

English Version

Earth-moving machinery - Wheeled or high-speed rubber-tracked machines - Performance requirements and test procedures for brake systems (ISO 3450:2011)

Engins de terrassement - Engins sur pneumatiques ou sur chenilles caoutchouc à grande vitesse - Exigences de performance et modes opératoires d'essai des systèmes de freinage (ISO 3450:2011)

Erdbaumaschinen - Maschinen auf Rädern oder schnelllaufende gummigleiskettenbereifte Maschinen - Anforderungen und Prüfungen für Bremssysteme (ISO 3450:2011)

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## Foreword

This document (EN ISO 3450:2011) has been prepared by Technical Committee ISO/TC 127 "Earth-moving machinery" in collaboration with Technical Committee CEN/TC 151 "Construction equipment and building material machines - Safety" 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of an identical text or by endorsement, at the latest by May 2012, and conflicting national standards shall be withdrawn at the latest by May 2012.

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

This document supersedes EN ISO 3450:2008.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

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

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### Endorsement notice

The text of ISO 3450:2011 has been approved by CEN as a EN ISO 3450:2011 without any modification.

**Annex ZA**  
(informative)

**Relationship between this European Standard and the Essential  
Requirements of EU Directive 2006/42/EC**

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide one means of conforming to Essential Requirements of the New Approach Directive 2006/42/EC on machinery.

Once this standard is cited in the Official Journal of the European Union under that Directive and has been implemented as a national standard in at least one Member State, compliance with the normative clauses of this standard confers, within the limits of the scope of this standard, a presumption of conformity with the relevant Essential Requirements of that Directive and associated EFTA regulations.

**WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this Standard.**

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 3450 was prepared by Technical Committee ISO/TC 127, *Earth-moving machinery*, Subcommittee SC 2, *Safety, ergonomics and general requirements*.

This fourth edition cancels and replaces the third edition (ISO 3450:1996), which has been technically revised.

# Earth-moving machinery — Wheeled or high-speed rubber-tracked machines — Performance requirements and test procedures for brake systems

## 1 Scope

This International Standard specifies minimum performance requirements and test procedures for the service, secondary and parking brake systems of wheeled and high-speed rubber-tracked earth-moving machines, for the uniform assessment of those brake systems.

It is applicable to the following earth-moving machinery, operating on work sites or in mining, or travelling on public roads:

- self-propelled, rubber-tyred earth-moving machines, as defined in ISO 6165;
- self-propelled rollers and landfill compactors, as defined in ISO 6165 and ISO 8811;
- self-propelled scrapers, as defined in ISO 7133;
- remote-control machines, as defined in ISO 6165, wheeled or rubber-tracked;
- derivative earth-moving machines with rubber tyres;
- earth-moving machines with rubber tracks and a maximum machine speed  $\geq 20$  km/h.

It is not applicable to pedestrian-controlled earth-moving machinery (see ISO 17063) or crawler earth-moving machines with steel or rubber tracks that travel at  $< 20$  km/h (see ISO 10265). While purpose-built underground mining machines are not within the scope of this International Standard, its provisions can generally be applied to those machines with some braking performance modifications and additions (see Annex A).

**NOTE** At the time of publication, no International Standard dedicated to purpose-built underground mining machines had been developed.

## 2 Normative references

The following referenced documents are indispensable for the application 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 6014, *Earth-moving machinery — Determination of ground speed*

ISO 6016, *Earth-moving machinery — Methods of measuring the masses of whole machines, their equipment and components*

ISO 6165, *Earth-moving machinery — Basic types — Identification and terms and definitions*

ISO 7133, *Earth-moving machinery — Tractor-scrapers — Terminology and commercial specifications*

ISO 8811, *Earth-moving machinery — Rollers and compactors — Terminology and commercial specifications*

ISO 9248, *Earth-moving machinery — Units for dimensions, performance and capacities, and their measurement accuracies*

ISO 10968, *Earth-moving machinery — Operator's controls*

ISO 15998, *Earth-moving machinery — Machine-control systems (MCS) using electronic components — Performance criteria and tests for functional safety*

### 3 Terms and definitions

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

#### 3.1

##### **brake system**

##### **braking system**

all components which combine together to stop and/or hold the machine, including the brake control(s), brake actuation system, the brake(s) themselves and, if the machine is so equipped, the retarder .

#### 3.1.1

##### **service brake system**

primary system used for stopping and holding the machine

#### 3.1.2

##### **secondary brake system**

system used to stop the machine in the event of any single failure in the service brake system

#### 3.1.3

##### **parking brake system**

system used to hold a stopped machine in a stationary position and which, if applicable, may also be part of secondary brake system

#### 3.1.4

##### **hydrostatic brake system**

hydrostatic or other similar propel drive system used to meet one or more of the brake system requirements

#### 3.1.5 Braking system components

##### 3.1.5.1

##### **brake control**

component directly activated by the operator to cause a force to be transmitted to the brake(s)

##### 3.1.5.2

##### **brake actuation system**

all components between the brake control and the brake(s) which connect them functionally

##### 3.1.5.3

##### **brake**

##### **brakes**

component which directly applies a force to oppose movement of the machine

NOTE The different types of brake include friction, mechanical, electrical, regenerative devices and hydrostatic or other fluid types.

##### 3.1.5.4

##### **common component**

component that performs a function in two or more brake systems

EXAMPLE Pedal, valve.

##### 3.1.5.5

##### **retarder**

energy-absorption device normally used to control machine speed

#### 3.2

##### **hydrostatic drive system**

hydraulic system where hydraulic motors form a direct drive to the wheels or track to propel the machine and slow machine movement

**3.3****machine test mass**

operating mass of a machine which includes the heaviest combination of cab, canopy, operator protective structures (if required) with all their components and mountings, any combination of equipment approved by the manufacturer of the machine, including operator and full liquid systems in accordance with ISO 6016 (e.g. machine configuration and direction of travel having the most adverse effect on braking)

NOTE 1 For rollers, the sprinkler water reservoir(s) shall be full.

NOTE 2 For self-propelled scrapers with semi-trailed units, towed trailers and all types of dumpers, the machine test mass shall also include the maximum specified payload as per the machine manufacturer's specifications. For all other machines, the payload shall not be included.

**3.4****stopping distance***s*

distance travelled by the machine from the point on the test course at which the machine brake control actuation begins (e.g. operator actuates the brakes) to the point on the test course where the machine is fully stopped

NOTE 1 It is expressed in metres (m).

NOTE 2 It does not take into account the operator reaction time, unless stated, but does take into account the system reaction time.

**3.5****mean deceleration***a*

average rate of change in the velocity of the machine from the instant the brake control actuation begins until a full stop is achieved

NOTE It is expressed in metres per second squared (m/s<sup>2</sup>), calculated from

$$a = \frac{v^2}{2s}$$

where

*v* is the velocity of the machine immediately prior to the brake control being activated, in metres per second (m/s);

*s* is the stopping distance, in metres (m).

**3.6****burnishing**

procedure used to condition the frictional surfaces of a brake

**3.7****brake system pressure**

fluid pressure available to the brake control

**3.8****brake application pressure**

measured fluid pressure used to actuate the brakes

**3.9****modulated braking**

ability to continuously and progressively increase and decrease the braking force by operation of the brake control

EXAMPLE A system allows the braking force to be increased and decreased over time, based on single or repeated movements of the brake control.



### 3.10

#### **test course**

surface upon which the test is carried out

NOTE See 5.3.

### 3.11

#### **cold brakes**

(brake systems containing friction elements) condition of brakes where

- the brakes have not been actuated in the previous hour except in accordance with the applicable performance test (see Clause 6),
- the brakes have been cooled to 100 °C or less when measured on the brake disc or the outside of the brake drum, or
- in the case of totally enclosed brakes, including oil-immersed brakes, the temperature measured on the outside of the housing closest to the brake is below 50 °C or within the brake manufacturer's specifications

### 3.12

#### **maximum machine speed**

maximum speed determined in accordance with ISO 6014, or equivalent

### 3.13

#### **back throttling**

action of applying slight forward or reverse power to a hydrostatic or other similar drive system in order to hold the machine stationary

### 3.14

#### **derivative earth-moving machine**

machine with a combination of features from other earth-moving machines, thereby creating different configurations or arrangements

EXAMPLE Machine having the front-mounted equipment of a loader on a non-self-loading, rear-mounted dumper body.

### 3.15

#### **safe state**

condition in which, after a malfunction of the machine control system, the controlled equipment, process or system is automatically or manually stopped or switched into a mode that prevents unexpected performance or the potentially hazardous release of stored energy

### 3.16

#### **dumper**

self-propelled crawler or wheeled machine with an open body, which transports and dumps or spreads material, and where loading is performed by means other than the dumper

[ISO 6165]

NOTE For semi-trailed dumpers, see ISO 7132:2003, Figures 3, 16 and 20.

#### 3.16.1

##### **rigid-frame dumper**

dumper having a rigid frame and wheel or crawler steering

[ISO 6165]

NOTE Rigid-frame and articulated-frame dumpers are illustrated in ISO 7132:2003, Figures 1 and 2, 8 and 9, 14 and 15, and 18 and 19.

**3.16.2****articulated-frame dumper**

⟨wheeled machine⟩ dumper with an articulated frame which accomplishes the steering of the dumper

[ISO 6165]

NOTE Rigid-frame and articulated-frame dumpers are illustrated in ISO 7132:2003, Figures 1 and 2, 8 and 9, 14 and 15, and 18 and 19.

**3.17****trailer**

transport machine with one or more axles which, according to its design, is suitable and intended for coupling to a self-propelled machine

**3.18****fully developed deceleration rate**

maximum continuous deceleration rate which the machine is capable of developing on a specified constant slope, with a specific machine test mass and surface condition and an initial (prior to deceleration) machine travel speed

**3.19****purpose-built underground mining machine**

specialized earthmoving machine designed for underground use which may have a lower height profile and trailer attached

EXAMPLE Underground dump trucks, tele-dumpers, load haul dumps, scoops, coal haulers, power trams, chock carriers, personnel carriers, loading machines.

**3.20****machine control system****MCS**

components needed to fulfil the function of the system, including sensors, signal processing unit, monitor, controls and actuators or several of these

NOTE The extent of the system is not limited to the electronic controls, but is defined by the machine-related function of the complete system. It therefore consists generally of electronic, non-electronic and connection devices. This can include mechanical, hydraulic, optical or pneumatic components/systems.

[ISO 15998]

**4 General requirements**

The requirements of this clause apply to all machines within the scope of this International Standard.

All brake systems shall be designed, constructed and installed such that contamination and/or its effects are minimized.

**4.1 Required brake systems****4.1.1 All machines shall be equipped with**

- a) a service brake system,
- b) a secondary brake system, and
- c) a parking brake system.

Service, secondary and parking brake systems may share common components or functions and do not have to be three independent and separate systems.

**4.1.2** No brake system (including hydrostatic systems) shall contain a disconnecting device such as a clutch or shiftable gear-box which allows disabling of the brake, except for systems in accordance with a) and/or b), as follows:

- a) any device designed to disconnect the service or secondary brake power source for cold weather starting shall require application of the parking brake before disconnection can take place;
- b) a parking brake disconnect (release) designed to allow movement of disabled machines shall be located outside the operator's station unless it can be reapplied immediately.

**4.1.3** All machines shall have service brakes of an equal nominal capacity rating applicable to each of the wheels (or equivalent) of at least one axle. Dumpers and self-propelled scrapers with semi-trailed unit(s) shall have service brakes applicable to at least one axle of the towing machine and one axle of each semi-trailed unit.

**4.1.4** For rollers, the service and secondary brakes shall apply to all power-driven drums and wheels. Each drum of a split drum shall have the same nominal brake torque. The brake of a single-drum roller and a combined roller shall apply to all wheels and to the drum.

**4.1.5** If the parking brake is intended to stop creep movement, the parking brake system shall permit actuation of the parking brake during travel.

## **4.2 Common components**

Service, secondary and parking brake systems can share common components. Where common components are used, the machine's braking performance shall meet the requirements for secondary brake systems given in 4.5 and 4.7, as applicable. If there is a failure in any single component within the brake system — except for tyres, drum or track — braking performance shall be in accordance with Table 3.

Acceptable performance is achieved for common brake control failure as follows. If there is a failure with a common brake control (lever, pedal, etc.) used to actuate the combined service and secondary brake systems, and there is another dynamic braking capability provided with the machine (e.g. parking brake with dynamic braking capability), the dynamic braking capability shall stop the machine after the failure within 120 % of the stopping distance for secondary brakes (under secondary test conditions) in accordance with Table 3. This dynamic braking capability may be applied automatically and without modulation. An indication should be given to the operator simultaneous with, or before, application of the brake system, if applied automatically.

## **4.3 Brake control systems**

All brake system controls shall be capable of being applied by an operator from the operating position. Parking brake system controls shall be arranged so that, unless immediately reapplied, they cannot be released once applied.

Unintended brake control activation can be avoided through compliance with ISO 10968.

Brake control systems should be designed to avoid any unintended application or release of brakes during normal operation. This does not preclude the automatic application of a brake system due to intended design conditions that also meet the requirements of this International Standard.

The arrangement of the brake system controls should be in accordance with ISO 10968. If not, an instructional sign shall be provided (e.g. using symbols) explaining the control arrangement. Brake pedals and hydrostatic brake system controls are obvious and may not require machine instructions.

A brake control system shall prevent or minimize any uncontrolled braking performance (random brake applications, releases or sporadic braking performance, etc.) during normal operation (start, stop or normal travel operation of the machine, etc.).

Electric, electronic and electronic machine control systems (MCS) for service, secondary or parking brakes shall comply with ISO 15998.

The operator should be able to apply the service or secondary brake while retaining control of the steering device on the machine with at least one hand.

#### 4.4 Service brake systems

All machines shall meet the service brake performance requirements given in Clause 6, as applicable. The service brake system shall have modulated braking for machines designed for maximum machine speeds greater than 6 km/h. If a travel mode that limit the maximum machine speed to 6 km/h or less can be selected, modulation is not required in this mode.

If other systems receive power from the service brake system, any failure in those systems that reduces service brake system performance shall be considered as a failure in the service brake system.

#### 4.5 Secondary brake systems

All machines shall meet the secondary brake performance requirements given in Clause 6, as applicable. The secondary brake system shall have modulated braking for maximum machine speeds greater than 20 km/h.

#### 4.6 Parking brake systems

All machines shall meet the parking brake requirements of Clause 6, as applicable.

After application of the parking brake, the parking brake system shall not depend on an exhaustible energy source or continuous operator action (e.g. hand or foot effort). The parking brake system may use common components, provided the requirements of 6.4 and Table 2 are met. The parking brake, operating according to the manufacturer's specifications, shall be in accordance with Table 2, regardless of any contraction of the brake parts or leakage of any kind.

**NOTE** Mechanical springs are not considered to be an exhaustible energy source. Back throttling by a hydrostatic drive system does not meet the parking brake requirements, as back throttling requires continuous operator action.

The parking brake shall require an action by the operator prior to release of the parking brake control. The parking brake shall not automatically release during normal start up or upon loss of power to the parking brake system or parking brake MCS.

A parking brake may be applied automatically (e.g. spring- or control-system-activated), in which case it shall be applied or remain applied after the machine is in a stopped condition and the engine shut down.

Machines with the capability for a self test of the parking brake shall include design provisions that the machine does not propel unless there is a propel activation by the operator during the self test.

#### 4.7 Hydrostatic brake systems

For a machine fitted with a hydrostatic brake system, the service and secondary brakes shall be in accordance with 4.4 and 4.5, respectively.

Typical hydrostatic brake systems have an exhaustible power supply and would not be able to meet the requirements for parking brakes given in 4.6.

Service brake application shall be obtained by one of the following means:

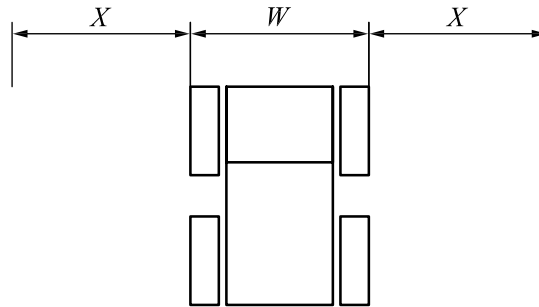
- operation of a single control;
- moving the foot from the drive pedal to the brake pedal;
- at the start of the braking sequence, releasing the drive control(s) and moving to the neutral or reverse propel position using hand or foot.

A brake system additional to the service brake may be used to hold the machine when there is creep movement. A machine may be held stationary, regardless of the grade, using the throttle of the hydrostatic or similar propel drive system (back throttling).

#### 4.8 Systems with combined brake and steer function

If the braking system has a combined brake and steer function and is used as the secondary brake system, the machine shall maintain controllability during secondary brake stopping distance testing in accordance with Clause 6.

While remaining within the applicable secondary brake stopping distance specified in Table 3, the machine shall not veer outside a boundary lane,  $X$ , on either side of the machine, in accordance with Figure 1.



For  $W \leq 2$ ,  $X$  shall be  $1,25W$ .

For  $W > 2$ ,  $X$  shall be 2 m. This is intended to limit the machine veering outside the required public road traffic lane width.

##### Key

$W$  width of machine over wheels or tracks, m

$X$  width of boundary lane, m

**Figure 1 — Boundary conditions for secondary braking**

#### 4.9 Performance and warning devices for stored energy sources

If stored energy (e.g. reservoirs, accumulators) is used for the service brake system, the stored energy system shall be equipped with a low-energy warning device. The remaining pressure on the third service brake application after the warning signal shall have sufficient energy to provide secondary brake performance in accordance with Table 3, as applicable to the machine.

The warning device shall readily attract the operator's attention by providing a continuous (e.g. steady or pulsating) visible and/or audible warning. Gauges indicating pressure or vacuum do not meet this requirement.

#### 4.10 Braking systems with electronic MCS

The electronic control system for a braking system shall meet safe state requirements as determined by the manufacturer using a risk assessment methodology. An electronic MCS complying with ISO 15998 meets such safe state requirements.

If the maximum machine speed is limited by design to less than 6 km/h, these safe state requirements are fulfilled when any of the braking systems can bring the machine to a stop within the brake stopping distances given Table 3.

Braking systems on machines that meet the requirements of this International Standard also achieve the safety concept of ISO 15998 for earth-moving machinery braking systems. A risk assessment of the brake MCS needs to be carried out to determine if functional braking after any single failure involving an electrical and/or electronic MCS meets the braking performance requirements of this International Standard.

**NOTE** ISO 15998 also requires additional testing of the MCS to verify its performance and modes of failure.

#### 4.11 Machines designed to tow trailers

All performance requirements given in this International Standard that apply to the service, secondary and parking brakes of a machine also apply to the combination of a machine and trailer(s).

The trailer or trailed unit(s) do not require brakes if the towing machine's brakes meet the service, secondary and parking brake requirements when tested with the combined machine and trailer mass, including the specified trailer payload.

The trailer brakes should be evaluated for protection against jack-knifing, if applicable.

#### 4.12 Machine instructions and labels

##### 4.12.1 General

Operational limitations of the brake control system according to the manufacturer's specifications, if applicable, shall be included in one or the other of the following:

- operator's manual;
- instructional sign;
- machine monitor displays.

**EXAMPLE** Operating precautions for braking system default conditions where the brake or retarding operating characteristics may be automatically changed creating new brake performance characteristics such as automatic shift of the transmission to neutral or potential damage to the parking brake due to propelling through the parking brake.

If brake burnishing is recommended by the brake or machine manufacturer, the brake burnishing procedure shall be included in the operator's or maintenance manual for the machine.

The manufacturer of any machine equipped with a retarder shall provide the following instructions:

- a) in the operator's manual, the maximum machine speed and/or the transmission gear to be engaged when the loaded machine descends specific slopes as specified by the machine manufacturer;
- b) an instruction sign or machine monitor display containing the information specified in a), located in the operator's compartment and readily visible to the operator.

Instructional signs or machine monitor displays showing the retarding ability for slopes shall not exceed the minimum brake holding performance of the service and parking brakes as a percentage holding slope (see 6.4.2).

##### 4.12.2 Braking system and periodic verification instructions

Information on brakes may be provided in manuals, labels or other means readily available to the operator while in the operator's station along with precautions about the limitation of this information. If braking system and periodic verification instructions are provided by the machine manufacturer, they should include the following:

- a) daily brake check method instructions:
  - a method for verifying the functionality of the service and parking brakes;
  - provisions for verifying the functionality of the secondary brakes if the service and/or parking brake check method does not verify functionality of the secondary brakes;
- b) in-service, periodic or post-maintenance brake verification instructions:
  - a method for verifying the functionality of the service and parking brakes including acceptance criteria;
  - a means of verifying the functionality of the secondary brakes.

The instructions are to include a notice to the user that the machine is to be immediately taken out of service until corrected if the service, secondary or parking brakes do not operate within specifications or performance requirements as defined by the daily brake check method, in-service, periodic or post-maintenance brake verification.

Instructions for the periodic verification of braking systems may give test conditions different than those prescribed in this International Standard in order to permit testing or other verification by the user.

#### **4.12.3 Additional instructions for machines designed to tow trailers**

If applicable, information on the machine's allowable trailer towing capacity shall be provided in machine manuals or labels along with any other applicable trailer towing instructions or precautions by the earth-moving machinery manufacturer. The information, if provided, should include the maximum un-braked trailer towing load and the maximum combination of payload and towing load for the earth-moving machinery.

#### **4.13 Estimating brake slope capability**

The estimated brake slope capability defines the ability of a braking system to stop and hold a machine on a slope. Other factors, such as ground conditions, side-slopes, speed, payload retention or the need to maintain the machine within the earth-moving machinery manufacturer's specifications can limit the machine's operating slope capability to slopes less steep than those where the brakes are actually able to stop and hold the machine.

Annex B gives one method for estimating brake slope capability.

### **5 Test conditions**

#### **5.1 Overall test parameters**

The manufacturer's operational precautions shall be observed when carrying out the performance tests. All machine parameters related to braking systems shall be within the machine manufacturer's specifications, including tyre size and pressure, brake adjustment, warning actuation points and braking system pressures, which shall be within the machine manufacturer's specification range. No manual adjustment, such as readjustment to prevent diminished or improved braking performance, shall be made to the braking system during any single performance test.

The instruments used to carry out the measurements shall be of an accuracy and be measured in units in accordance with ISO 9248.

The performance requirements given in Tables 2 and 3 shall be achieved from single-stop and hold testing at the service limit condition for the braking systems. These requirements shall be validated by physical testing or alternative means, including calculation and extrapolation from physical test data. The validation means shall be recorded in the test report in accordance with Clause 7.

See 6.4.3 and 6.6 for alternative braking system performance test methods.

NOTE Hydrostatic brake systems typically are not materially affected by brake wear limits.

#### **5.2 General test conditions**

When the machine transmission provides a selection of gear ratios, the stopping tests shall be conducted with the transmission in the gear corresponding to the test speed specified. The power train may be disengaged prior to completing the stop.

Retarders shall not be used during the service brake performance tests, but may be used during the secondary brake performance test. A hydrostatic or similar propel drive system is not considered to be a retarder.

Machines with operator-selectable, multiple-drive axles shall be brake-performance tested with the non-braked selectable axle(s) disengaged.



Equipment (blades, buckets, dozers, etc.) shall be in the transport position recommended by the manufacturer.

Burnishing or conditioning of brakes before testing is permissible. The burnishing procedures shall be verified by a review of the supplied instructions or in consultation with the machine or brake manufacturer.

Immediately prior to testing, the machine shall be operated until the engine, transmission and machine fluids are at normal operating temperature(s) as specified by the manufacturer.

The machine test speed shall be that speed measured immediately prior to the brake control being applied.

Brake-holding performance tests shall be performed with the power train disengaged and the engine at worst case (e.g. idle or stopped) except for hydrostatic or similar propel drive systems, which shall be engaged to the power train.

When testing a vibratory roller, all tests shall be conducted without vibration.

On machines where hydrostatic braking is used as the service brake, the stopping and holding performance (e.g. back throttling) of the service brake system shall be tested with the engine running.

At minimum, all data required for completion of the test report in accordance with Clause 7 shall be recorded.

### 5.3 Test course

The test course shall consist of a hard, dry surface with a well-compacted base. Ground moisture may be present to the extent that it does not adversely affect the braking test.

The test course shall not have a slope of more than 3 % at right-angles to the direction of travel.

Slope in the direction of travel shall be no greater than 1 %, or as specified for the test being carried out. The exceptions to this are rigid-frame dumpers, articulated-frame dumpers and tractor-scrapers of over 32 000 kg machine test mass, for which the test course shall have a downward slope of  $(9 \pm 1) \%$  in the direction of machine travel.

The approach to the test course shall be of sufficient length, smoothness and uniformity of slope to ensure the required machine speed is reached before the brakes are actuated.

### 5.4 Machine test configuration

Service brake and secondary brake system stopping distance tests — except for those carried out on hydrostatic brake systems — shall be conducted with cold brakes.

For rigid-frame dumpers, articulated-frame dumpers and tractor-scrapers of over 32 000 kg machine test mass, the transmission shall be engaged in a gear in which the engine does not exceed the maximum engine rotational speed, in revolutions per minute (r/min) or frequency ( $\text{min}^{-1}$ ), specified by the manufacturer.

All brake tests shall be performed using the machine configuration (excluding the service limit requirements given in 5.1) having the most adverse effect on braking and with the machine test mass applicable to the machine type.

**NOTE** As stated in the definition of 3.3, the machine test mass for all dumpers and self-propelled scrapers also includes the maximum payload specified by the machine manufacturer.

Record the axle load distribution as applicable and report the results in the test report (see Clause 7).



## 6 Performance tests

### 6.1 General

The following performance tests shall be performed on all machines within the scope of this International Standard and on all braking systems, as applicable, under the test conditions given in Clause 5. The brake holding and control forces shall be measured and reported in accordance with Clause 7.

NOTE The provisions of 6.3 are not applicable to service brake systems not fitted with stored energy sources (e.g. reservoirs or accumulators).

### 6.2 Braking system controls

During the performance tests, the control forces shall not exceed the values given in Table 1.

**Table 1 — Maximum force levels for braking system controls during performance tests**

Type of control	Max. force to be applied N
Finger grasp (flip levers and switches)	20
Hand grasp	
— upwards	400
— downwards, sideways, fore-aft	300
Foot treadle (ankle control)	350
Foot pedal (leg control)	600

### 6.3 Stored energy sources

#### 6.3.1 Service brake system recovery capacity

Set the engine speed control to obtain the maximum engine rotational speed (r/min) or frequency ( $\text{min}^{-1}$ ). Measure the brake application pressure near the brake. The service brake system's stored energy sources shall have the capacity to deliver at least 70 % of the pressure measured during the first brake application after the service brakes have been fully applied:

- for dumpers, self-propelled scrapers and wheeled excavators, 12 times at the rate of four applications per minute;
- for all other machines, 20 times at the rate of six applications per minute.

#### 6.3.2 Secondary brake system capacity

If the service brake system's stored energy sources are used to apply the secondary brake system, the stored energy source capacity shall meet the following requirement with the energy source disconnected and the machine stationary.

- The remaining capacity of the service brake system's stored energy sources shall meet the secondary brake stopping requirements specified in Table 3, as applicable, after five full service brake applications at a rate of  $\leq 1$  s on and 1 s off. The full service brake applications shall be within the force level requirements of Table 1.

#### 6.3.3 Test performance

The stored energy system for the service brakes shall be tested to and shall achieve the requirements given in 4.9.

The warning device shall activate prior to automatic application of a secondary brake system during the test.

The service brake system's stored energy may be reduced by any suitable means for testing.

## 6.4 Holding performance

### 6.4.1 General

All machines shall be tested in both the forward and reverse directions.

For hydrostatic or similar propel drive systems, back throttling may be used to meet the holding performance criteria for service brake systems and, if used, shall be reported in the test report.

### 6.4.2 Service and parking brakes

With the machine's power train as specified in 5.2, the service and parking brake systems shall be capable of holding the machine motionless on a slope in accordance with Table 2.

**Table 2 — Service and parking brake holding performance**

Brakes	Machine type	Slope %
Service brake	Rigid-frame dumpers and articulated-frame dumpers having a machine test mass >32 000 kg	20
	Rollers (self-propelled, ride-on vibratory steel-wheeled, static-wheeled and rubber-tyred)	20
	Rigid-frame dumpers, articulated-frame dumpers, semi-trailed dumpers and their combinations with towed trailers having a machine test mass ≤32 000 kg	25
	All other earth-moving machinery, including self-propelled scrapers	25
Parking brake	Rigid-frame dumpers, articulated-frame dumpers, self-propelled scrapers and their combinations with towed trailers	15
	Rollers (self-propelled, ride-on vibratory steel-wheeled, static-wheeled and rubber-tyred)	20
	Semi-trailed dumpers	20
	All other earth-moving machines	20

### 6.4.3 Brake holding performance tests

Brake holding performance tests may be carried out either

- at a test site with the specified slope and slip-resistant surface, or
- on a tilt platform with a slip-resistant surface, or
- by applying a pulling force to the stationary machine with the brake applied and the transmission in neutral on a test course with a slope of no more than 1 % slope in the direction of travel.

For alternative c), the pulling force shall be applied horizontally near the ground to achieve a minimum force equivalent to the slopes specified in Table 2. The equivalent force, expressed in newtons, shall be

- 1,46 times the machine test mass in kilograms for a 15 % slope,
- 1,92 times the machine test mass in kilograms for a 20 % slope, and
- 2,38 times the machine test mass in kilograms for a 25 % slope.

Pulling force testing has limitations versus testing on a slope. The machine's holding capacity on a slope can change due to a change in axle weight distribution and all the wheels might not be restrained by the brakes.

Another alternative, d), is to use the machine's propel system to simulate a static grade equivalent and demonstrate holding performance as required in Table 2 by conducting a propel stall test as follows.

Place the machine on a horizontal surface. Energize the propel system to a level that generates the equivalent brake holding requirements given in Table 2 for the applicable machine while simultaneously engaging the brake holding system being tested. Record the propel system output during the test simultaneously with the wheel speed in order to demonstrate that there was no motion during the brake holding test.

Measurement of indirect parameters such as torque/pressure/current may be used with the accompanying calculations (e.g. gear ratio, tyre size) to determine ground force output. The calculations related to measured parameters and brake holding performance shall be included in the brake test report. Holding performance is considered to have been successfully verified when the braking holding system resists movement during propel system application of the tractive force equivalent to the holding requirements of Table 2. Tyre or track movement during the test and before meeting the holding performance requirements of Table 2 shall be considered a failure of brake holding performance.

#### **6.4.4 Durability test of parking brake when used as secondary brake**

If the parking brake system is used as part of the secondary brake system, the parking brake shall meet the holding performance requirements of Table 2 following one dynamic stop from the machine test speed in accordance with 6.5, with the machine test mass appropriate to the machine (see 3.3), and on a level surface with no adjustment of the parking brake. For rollers, the parking brake durability test requires the roller to be subjected to five stops. Locking-up of the tyres is permitted when applying the parking brake.

### **6.5 Stopping performance**

#### **6.5.1 General**

All machines shall be tested to the stopping distances given in Table 3.

Stopping shall be from one of the following machine test speeds, as applicable, within a tolerance of  $\pm 2$  km/h:

- for rigid-frame dumpers and articulated-frame dumpers of machine test mass  $\leq 32\,000$  kg, stopping from either 80 % of the maximum machine speed or 32 km/h, whichever is the greater (see 6.5.5 for those dumpers having a machine test mass  $> 32\,000$  kg);
- for machines with a maximum machine speed of  $< 32$  km/h, stopping from that speed;
- for all other machines, stopping from either 80 % of the maximum machine speed or 32 km/h, whichever is the greater.

Beginning with cold brakes, except for hydrostatic brake systems, the service and secondary brake system stopping distance tests shall be conducted twice — once in each direction of the test course — with the machine travelling forward and with at least 10 min between stops.

The measured stopping distance and machine speed shall be the average of the two tests (one in each direction of the test course) for the service and secondary brake systems, and shall be reported in the test report in accordance with Clause 7.

#### **6.5.2 Service brake systems**

The service brake system shall stop the machine within the stopping distance for the applicable machine type specified in Table 3.

#### **6.5.3 Secondary brake systems**

The secondary brake system shall stop the machine within the stopping distance for the applicable machine type in accordance with Table 3.

NOTE National or other regulations, which could be more stringent, can apply.

If the machine is equipped with a retarder, it may be used prior to and during the test.

The secondary brake system shall be tested to measure the stopping of the machine in the event of any single failure in the service brake system. During this test, modify the service brake system or use equivalent means to simulate the most adverse single failure of the service brake system.

**Table 3 — Stopping performance**

Machine types	Maximum stopping distance $s$ m	
	Service brake	Secondary brake
Scrapers, rigid-frame dumpers and articulated-frame dumpers with machine test mass $\leq 32\,000$ kg and semi-trailed dumpers of any mass <sup>a</sup>	$\frac{v^2}{44} + 0,1(32 - v)$	$\frac{v^2}{30} + 0,1(32 - v)$
Scrapers, rigid-frame dumpers and articulated-frame dumpers with machine test mass $> 32\,000$ kg	$\frac{v^2}{48 - 2,6\alpha}$	$\frac{v^2}{34 - 2,6\alpha}$
Rollers	$0,2(v + 5) + \frac{v^2}{150}$	$0,4(v + 5) + \frac{v^2}{75}$
All other earth-moving machines, including towed trailers with payloads	$0,2(v + 5) + \frac{v^2}{160}$	$0,4(v + 5) + \frac{v^2}{80}$
$v$ initial speed, in km/h.		
$\alpha$ test slope as a percentage between 8 % and 10 %.		
<sup>a</sup> The term $0,1(32 - v)$ is deleted from the formula for speeds over 32 km/h.		

#### 6.5.4 Heat fade test for all machines except rigid-frame and articulated-frame dumpers with machine test mass $> 32\,000$ kg

This test shall be performed on all machines except rigid-frame and articulated-frame dumpers of machine test mass  $> 32\,000$  kg.

Apply and release the service brakes to complete four consecutive stops at, or as near as possible to, the maximum deceleration of the machine without sliding of the tyres or tracks. After each stop, the machine test speed according to 6.5.1 shall be regained as quickly as possible using maximum machine acceleration. A fifth consecutive stop shall be measured which shall not exceed 125 % of the service brake stopping distance according to Table 3.

#### 6.5.5 Brake tests for rigid-frame and articulated-frame dumpers with machine test mass $> 32\,000$ kg

The test shall be performed on rigid-frame dumpers and articulated-frame dumpers of over 32 000 kg machine test mass, on the test course for those machines as specified in 5.3.

The transmission shall be engaged in a gear in which the engine does not exceed the maximum engine rotational speed, in revolutions per minute (r/min) or frequency ( $\text{min}^{-1}$ ), specified by the manufacturer.

The service brake system shall be tested by means of five stopping tests at 10 min to 20 min intervals between stops from a machine speed of  $\geq (50 \pm 3)$  km/h or the maximum machine speed if less than 50 km/h. The stopping distance shall not exceed that specified in Table 3.

The secondary brake system shall be tested by means of a single stopping test carried out from a machine speed of  $(25 \pm 2)$  km/h. If the machine is equipped with a retarder, it may be used prior to and during this test. The stopping distance shall not exceed that specified in Table 3.

## 6.6 Alternative testing

### 6.6.1 Lab testing

For braking system functions capable of being reproduced in a lab environment, alternative lab testing may be used to determine service, secondary and parking brake performance. The lab test equipment should be capable of producing the same operating environment as the brake would see in the machine. The test system shall be set up to resist and measure torque to the brake at a torque level capable of driving through the brake holding force and brake retarding force. The lab test system shall be validated by correlation with prior historical machine test data.

For service brake and secondary brake systems, the dynamic load on the brakes shall be duplicated in order to meet the cold brake stopping performance requirements of this International Standard. This data shall be measured and recorded in the test report as specified in Clause 7.

For parking brake systems, the maximum brake holding torque should be measured and recorded in the test report as specified in Clause 7.

### 6.6.2 Alternative secondary brake testing for hydrostatic or similar propel drive machines

On machines using secondary brakes other than hydrostatic or similar propel drives, the retarding force of the propel motors shall be removed from the drive train. Alternatively, the motors and gear final drives may be disengaged from the drive train before stopping distance tests are run.

However, if it is difficult to remove the propel drive motor retarding force or disengage the motor and gear final drive from the drive train, the secondary brake system may be tested as follows.

With the machine stationary, including any movement for drive train tolerance, and with the variable motors set to maximum displacement and any mechanical transmissions set in the lowest speed range, apply the secondary brake and engage the propel drive system at the full rated pressure, alternately in forward and reverse. The machine shall remain stationary with creep movement of less than 30 mm/s other than drive train tolerance in the brake/drive train components.

## 7 Test report

The test report shall contain the following information:

- a) reference to this International Standard;
- b) place and date of measurement;
- c) type of machine;
- d) make of machine;
- e) model and serial number of the machine;
- f) condition of the braking system (new, in operation for 1 000 h, within manufacturer's specifications, etc.);
- g) mass and axle distribution of the machines as tested, in kilograms;
- h) manufacturer's approved maximum machine test mass and maximum axle distribution, in kilograms;
- i) as applicable, drum size, track size, tyre size, ply rating, tread pattern and pressure, in megapascals;
- j) description of the brakes (e.g. disc or drum, hand or foot control);
- k) type of braking system (e.g. mechanical or hydraulic);
- l) surface of the test course (e.g. asphalt, concrete or soil);
- m) longitudinal and cross slope of the test course;

- n) results of all stopping and holding tests and, if applicable, alternative brake holding calculations or methods;
- o) percentage of the service brake system stored energy after the brake application test calculated from (see 6.3.1):

$$p = \frac{p_2}{p_1} \cdot 100$$

where

- $p$  is the residual pressure as a percentage;
- $p_1$  is the brake application pressure during the first brake application;
- $p_2$  is the lowest brake application pressure measured during subsequent brake applications.

- p) force levels applied to the controls (see 4.3 and 6.2);
- q) machine maximum speed and if applicable, machine test speed, in kilometres per hour;
- r) which tests were carried out using the hydrostatic brake system as one of the braking systems;
- s) parking brake durability test results if applicable (see 6.4.4);
- t) if applicable, a statement of evaluation and supporting information to the effect that maximum brake wear does not materially affect brake performance results;
- u) if applicable for estimating brake slope capability, type of tyres, tyre pressure, measured tyre rolling radius, and fully developed deceleration rate.

## **Annex A** (informative)

### **Braking for purpose-built underground mining machines**

**IMPORTANT** — Underground mining is one of the most regulated work sectors worldwide. Requirements can be very prescriptive in nature. This annex is an attempt to describe generic braking performance for purpose-built underground mining machines. Because of the prescriptive nature of underground mining regulations, it is necessary to research the regional underground mining requirements where machines are intended to be used to confirm the regional regulatory requirements.

#### **A.1 General**

This annex presents recommendations for braking systems used in underground mining applications. The provisions given in the main body of this International Standard should only be applied to purpose-built underground mining machines with the recommended additions and modifications in this annex. Machinery designed for surface use that is used underground should be evaluated by the manufacturer and the end user.

No device that traps a column of fluid to hold the brake in the applied position should be installed in any brake system, unless the trapped column of fluid is released when the equipment operator is no longer in contact with the brake activation device.

**NOTE** Some information on regional requirements for coal or gassy mining applications is given in A.12.

#### **A.2 Terms and definitions**

For the purposes of this annex, the terms and definitions given in Clause 3 and the following apply.

**NOTE** For purpose-built underground mining machines, the maximum specified payload as per the machine manufacturer's specifications is included in the machine test mass (3.3), except where noted in A.10.2 for testing without payload after the loaded braking performance has been tested.

##### **A.2.1**

##### **peak deceleration**

maximum deceleration value derived during a brake test run

#### **A.3 Brake system controls (see 4.3)**

The parking brake control should be considered a primary control as per ISO 10968. It should have a distinct shape and colour in relation to the other controls.

**NOTE** There are different regional requirements for the movement required to apply the parking brake control. Typical underground mining applications use a push-to-apply motion on the parking brake control. However, there are regions that require pull to apply.

## A.4 Service brake systems (see 4.4)

### A.4.1 Stopping performance

The recommended formula for the service brake stopping distance,  $s$ , in metres, is

$$s = \frac{vt}{3,6} + \frac{v^2}{26a} \quad (\text{A.1})$$

where

$v$  is the initial speed in km/h;

$t$  is a time of 0,35 s;

$a$  is the mean deceleration, in  $\text{m/s}^2$  ( $= 0,28g$  or  $2,75 \text{ m/s}^2$ ).

This represents 28 % brake efficiency, recommended for machines used on gradients of up to 20 % (11,3°). If a brake efficiency of 20 % were used, it would be the brake efficiency recommended for machines used on gradients of up to 12,3 % (7°).

When tested for stopping performance, the machine should demonstrate at least a  $0,75 \text{ m/s}^2$  fully developed deceleration rate after the design slope has been accounted for.

If the machine is used on gradients of more than 20 %, the minimum brake efficiency should be 8 % more than the sine, expressed as a percentage of the maximum slope on which the machine is intended to be used.

### A.4.2 Holding performance

The service brake should be capable of holding the machine stationary (no creep) on the maximum design grade plus a 20 % factor of safety.

## A.5 Secondary brake systems (see 4.5)

The recommended formula for the secondary brake stopping distance,  $s$ , in metres, is Equation (A.1), except that, for secondary brakes,  $t = 1 \text{ s}$  and  $a = 0,18g$  or  $1,77 \text{ m/s}^2$ .

When tested for stopping performance, the machine should demonstrate at least a  $0,45 \text{ m/s}^2$  fully developed deceleration rate after the design slope has been accounted for.

Hydrostatic brake systems should not be used as the secondary brake.

Retarders should not be used during secondary brake system performance testing.

Secondary brakes on purpose-built underground mining machines may be applied without modulation.

If secondary brakes are applied automatically, there should be a warning given to the operator prior to their application.

If automatic brakes are separate from the secondary brake system, their performance should be at least the same as that of the secondary brake.

## A.6 Parking brake systems (see 4.6)

The parking brake should be capable of holding the machine stationary on the maximum design slope with a 20 % factor of safety. The minimum design slope is 25 %.



The parking brake should be applied automatically whenever the engine is stopped by the operator, or stops for any other reason (e.g. the operation of the automatic engine protection system). For an engine stoppage, the response time of the parking brake should not exceed 2 s from the time the engine ceases rotation.

If the parking brake has been automatically applied, it should have to be released by a specific action of the operator.

The machine should be fitted with an interlock system to prevent it from being driven with the parking brake applied. Procedures or a system that accommodates a daily brake test (as described in 4.12.2) can be provided. A means of moving the machine in an emergency situation can be provided.

Machine retrieval instructions should be supplied to explain the procedure for releasing the parking brake.

Automatic parking brakes should include a means in the machine operator's compartment to apply the brakes manually without shutting off the equipment and to release and reengage the parking brakes without having to start the equipment. If the brake is manually released, the brake should be automatically reapplied when the machine is started. A means of preventing the machine from being restarted until the brake is manually applied also meets this recommendation.

Hydrostatic drive trains should be disconnected during parking brake testing.

The parking brake should be released only by a control that does not operate any other equipment function, i.e. dedicated solely to the parking brake system.

The parking brake holding performance can be checked by performance on the actual slope or by achieving sufficient holding performance while being towed against the parking brake on the level.

## **A.7 Hydrostatic brake systems (see 4.7)**

For machines with hydrostatic transmissions, back throttling should not be used to meet the holding performance criteria. For service brake holding, the parking brake may be used in addition to the service brake to hold the machine when there is creep movement.

## **A.8 Machines designed to tow trailers (see 4.11)**

If the towing machine's brakes alone cannot meet the service, secondary and parking brake requirements, as applicable, when tested using the machine and trailer mass plus the total towing machine and trailer payload, then the towed trailer(s) should be equipped with brakes that act on each trailer wheel as part of these systems. If the trailer is designed with wheels that have an equally distributed load in all the conditions, then the brakes need only act on the wheels required to meet the stopping requirements.

The trailer brakes should act on both sides of an axle.

The trailer service brakes, secondary brakes and parking brakes should be designed such that they cannot be applied independently of the tractor's brakes.

The towing machine's parking brake control should apply the parking brakes of the machine and of any towed trailers, if so equipped.

Trailer parking brake systems should be designed such that they are applied automatically whenever the trailer is disconnected from the towing tractor.

If there are no parking brakes on the trailer and the trailer needs to be set by itself, a means should be provided on the trailer to hold it stationary (chocks are not preferred).

Machine/trailer combinations should be tested only in the forward direction.

## **A.9 General test conditions (see 5.2)**

Retarders should not be used during service and secondary brake testing.

All machines should be tested on a test course as described in 5.3.

## **A.10 Performance tests** (see Clause 6)

### **A.10.1 Holding performance** (see 6.4)

See A.4.2. for the recommended service brake holding performance.

See A.6 for the recommended parking brake holding performance.

### **A.10.2 Stopping performance** (see 6.5)

#### **A.10.2.1 Service brakes** (see 6.5.2)

See A.4.1 for the recommended service brake stopping performance.

The testing of purpose-built underground mining machines for stopping performance should be as follows:

- a) machines that travel as fast in reverse as they do in forward, e.g. LHD (load haul dump) machines:
  - five stops in forward at the maximum test mass with maximum specified payload;
  - five stops in reverse at the maximum test mass with maximum specified payload;
  - five stops in forward at the maximum test mass without payload;
  - five stops in reverse at the maximum test mass without payload.
- b) machines that travel primarily in forward, e.g. dumpers or machines with trailers:
  - five stops in forward at the maximum test mass with maximum specified payload;
  - five stops in forward at the maximum test mass without payload.

These tests should be run at a minimum of 80 % of maximum speed.

The stops should be separated by a maximum of 10 min.

The peak deceleration should be recorded.

#### **A.10.2.2 Secondary brakes** (see 6.5.3)

See A.5 for the recommended secondary brake stopping performance.

The testing of purpose-built underground mining machines for stopping performance should be as follows:

- three stops in forward at the maximum test mass with maximum specified payload;
- three stops in forward at the maximum test mass without payload.

These tests should be run at maximum speed or 25 km/h, whichever is the lesser speed.

The stops should be separated by a maximum of 10 min.

## **A.11 Test report** (see Clause 7)

Some jurisdictions require that fully developed deceleration rates be reported.

## A.12 Coal/gassy mining applications

**IMPORTANT — Gassy mines, such as coal mines, are even more heavily regulated than other mines. Legal requirements and certifications required by regulatory bodies need to be extensively researched.**

In Australia, the brakes used in coal mines typically have a maximum allowable brake temperature of 150 °C for any exposed surface.

In the USA, MSHA (Mine Safety and Health Administration) requires service and emergency brakes, with the performance of the emergency brakes being equal to that of the service brakes.

## Annex B (informative)

### Brake slope capability calculation method

Brake slope capability (BSC) can be calculated using the fully developed deceleration rate, measured with an accelerometer during the brake stopping performance testing. BSC is a measure of the brake's ability to stop and hold the machine, *not* of the machine's operating slope capability. Other factors need to be considered when determining the machine slope capability on the specific area where the machine is intended to work (see 4.13).

BSC, the percent slope on which the brakes stop a machine, can be calculated using Equation (B.1) and the measured fully developed deceleration rate, DR:

$$BSC = \left\{ \left[ (DR + b) \cdot MR \cdot TR \right] - SR \right\} \cdot 100 \quad (B.1)$$

where

DR	is the brake deceleration rate, the fully developed deceleration rate, in $g$ s, where $g$ is defined as the deceleration rate in metres per second squared divided by 9,8;
$b$	is the slope on which the machine is evaluated or tested; it is divided by 100 for the equation;
SR	is the brake stopping rate, the desired deceleration rate, in $g$ s, on a slope (typical desired deceleration rates are 0,06 $g$ ~ 0,08 $g$ for primary brakes and 0,03 $g$ ~ 0,04 $g$ for secondary brakes);
MR	is the machine mass ratio, the ratio of the mass of a machine during testing according to this International Standard divided by the machine mass on the work site, the actual machine mass including payloads and any options for or modifications to the machine;
TR	is the tyre radius ratio, the ratio of the machine tyre radius during testing according to this International Standard to the machine tyre radius on the work site, thereby allowing for different tyre options.

Equation (B.1) can be applied to both primary and secondary brake systems using the appropriate desired deceleration rate for the particular brake system.

**EXAMPLE 1** Brake slope capability of the service brakes on a 20 t wheeled loader with the same mass ( $MR = 1,0$ ), tyres ( $TR = 1,0$ ) and slope ( $b = 0$ ) as tested during the brake testing, with a measured brake deceleration rate of 0,5 $g$ :

$$BSC = \left\{ \left[ (0,5 + 0) \cdot 1,0 \cdot 1,0 \right] - 0,06 \right\} \cdot 100 = 44 \%$$

**EXAMPLE 2** Brake slope capability of the secondary brakes on a 100 t dumper carrying 10 % more than the rated load ( $MR = 0,91$ ), with tyres 3 % larger ( $TR = 0,97$ ) than standard tyres, and a measured brake deceleration rate of 0,25 $g$  and slope,  $b$ , of 0:

$$BSC = \left\{ \left[ (0,25 + 0) \cdot 0,91 \cdot 0,97 \right] - 0,03 \right\} \cdot 100 = 19 \%$$

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