	600	0,19	0,29	0,39	0,47	0,55	0,61	0,69	0,76	0,82	0,88	0,93	0,98	1,00
Freight wagon	600	0,17	0,28	0,37	0,46	0,53	0,60	0,67	0,73	0,78	0,83	0,88	0,93	0,96
	500	0,19	0,32	0,42	0,52	0,60	0,68	0,75	0,82	0,89	0,95	—	—	—

6.4.9 Train unit brake ratio

The train unit brake ratio, *b*, is calculated as set out in Formula (37) or Formula (38):

$$b = \frac{B \cdot 10^3}{(P + G) \cdot g} \tag{37}$$

or

$$b = 1\,000 \cdot \vartheta_h \cdot \varphi_h \tag{38}$$

where

b is the train unit brake ratio, in N/kN;

B is the total braking force of train, in kN;

P is the mass of locomotive, in t;

G is the hauled mass, in t;

g is the standard acceleration of gravity, in m/s^2;

ϑ_h is the conversion braking ratio of train;

φ_h is the conversion friction coefficient.

6.4.10 Dynamic brake force

Dynamic brake force, B_d, includes the rheostatic brake (electrical locomotive and diesel locomotive) and regenerative brake (electrical locomotive) and is defined.