TECHNICAL REPORT

ISO/TR 29944

First edition
2010-02-15

Powered industrial trucks and tractors — Brake performance — Determination of measurement procedures

Chariots de manutention et tracteurs industriels automoteurs — Capacité de freinage — Détermination des modes opératoires de mesure

Reference number
ISO/TR 29944:2010(E)

Contents

Page

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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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/TR 29944 was prepared by Technical Committee ISO/TC 110, *Industrial trucks*, Subcommittee SC 2, *Safety of powered industrial trucks*.

Introduction

The first edition of ISO 6292, published in 1996, defined two types of measurement method for verifying the brake performance of an industrial truck:

— drawbar drag measurement (DBD);

— truck deceleration measurement.

DBD is specified in the US standard ANSI/ITSDF B56.1 [1] and the Australian standard AS 2359-1 [2].

Both measurement methods verify braking force, each method differently. Both have inherent disadvantages, insofar as neither caters for brake system features that extend the stopping distance, i.e. initial response time and braking force build-up time, or state-of-the-art such as regenerative braking systems or other systems with a significant relationship between velocity of the truck and brake force.

ISO 6292:1996 also allowed for other methods or procedures for the assessment of brake performance, including the use of an accelerometer and chassis dynamometer, provided they gave equivalent accuracy. Nevertheless, it provided no further guidance or specification in relation to these. The first edition of ISO 6292 also permitted the use of stopping distance as a measurement method; however, it did not define any further basis for using that method.

International Standards such as ISO 3450 [3] and national/regional regulations such as EU Directive 71/320/EEC [4] describe the measurement of stopping distance as a means of verifying the braking performance of the vehicle. While ANSI/ITSDF B56.1 does specify a formula for determining stopping distance, it does not take into account the brake system reaction time.

In light of the above, an ad-hoc group was established within ISO/TC 110/SC 2/WG 7 to revise ISO 6292 with the objective of establishing stopping distance as a further measurement method. It was recognized that the determination of stopping distance needs to include the brake system reaction time, but not the human reaction time. In order to ensure widespread acceptance of the revised International Standard, it was also decided that the drawbar drag method should be maintained, subject to that method's ability to reproduce results of equivalent accuracy.

This Technical Report analyses the above-mentioned methods and explains the determination of the values used in the second edition, ISO 6296:2008, to calculate stopping distance and drawbar drag. Because a detailed description of all aspects within that International Standard was not possible, for the purposes of this Technical Report it was decided to summarize the determination of ISO 6292 requirements.

Powered industrial trucks and tractors — Brake performance — Determination of measurement procedures

1 Scope

This Technical Report describes the selection and calculation of the stopping distance and braking force used in the application of ISO 6292.

It does not cover test procedures, control forces or component strengths.

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 611, *Road vehicles — Braking of automotive vehicles and their trailers — Vocabulary*

ISO 6292:2008, *Powered industrial trucks and tractors — Brake performance and component strength*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 611 and the following apply.

3.1
stopping distance
s_0
distance travelled by the truck during the total braking time, from the instant when the driver begins to actuate the control device until the instant when the truck stops

3.2
brake reaction distance
s_r
distance travelled by the truck during the time from the instant when the driver begins to actuate the control device until the instant when the two vehicle speed straight lines (truck velocity while travelling and decreasing velocity while braking with mean fully deceleration) intersect

3.3
braking distance
s_b
distance travelled by the truck during the time from the instant when the two vehicle speed straight lines (truck velocity while travelling, and decreasing velocity while braking with mean full deceleration) intersect until the instant when the truck stops

4 Technical considerations

4.1 General

The objectives in revising ISO 6292 were to

— introduce the stopping distance (SD) measurement method,

— maintain the figures for mean deceleration (Groups A1, A2, B1) fixed by the first edition,

— establish a new definition of deceleration for Group C, the justification being that the requirements of ISO 6292 and ANSI/ITSDF B56.1 were not aligned,

— maintain drawbar drag measurement (DBD) as a method,

— define state-of-the-art brake reaction time (BRT), and

— enable calculation of the limiting values of SD and DBD in an easy and unmistakable way.

4.2 Research

In order to establish a basis for the preparation of a revised ISO 6292, several tests were performed.

4.2.1 Stopping distance measurement

The task was to determine the stopping distance of a wide range of industrial trucks. The SD method was carried out on standard-production trucks. The trucks were confirmed as meeting the requirements of ISO 6292:1996.

The following truck types were tested.

a) Electric counterbalanced trucks

The service brake system was an electrical brake system or a friction-type system (drum brakes).

b) Order-picking trucks (horizontal and vertical) and pedestrian-propelled stacking trucks

The service brake system was an electrical brake system.

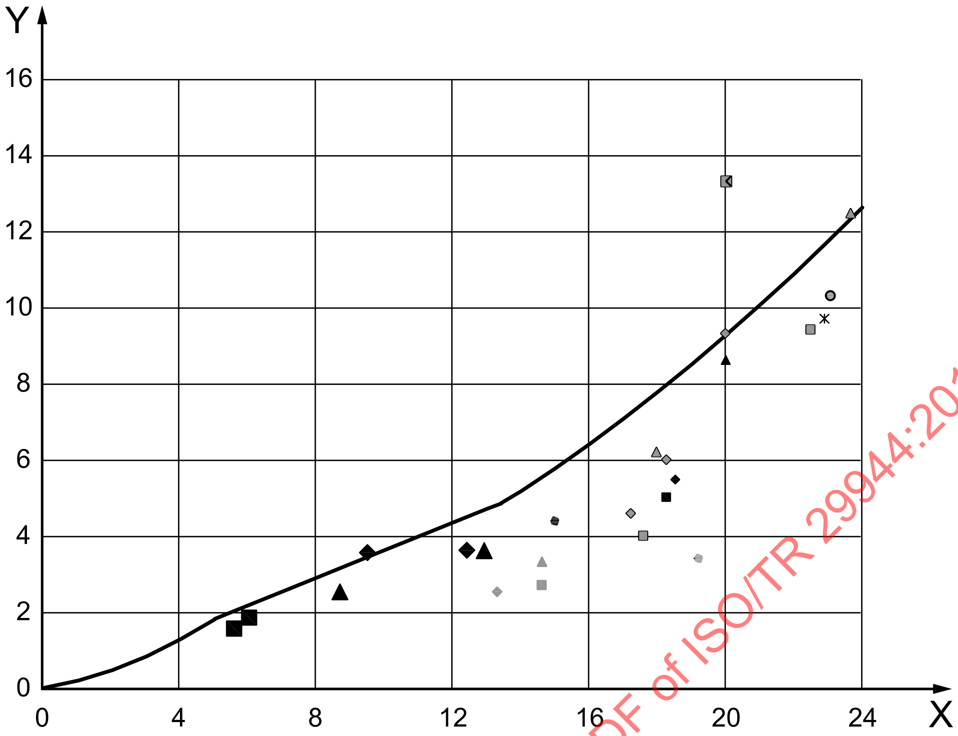
c) Reach trucks

The service brake system was a friction-type system (drum brakes).

d) IC trucks

The service brake system was a friction-type system (drum brakes) or hydrostatic transmission system.

Measurement data on SD was obtained from trucks in the USA, Japan and Germany. Figure 1 shows a summary of the results.



Key

X truck velocity, km/h

Y SD, m

- Electric 1.6t
- Electric 2t
- Electric 2t (F)
- Electric 3t
- IC drum brakes 2,5t (A)
- IC drum brakes 2,5t (D)
- IC drum brakes 2,5t (B)
- IC drum brakes 2,5t (C)
- IC drum brakes 3t
- IC drum brakes 3,2t (power ass.)
- IC drum brakes 4t
- IC drum brakes 16t (1)
- IC drum brakes 16t (2)
- IC Hydrostat 1.6t
- IC Hydrostat 2.5t
- IC Hydrostat 3t
- IC Hydrostat 5t
- IC Hydrostat 8t
- Order picker
- Pedestrian propelled stacking truck
- Reach Truck drum brake
- ISO 6292 A1 (BRT 0,54 s)

Figure 1 — Stopping distance

The following insights were gained when performing the examination:

- the brake force needs to be controllable in a sensitive way to avoid loss of load;
- tests showed that a too-high deceleration rate would not improve safety because during high deceleration hazardous situations such as load movement, instability and loss of load are more likely to occur and therefore the maximum deceleration of the truck needs to be limited;
- truck adjustment optimized for safe truck handling limited the deceleration value of some of the tested trucks.

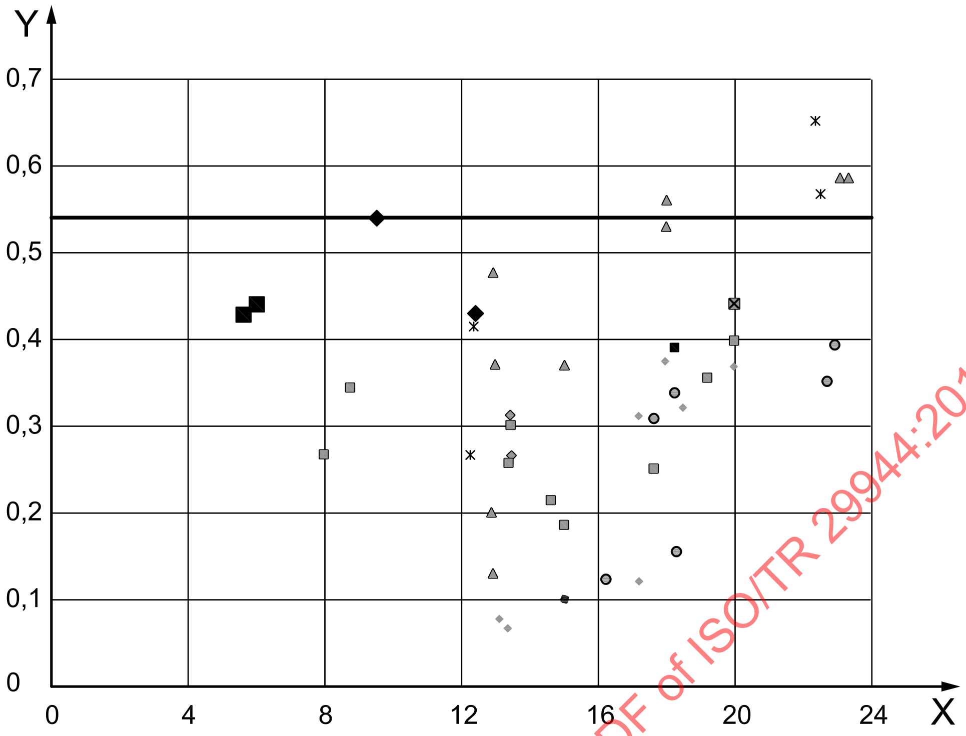
4.2.2 Brake reaction time

The second task was to determine the characteristic brake reaction time of industrial trucks.

Measurement data on actual BRT was obtained from trucks in the USA, Japan and Germany.

The BRT was measured in accordance with ISO 611, which states the difference between t_0 (instant when the the control device is actuated) and t_4 (instant when the vehicle speed straight lines intersect).

This research produced widely varying brake reaction times. Figure 2 is a summary of the results and shows the range of BRT for different trucks.



Key

X truck velocity, km/h

Y BRT, s

- Electric 1.6t
- Electric 2t
- Electric 2t (F)
- Electric 3t
- IC drum brakes 2,5t (A)
- IC drum brakes 2,5t (D)
- IC drum brakes 2,5t (B)
- IC drum brakes 2,5t (C)
- IC drum brakes 3t
- IC drum brakes 3,2t (power ass.)
- IC drum brakes 4t
- IC drum brakes 16t (1)
- IC drum brakes 16t (2)
- IC Hydrostat 1.6t
- IC Hydrostat 2.5t
- IC Hydrostat 3t
- IC Hydrostat 5t
- IC Hydrostat 8t
- Order picker
- Pedestrian propelled stacking truck
- Reach truck drum brake
- Proposed BRT

Figure 2 — Brake reaction time (BRT)

NOTE EU Directive 71/320/EEC states values for cars of 0,36 s and for lorries 0,54 s. Based on a similar design of braking components for industrial trucks, engineering knowledge, and measured test data, the formulas given below utilize 0,54 s as a BRT basis for the stopping distance formulas.

4.3 Determination of formulas

4.3.1 Stopping distance formulas for trucks in Groups A1, A2 and B

The formulas are derived from the formula for steady and linear motion:

$$s = v \cdot t$$

and the formula for constantly accelerating linear motion:

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

For a better understanding of the following, see the graph in Annex A. The stopping distance, s_0, is the addition of the distance travelled during the initial response time (see Figure A.1 between t_0 and t_1), braking force build-up time (with no or partial deceleration, see Figure A.1 between t_1 and t_4) and the distance travelled during deceleration with a stabilized value (mean deceleration, see Figure A.1 between t_4 and t_7).

The distance travelled during response time and braking force build-up time was summarized as brake reaction distance, s_r.

The distance travelled during deceleration is defined as the braking distance, s_b.

The stopping distance, in metres, becomes

$$s_0 = s_r + s_b$$

Using the defined value for BRT (see 4.2.2), the first part becomes

$$s_r = \frac{v}{t} = \frac{v\,[\frac{\text{km}}{\text{h}}] \cdot 1\,000\,\frac{\text{m}}{\text{km}}}{3\,600\,\frac{\text{s}}{\text{h}}} \cdot 0{,}54\ \text{s} = 0{,}15v$$

$$s_r = 0{,}15v$$

where v is the actual truck velocity in km/h.

For the second part, it was decided (see 4.1) to keep the values for mean deceleration stated in ISO 6292:1996, where the values are defined as braking capacity, C_b, as a percentage:

$$C_b = \frac{a}{g} \cdot 100$$

$$a = \frac{C_b}{100} \cdot g$$

where

a is the fully developed braking deceleration in m/s²;

g is the acceleration of free fall in m/s² (g = 9,81 m/s²).

Annex B presents an adaptation of ISO 6292:1996, Figure 1, a graph showing truck deceleration against truck velocity.

Determination of the formula is explained for the trucks in Group A. Determination for other types follows the same determination format.

The second part of the formula becomes

$$s_b = \frac{v^2}{2a_m} = \frac{v^2[\frac{\text{km}}{\text{h}}] \cdot \left(\frac{1\,000\frac{\text{m}}{\text{km}}}{3\,600\frac{\text{s}}{\text{h}}}\right)^2}{2a_m} = \frac{v^2[\frac{\text{km}}{\text{h}}] \cdot \left(\frac{1\,000\frac{\text{m}}{\text{km}}}{3\,600\frac{\text{s}}{\text{h}}}\right)^2}{2 \cdot \frac{C_b}{100} \cdot 9{,}81\frac{\text{m}}{\text{s}^2}}$$

For truck velocities less than or equal to 5 km/h, the mean deceleration as a percentage of gravity is $C_b = 9{,}3$ % constant.

$$s_b = \frac{v^2[\frac{\text{km}}{\text{h}}] \cdot \left(\frac{1\,000\frac{\text{m}}{\text{km}}}{3\,600\frac{\text{s}}{\text{h}}}\right)^2}{2 \cdot \frac{9{,}3\%}{100} \cdot 9{,}81\frac{\text{m}}{\text{s}^2}} = \frac{v^2[\frac{\text{km}}{\text{h}}]}{23{,}65}$$

$$s_b = \frac{v^2}{23{,}65}$$

In this velocity range, the stopping distance, s_0, becomes

$$s_0 = s_r + s_b = 0{,}15\,v + \frac{v^2}{23{,}7}$$

where v is the actual truck velocity in km/h.

For truck velocities greater than 5 km/h and less than or equal to 13,4 km/h, the mean deceleration increased in relation to the truck velocity ($C_b = 1{,}86\,v$, from ISO 6292:1996, Table 1):

$$s_b = \frac{v^2[\frac{\text{km}}{\text{h}}] \cdot \left(\frac{1\,000\frac{\text{m}}{\text{km}}}{3\,600\frac{\text{s}}{\text{h}}}\right)^2}{2 \cdot \frac{C_b}{100} \cdot 9{,}81\frac{\text{m}}{\text{s}^2}} = \frac{v^2[\frac{\text{km}}{\text{h}}] \cdot \left(\frac{1\,000\frac{\text{m}}{\text{km}}}{3\,600\frac{\text{s}}{\text{h}}}\right)^2}{2 \cdot \frac{1{,}86v}{100} \cdot 9{,}81\frac{\text{m}}{\text{s}^2}} = \frac{v[\frac{\text{km}}{\text{h}}]}{4{,}72}$$

$$s_b = \frac{v}{4{,}72}$$

In this velocity range, the stopping distance, s_0, in metres, becomes

$$s_0 = 0{,}15\,v + \frac{v}{4{,}7}$$

where v is the actual truck velocity in km/h.

For truck velocities greater than 13,4 km/h, the mean deceleration as a percentage of gravity is $C_b = 25$ % constant (from ISO 6292:1996, Table 1):

$$s_b = \frac{v^2[\frac{km}{h}] \cdot \left(\frac{1000 \frac{m}{km}}{3600 \frac{s}{h}} \right)^2}{2 \cdot \frac{25\%}{100} \cdot 9{,}81 \frac{m}{s^2}} = \frac{v^2[\frac{km}{h}]}{63{,}57}$$

For velocities greater than 13,4 km/h, the stopping distance, s_0, in metres, becomes

$$s_0 = 0{,}15\,v + \frac{v^2}{63{,}6}$$

where v is the actual truck velocity in km/h.

4.3.2 Determination of stopping distance formulas for trucks within Group C

For Group C it was not possible to keep the values for mean deceleration of ISO 6292:1996, because the values defined in ANSI/ITSDF B56.1 are based upon an incompatible principle; therefore new deceleration values were needed:

— for velocities less than 4 km/h, the braking force remains at a constant level to avoid creeping;

— to keep the principle of the standard, the velocity ranges correspond to those of the other groups;

— the maximum deceleration is limited to 1,47 m/s^2 (15 % of g).

The graph in Annex C shows deceleration values taken from ISO 6292:1996, ANSI/ITSDF B56.1 and the Working Group's proposals.

4.3.3 Determination of braking force formulas

The drawbar drag measurement method has been maintained as an applicable measurement method, subject to the method's ability to produce results equivalent in accuracy to that of the SD method.

The braking force is calculated from deceleration multiplied by the mass of the truck:

$$F = ma$$

The calculation assumes that the braking force corresponds to the values for C_b fixed in ISO 6292:1996, Table 1 and Figure 1:

$$C_b = \frac{F}{m \cdot g} \cdot 100$$

$$F = m \cdot \frac{C_b \cdot g}{100}$$

where

C_b is the braking capacity in %;

F is the braking force, in N;

m is the mass of the laden truck, in kg;

g is the acceleration of free fall in m/s^2 ($g = 9{,}81$ m/s^2).

To obtain comparable results from both methods, it is necessary that the BRT does not exceed 0, 54 s, and that this be verified by a type test.

If the BRT of the examined brake system is unknown, the method is not acceptable for verifying the performance of the brake system.

Determination of the formula is explained for the trucks in Group A. Determination for other types follows the same determination format.

For truck velocity less than or equal to 5 km/h, the mean deceleration as a percentage of gravity is $C_b = 9{,}3\ \%$ constant (from ISO 6292:1996, Table 1):

$$F = m \cdot \frac{C_b \cdot g}{100} = m \cdot \frac{9{,}3\% \cdot 9{,}81 \frac{m}{s^2}}{100\%} = m \cdot 0{,}91$$

$$F = 0{,}91m$$

where

F is the braking force, in N;

m is the mass of the laden truck, in kg.

For truck velocities greater than 5 km/h and less than or equal to 13,4 km/h, the mean deceleration increases in relation to the truck velocity ($C_b = 1{,}86v$; from ISO 6292:1996, Table 1).

$$F = m \cdot (1{,}86v)[\%] \cdot \frac{9{,}81 \frac{m}{s^2}}{100\%} = m \cdot 0{,}182v$$

$$F = 0{,}182vm$$

where

F is the braking force, in N;

m is the mass of the laden truck, in kg;

v is the actual truck velocity in km/h.

For truck velocities greater than 13,4 km/h, the mean deceleration as a percentage of gravity is $C_b = 25\ \%$ constant (from ISO 6292:1996, Table 1):

$$F = m \cdot \frac{C_b \cdot g}{100} = m \cdot \frac{25\ \% \cdot 9{,}81 \frac{m}{s^2}}{100\ \%} = m \cdot 2{,}45$$

$$F = 2{,}45m$$

where

F is the braking force, in N;

m is the mass of the laden truck, in kg.

5 Conclusion

The research concluded that

a) the stopping distance method provides a reasonably accurate method of determining and measuring brake system performance, from the results of which limit values for stopping distance can be defined;

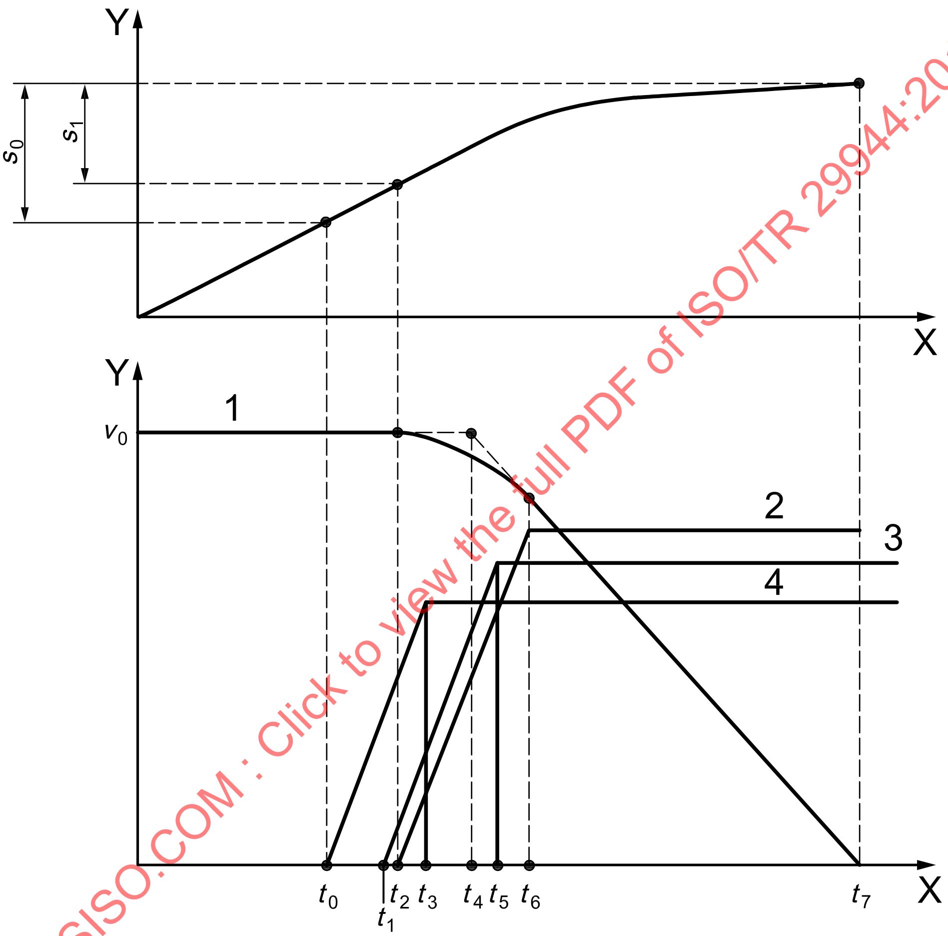
b) the draw bar drag method is still applicable if the brake reaction time is within an acceptable range;

c) the requirements of the revised ISO 6292 are comparable to other standards in respect of industrial vehicles.

Annex A
(informative)

Timing responses during stopping (from ISO 611)

See Figure A.1.



Key

X time

Y distance

1 vehicle speed

2 deceleration

3 line pressure

4 control travel

v_0 initial vehicle speed

s_0 stopping distance

s_1 braking distance

t_0 instant when the driver begins to actuate the control device, i.e. the instant when the control device starts to move

t_1 instant when the line pressure begins to increase

t_2 instant when deceleration begins to increase

t_3 instant when the control device reaches its intended position

t_4 instant when the two vehicle speed straight lines intersect (as in diagram)

t_5 instant when the line pressure reaches its stabilized value

t_6 instant when the deceleration reaches its stabilized value

t_7 instant when the vehicle stops

Figure A.1 — Idealized timing responses during stopping