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Interested committees:

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Part 2: General algorithms utilizing step by step calculation.

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This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at <https://standardsdevelopment.bsigroup.com/>. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 20138-2

Railway applications — Calculation of braking performance (stopping, slowing and stationary braking) —

Part 2: General algorithms utilizing step by step calculation

*Applications ferroviaires — Calcul des performances de freinage
(freinage d'arrêt, de ralentissement et d'immobilisation) —*

Partie 2: Algorithmes généraux utilisant le calcul pas à pas

ICS: 45.020

ISO/TC 269/SC 2

Secretariat: **AFNOR**

Voting begins on:
2024-11-20

Voting terminates on:
2025-02-12

This document is circulated as received from the committee secretariat.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 02, *Rolling stock*.

This second edition cancels and replaces the first edition (ISO 20138-2:2019), which has been technically revised.

The main changes are as follows:

- normative reference to ISO 24478 has been added;
- [Clause 3](#) “Terms and definitions” has been revised (terms 3.1 and 3.2 have been deleted and the document refers to ISO 24478 and ISO 20138-1 only);
- [Clause 4](#) “Symbols” and [Table 1](#) have been revised;
- [Clause 5](#) “General explanation of step-by-step calculation” has been revised;
- [Clause 6](#) “Considerations for stopping/slowing distances and deceleration calculations” has been revised;
- [Annex A](#) “Workflow of kinetic calculations” has been revised;
- [Annex B](#) has been revised and renamed in “Calculation of retarding forces (non-stationary)”;
- [Annex C](#) “Examples for brake calculation” has been revised;
- Bibliography has been revised.

A list of all parts in the ISO 20138 series can be found on the ISO website.

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

Introduction

This document describes methodologies for calculation of braking performance such as stopping distance, deceleration, power and energy for railway rolling stock.

The objective of this document is to enable the railway industry and operators to work with common calculation methods.

The ISO 20138 series consists of two parts (ISO 20138-1 and this document) which complement each other.

This document describes the step by step calculation methods for railway applications applicable to all countries. In addition, the algorithms provide a means of comparing the results of other braking performance calculation methods.

The methodology of step by step calculation is based on numerical time integration.

The step by step calculation method cannot be used for stationary braking. This document considers an example for stationary braking of a multiple unit in accordance with ISO 20138-1.

When calculating stopping and slowing distances using the step by step calculation method, it is intended that both ISO 20138-1 and this document be considered.

Railway applications — Calculation of braking performance (stopping, slowing and stationary braking) —

Part 2: General algorithms utilizing step by step calculation

1 Scope

This document specifies the methodologies for calculation of braking performance for railway rolling stock.

This document describes the general algorithms/formulae using instantaneous value inputs to perform calculations of brake equipment and braking performance, in terms of stopping/slowng distances, braking power and energy for all types of rolling stock, either as vehicles or units.

The calculations can be performed at any stage of the assessment process (design, manufacture, testing, verification, investigation, etc.) of railway rolling stock. This document does not set out specific acceptance criteria (pass/fail).

This document is not intended to be used as a design guide for the selection of brake subsystems and does not specify performance requirements. This document does not provide a method to calculate the extension of stopping distances when the level of demanded wheel/rail adhesion exceeds the available wheel/rail adhesion (wheel slide activity).

This document contains examples of the calculation of braking forces for different brake equipment types and examples of the calculation of stopping distance for vehicles or units.

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

ISO 24478, *Railway applications — Braking — General vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20138-1 and ISO 24478 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 Symbols

For the purposes of this document, the general symbols given in [Table 1](#) and ISO/DIS 20138-1:2024, Table 1 apply.

Table 1 — Symbols

Symbol	Definition	Unit
a	Instantaneous deceleration	m/s ²
$a_{f(t) = 100 \%}$	Deceleration during each chosen time step	m/s ²
a_j	Constant deceleration during iteration step j	m/s ²
$D_{\max}$	Wheel diameter max.	m
$D_{\min}$	Wheel diameter min.	m
$F_{B,\tau,\text{req,rem}}$	Remaining force of static mass	N
$F_{\text{pad},i}$	Brake pad force (i is an index used for sorting)	N
$F_{r,n}$	Instantaneous braking force of brake system type n	N
$F_{r,n,j}$	Instantaneous braking force for brake system type n during iteration step j	N
$F_{r,\text{nom}}$	Nominal retarding force	N
$f(t)$	Factor dependent on time	—
$f(t) = 100 \%$	Index for 100 % applied braking force without consideration of any time characteristics	—
$f(v)$	Factor dependent on speed	—
$f(x)$	Factor (common characteristic) dependent on another variable x	—
i_{tra}	Transmission ratio	—
j	Iteration step number	—
P_n	Instantaneous braking power of brake system type n	W
s_j	Distance travelled from initiation of brake demand at time t_0 to time t_j	m
$s_{n,j}$	Distance travelled during iteration step j whilst the brake system type n is applied	m
$s_{\text{ref}(\Delta t)}$	Stopping/slowness distance, calculated with time step Δt	m
$s_{\text{comp}(2 \cdot \Delta t)}$	Stopping/slowness distance, calculated with doubled time step ($2 \cdot \Delta t$)	m
$s_{f(t) = 100 \%}$	Braking distance without consideration of any time characteristics from initial speed v_0 to final speed v_{fin}	m
t_j	Elapsed time from initiation of brake demand to iteration step j	s
Δt	Time step	s
v	Speed	m/s
v_j	Speed at time t_j	m/s
ε	Speed deviation from v_{fin}	m/s
μ	Coefficient of friction (brake pad or block)	—
ξ	Relative distance deviation	%
τ_{ax}	Instantaneous value of the required wheel/rail adhesion for the braked wheelset	—
τ_{req}	Required wheel/rail adhesion	—

5 General explanation of step-by-step calculation

5.1 Method

The step-by-step method is used when it is not appropriate or desirable to represent the non-constant retarding and braking forces by mean values. Further details of when the use of mean value calculations is appropriate are given in ISO 20138-1.

Time steps are defined in such a way that the braking forces can be considered as constant throughout each step's duration. The duration of each step can depend on changes in the braking force and is not necessarily fixed (i.e. algorithms can be based either on constant or adaptive time step integration schemes). Each time step is characterised by an initial state and a final state, e.g. an initial and a final speed.

For each time step, the distance travelled during that time step as well as the final speed are calculated and the deceleration at the end of that time step is calculated according to Newton's laws. The outputs of the calculations for each time step are used as inputs to the calculations for each subsequent time step.

The calculation shall be done in accordance with the workflow as shown in [Annex A](#).

5.2 Braking force models

Mathematical models for common brake subsystems (e.g. magnetic track brakes, electro-dynamic brakes, etc.) are described in [Annex B](#). The mathematical models for disc brakes, tread brakes and external deceleration forces (e.g. wind forces, running resistance) are described in ISO 20138-1.

The impact of time, speed, load, temperature, etc. on the nominal braking force can also be expressed in terms of dimensionless factors (functions), e.g. time dependency $f(t)$, speed dependency $f(v)$, etc. Thus, any deceleration force characteristics due to brake system applications or acting external forces (e.g. wind forces) can be modelled.

These dimensionless factors can take effect at the same time and are thus superposed by multiplication as set out in [Formula \(1\)](#).

$$F_r = F_{r,nom} \cdot f(t) \cdot f(v) \cdot \dots \cdot f(x) \quad (1)$$

where

F_r is the instantaneous braking force acting at the rail generated by the brake equipment, expressed in N;

$F_{r,nom}$ is the nominal braking force, expressed in N;

$f(t)$ is the factor dependent on time;

$f(v)$ is the factor dependent on speed;

$f(x)$ is the factor (common characteristic) dependent on another variable x .

NOTE For nominal retarding forces $F_{r,nom}$ the factors $f(t)$, $f(v)$ and $f(x)$ are equal to 1.

5.3 Algorithm

5.3.1 General description

Instantaneous values are the input data for step-by-step (iterative) calculation. The workflow of [Figure A.1](#) shall be used for performing stopping and slowing calculations.

The numerical integration is time-based.

Every calculation begins with the initial brake demand and the initial vehicle/unit speed.

The initial time step begins at time $t_0 = 0$ s simultaneously with the start of the braking demand. The braking forces which are acting in the initial time step are calculated.

The result of the first iteration step refers to $j = 1$, i.e. $v_1 = v_0 - a_0 \Delta t$, whereas initial values (e.g. initial speed) refer to index $j = 0$.

The vehicle/unit speed at the end of the time step and the distance travelled during this time step are calculated.

The value of the selected parameter (e.g. speed, distance) at the end of the time step is compared with its target value.

If the target value has not been reached, the calculations are repeated for the next time step.

The time step calculation continues until the target value is reached.

5.3.2 Time integration

The time integration should continue until the calculated value of the selected parameter (e.g. speed) is considered equal to the target value of that parameter, i.e. when the condition given in [Formula \(2\)](#) is achieved (where speed is used as an example selected parameter):

$$|v_j - v_{\text{fin}}| < \varepsilon \quad (2)$$

where

v_j is the speed at time t_j , expressed in m/s;

v_{fin} is the final speed, expressed in m/s;

ε is the speed deviation from v_{fin} , expressed in m/s.

A speed deviation not greater than 10^{-3} m/s is considered as suitable for high-speed train calculations. For lower speeds or slowing calculations, other values may be used.

Based on the calculation of braking forces and external forces, the constant deceleration a_j during iteration step j can be calculated as set out in [Formula \(3\)](#):

$$a_j = \frac{(\sum F_{r,n} + \sum F_{\text{ext}})_j}{m_{\text{dyn}}} \quad (3)$$

where

j is the iteration step number;

a_j is the constant deceleration during iteration step j , expressed in m/s^2 ;

$F_{r,n}$ is the instantaneous braking force of brake system type n , expressed in N;

F_{ext} is the external force, expressed in N;

m_{dyn} is the dynamic mass, expressed in kg.

If the target value of the selected parameter has not been achieved, the next time step integration is conducted, utilising the outputs of the preceding step, as shown in [Formulae \(4\)](#) to [\(8\)](#):

$$\text{Speed at start of step } t_{j+1} \quad v_{j+1} = v_j - a_j \cdot \Delta t \quad (4)$$

$$\text{Distance at start of step } t_{j+1} \quad s_{j+1} = s_j + v_j \cdot \Delta t - \frac{1}{2} \cdot a_j \cdot \Delta t^2 \quad (5)$$

$$\text{Deceleration during step } t_{j+1} \quad a_{j+1} = \frac{(\sum F_{r,n} + \sum F_{\text{ext}})_{j+1}}{m_{\text{dyn}}} \quad (6)$$

$$\text{Next time step} \quad t_{j+1} = t_j + \Delta t \quad (7)$$

$$\text{Next time increment} \quad j \rightarrow j+1 \quad (8)$$

where

- a_j is the constant deceleration during iteration step j , expressed in m/s^2 ;
- $F_{r,n}$ is the instantaneous braking force of brake system type n , expressed in N;
- F_{ext} is the external force, expressed in N (for decelerating force **positive** value, for accelerating force **negative** value);
- j is the iteration step number;
- m_{dyn} is the dynamic mass, expressed in kg;
- s_j is the distance travelled from initiation of brake demand at time t_0 to time t_j , expressed in m;
- t_j is the elapsed time from initiation of brake demand to iteration step j , expressed in s;
- Δt is the time step, expressed in s.

The final time step sometimes needs to be adjusted, if necessary, to meet the target value of the selected parameter (see [5.3.1](#)).

Other more detailed algorithms may be used if considered necessary.

5.3.3 Determination of time step/relative distance deviation ξ

The relative distance deviation ξ shall be calculated if the applied integration procedure imposes constant time steps. If an adaptive time integration is used, the requirements in this clause are not applicable.

The time step Δt shall be chosen in such a way that the relative distance deviation is not greater than the minimum precision required. The relative distance deviation ξ is obtained by two separate integrations. The original calculation with time step Δt determines the reference stopping/slowing distance $s_{\text{ref}(\Delta t)}$ and the second integration with doubled time step $2 \cdot \Delta t$ determines a new stopping/slowing distance $s_{\text{comp}(2 \cdot \Delta t)}$ for comparison. The relative distance deviation ξ is calculated in accordance with [Formula \(9\)](#) and shall not be greater than the minimum precision required.

The value of the relative distance deviation ξ shall not exceed a predefined limit value and can be calculated as set out in [Formula \(9\)](#):

$$\xi = \left| \frac{s_{\text{comp}(2 \cdot \Delta t)} - s_{\text{ref}(\Delta t)}}{s_{\text{ref}(\Delta t)}} \right| \cdot 100 \quad (9)$$

where

- ξ is the relative distance deviation, expressed in %;
- $s_{\text{ref}(\Delta t)}$ is the stopping/slowing distance, calculated with time step Δt , expressed in m;
- $s_{\text{comp}(2 \cdot \Delta t)}$ is the stopping/slowing distance, calculated with doubled time step $(2 \cdot \Delta t)$, expressed in m.

Usually, a relative distance deviation of $\xi \leq 0,1 \%$ is considered as acceptable. For low speeds and slowing calculations, greater values of deviation ratio may be used.

NOTE The definition of validation requirements of any numerical integration procedure is outside the scope of this document.

5.3.4 Equivalent system response time $t_{a,e}$

The calculation of equivalent system response time allows the assumption that braking consists first of a "free running time" with braking force equal to zero, followed by a braking time with fully applied braking force. ISO 20138-1 describes the equivalent response time when considering the free running time.

The equivalent system response time $t_{a,e}$ based on stopping and braking distance shall be calculated with two separate time integrations:

- the stopping/slowng distance calculated taking into account the time characteristics of each acting brake equipment type starting at time $t_0 = 0$ s simultaneously with the start of the braking demand until achieving the final speed v_{fin} ;
- the stopping/slowng distance calculated assuming each acting brake equipment type fully applies (100 %) at time $t_0 = 0$ s simultaneously with the start of the braking demand until achieving the final speed v_{fin} .

The equivalent system response time can be calculated as set out in [Formula \(10\)](#).

$$t_{a,e} = \frac{s - s_{f(t)=100\%}}{v_0} \quad (10)$$

where

v_0 is the initial speed, in m/s;

s is the stopping/slowng distance with all time characteristics taken into account, expressed in m;

$s_{f(t)=100\%}$ is the braking distance without consideration of any time characteristics from initial speed v_0 to final speed v_{fin} .

5.4 Supplementary dynamic calculations

5.4.1 Energy dissipated by each brake equipment type $W_{B,n}$

ISO 20138-1 describes the calculation of energy dissipated during braking based on mean braking forces for brake equipment types.

The total energy dissipated by each brake equipment type during iteration steps $j = 0$ to $j = J$ can be calculated based on instantaneous values as set out in [Formula \(11\)](#).

$$W_{B,n} = \sum_{j=0}^J (F_{r,n,j} \cdot s_{n,j}) \quad (11)$$

where

$W_{B,n}$ is the energy dissipated by brake equipment type n , expressed in J;

$F_{r,n,j}$ is the braking force for brake system type n during iteration step j , expressed in N;

$s_{n,j}$ is the distance travelled during iteration step j whilst the brake system type n is applied, expressed in m.

5.4.2 Value of the required wheel/rail adhesion for the braked wheelset (τ_{ax})

The value of the required wheel/rail adhesion for the braked wheelset can be calculated as set out in [Formula \(12\)](#).

$$\tau_{ax} = \frac{\sum_{n=1}^N F_{r,n} - m_{rot,ax} \cdot a}{m_{st,ax} \cdot g} \cdot \sqrt{i^2 + 1} \quad (12)$$

where

τ_{ax}	is the value of the required wheel/rail adhesion for the braked wheelset;
N	is the number of brake equipment types;
$\sum_{n=1}^N F_{r,n}$	is the sum of all wheel/rail adhesion dependent braking forces from all brake equipment types per wheelset, expressed in N;
$F_{r,n}$	is the braking force of brake system type n , expressed in N;
a	is the deceleration of the vehicle/unit, expressed in m/s^2 ;
g	is the standard acceleration due to gravity, expressed in m/s^2 ;
i	is the gradient of the track (positive rising/negative falling);
$m_{rot,ax}$	is the equivalent rotating mass per wheelset, expressed in kg;
$m_{st,ax}$	is the static mass per wheelset, expressed in kg.

5.4.3 Maximum braking power of each brake equipment type $P_{max,n}$

The step by step calculation can be used to determine the speed v when the maximum braking power $P_{max,n}$ for each brake equipment type n is reached.

The braking power P_n can be calculated as set out in [Formula \(13\)](#).

$$P_n = F_{r,n} \cdot v \quad (13)$$

The maximum braking power can be calculated as set out in [Formula \(14\)](#).

$$P_{max,n} = \max(P_n) \quad (14)$$

where

P_n	is the braking power of brake system type n , expressed in W;
$P_{max,n}$	is the maximum braking power of brake system type n , expressed in W;
$F_{r,n}$	is the braking force of brake system type n , expressed in N;
v	is the current speed, expressed in m/s.

The maximum braking power of a disc brake can also be calculated using the pad forces and the peripheral speed at the effective point of contact on the brake disc.

6 Considerations for stopping/slowing distances and deceleration calculations

6.1 Accuracy of input values

The accuracy of the calculation described here depends directly on the accuracy of the input data.

The accuracy of the input data values shall be relevant to the purpose of the calculation and shall be traceable as to how these values were established, e.g. engineer's estimation, test results, manufacturer's data. Supporting calculations or test reports (or extracts of these documents) should be attached with the performance calculation where applicable.