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Braking of road vehicles — Considerations on the definition of mean fully developed deceleration

Freinage des véhicules routiers — Considérations sur la définition de la décélération moyenne en régime

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Contents

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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 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 main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, 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).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13487, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 2, *Brake systems and equipment*.

Introduction

ECE Regulation No. 13 "Uniform Provisions Concerning the Approval of Vehicles of Categories M, N and O with Regard to Braking" determines the minimum legal braking performance for new road vehicles at the time of type-approval.

This braking performance is specified in terms of "stopping distance" and in terms of "mean fully developed deceleration" (mfdd).

The 08 series of amendments to ECE-R13 requires that both the above parameters must be fulfilled; furthermore, the 08 series of amendments prescribes the method of calculating the mean fully developed deceleration.

The chosen method of calculating the mfdd is based on the work done in ISO/TC 22/SC 2 Working Groups 6 and 10.

For this reason, it is useful to summarize the background information on this subject in this ISO Technical Report, by describing the physical fundamentals and the connection between stopping distance and mfdd; this will enable the persons responsible for determining the braking performance to analyse the results of testing, which are never exactly reproducible.

Because the legislative text does not stipulate the measuring equipment nor specific measuring procedures, this Technical Report may indicate alternative solutions to the Technical Services and to the manufacturers of measuring equipment; it will also address prospective computer-supported possibilities. In addition, the transition between different systems of units will be facilitated by this contribution.

The prospective legislative text will concede alternative methods of measuring the mfdd; these are explicitly explained in this Technical Report.

The report clearly indicates that in addition to the exact solutions for the mfdd (see equations 16 and 29), certain approximations (see equations 30, 31 and 33) are also permissible within the required accuracy, as documented by theoretical considerations and corresponding practical measurements with a vehicle.

For this reason, equation 31 was developed for computer-aided and equation 33 for graphical evaluations.

Symbols

Symbol	Unit	Description
$a\ (s)$	m/s^2	distance-dependent deceleration
$a\ (t)$	m/s^2	time-dependent deceleration
$\bar{a}$	m/s^2	representative constant deceleration
$\lvert\bar{a}\rvert$	m/s^2	absolute value of $\bar{a}$
a_B, a_E	m/s^2	decelerations at the beginning and end of evaluation range on the linear approximate solution for a (t)
$a_F\ (t)$	m/s^2	analytically given deceleration path with temporal drop
a_i, a_j	m/s^2	individual deceleration values
$a_L\ (t)$	m/s^2	linear approximate solution for a (t)
a_{max}	m/s^2	maximum value in a time-dependent deceleration path
a_{ms}	m/s^2	distance-related mean deceleration
a_{ms1}, a_{ms2}, a_{ms3}	m/s^2	examples of different distance-related mean deceleration
$\tilde{a}_{ms}$	m/s^2	approximate value for the distance-related mean deceleration in accordance with Equation (33)
a_{msN}	m/s^2	numerical approximate value for the distance-related mean deceleration in accordance with Equation (31)
a_{mt}	m/s^2	time-related mean deceleration
$\tilde{a}_{mt}$	m/s^2	approximate value for the time-related mean deceleration in accordance with Equation (34)
$a_R\ (t)$	m/s^2	analytically given deceleration path with temporal rise
$a_1\ (s)$, $a_2\ (s)$, $a_3\ (s)$	m/s^2	different distance-dependent deceleration paths
$a_1\ (t)$, $a_2\ (t)$, $a_3\ (t)$	m/s^2	different time-dependent deceleration paths
d_m	m/s^2	mfdd according to ECE Regulation No. 13
ds	m	distance differential
dt	s	time differential
dv	m/s	speed differential
mfdd	m/s^2	mean fully developed deceleration
s	m	distance
s_B, s_E	m	distances at the start and end of evaluation range
s_D	m	braking distance during the period of mfdd
$s_F\ (t)$	m	distance path during the analytically given deceleration $a_F\ (t)$
s_i	m	individual distance values
s_R	m	braking distance during response time and pressure build-up time

s_R (t)	m	distance path during the analytically given deceleration a_R (t)
s_1, s_2, s_3	m	braking distances with different deceleration paths
s_1 (t), s_2 (t), s_3 (t)	m	different distance paths
T	s	total braking time
t, t^i	s	time
t_B, t_E	s	points in time for the start and end of the evaluation range
t_R	s	sum of response time and pressure build-up time
t_S	s	time at the end of a stop
t_1	s	point in time at which the deceleration takes on the value 1/2 a_{max} at first time
t_2	s	point in time at which the deceleration takes on the value 1/2 a_{max} at last time
v	km/h	test speed
v (t)	m/s, km/h	variable speed
v_B, v_E	m/s	speeds at the start and end of evaluation range
v_F (t)	m/s	speed path during the analytically given deceleration a_F (t)
v_i	m/s	individual speed values
v_R (t)	m/s	speed path during the analytically given deceleration a_R (t)
v_0	m/s, km/h	initial speed
v_1 (t), v_2 (t), v_3 (t)	m/s	different speed paths
Δa_{msN}, $\Delta \tilde{a}_{ms}$, $\Delta \tilde{a}_{mt}$, $\Delta \tilde{a}_{msN}$	%	related differences of mean decelerations (Tables 5 and 6)
Δt	s	time increment
τ	s	time

Braking of road vehicles — Considerations on the definition of mean fully developed deceleration

1 Technical considerations

The ECE Regulation No. 13 "Uniform Provisions Concerning the Approval of Vehicles with Regard to Braking" deals in Annex 4 "Braking Tests and Performance of Braking Systems" with the observance of certain stopping distances and certain "mean fully developed decelerations" under defined test conditions.

The formulae applied for the judgement of the stopping distance ordinarily have the structure

$$s \le s_R + s_D = t_R \times v + \frac{v^2}{2 \times d_m} \qquad (1)$$

where :

s is the measured stopping distance, s_R the distance correlated to the response and pressure build-up time t_R, s_D the distance correlated to the mean fully developed deceleration phase, v the test speed and d_m the so-called "mean fully developed deceleration". e.g. for passenger cars (vehicles of category M_1 according to ECE-R13) the following values are valid:

$t_R = 0{,}36$ s, $v = 22{,}22$ m/s and $d_m = 5{,}8$ m/s^2

If the stopping distance shall be measured in the dimension m and in addition the dimension km/h shall be used for the speed, we get from (1) in the case of M_1-vehicles the formula as it is known from the Regulation No. 13:

$$s \le 0{,}1 \times v + \frac{v^2}{150} \qquad (2)$$

The problem is that there is until today no rule for determining the "mean fully developed deceleration" (mfdd) in such a way that it is commensurate to the existing legal requirements for stopping distances.

A procedure which establishes mfdd in such a way that it is in accordance with the stopping distance should additionally fulfil the following demands:

- Mfdd shall not be design-restrictive concerning the measuring devices i.e. even pure deceleration measurements shall be evaluable.

- The evaluation of the mfdd shall allow the use of modern computers as well as conventional methods.

- A representative part of the deceleration process must be chosen for the evaluation.

Until now, in national regulations in Europe, mean values have generally been based on time. There is no indication on any of the analytical processes that mean value formation based on time can lead to considerable errors, if the stopping distance or speed path is calculated with this time-related mean value.

Using various deceleration paths with the same time-related mean value, the following example shows that both the distance-related mean decelerations and the appertaining stopping distances assume different values.

Starting from the speed v_0 = 30 m/s, in a time interval of 0 to 6 s, the following deceleration paths are taken (Figure 1):

$$a_1\,(t) = -5\,m/s^2$$
$$a_2\,(t) = -(8\,m/s^2 - 1\,m/s^3 \times t)$$
$$a_3\,(t) = -(2\,m/s^2 + 1\,m/s^3 \times t) \qquad (3)$$

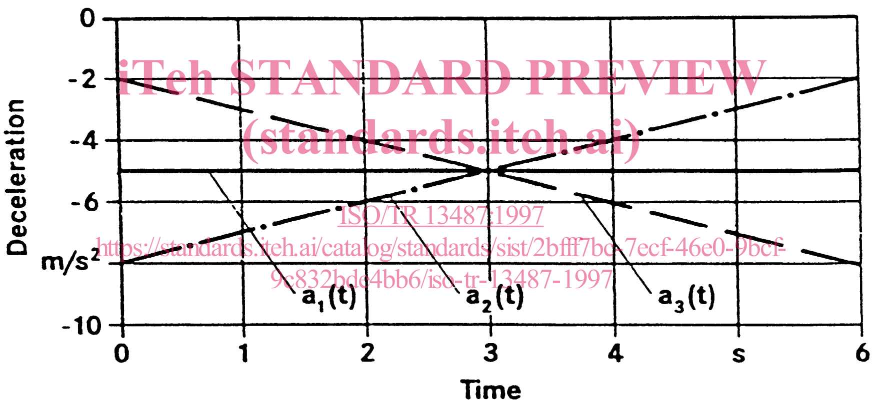

Figure 1 - Different deceleration paths with the same time-related mean value

Integration over time gives the speeds (Figure 2):

$$v_1\,(t) = 30\,m/s - 5\,m/s^2 \times t$$
$$v_2\,(t) = 30\,m/s - (8\,m/s^2 - 0{,}5\,m/s^3 \times t) \times t$$
$$v_3\,(t) = 30\,m/s - (2\,m/s^2 + 0{,}5\,m/s^3 \times t) \times t \qquad (4)$$

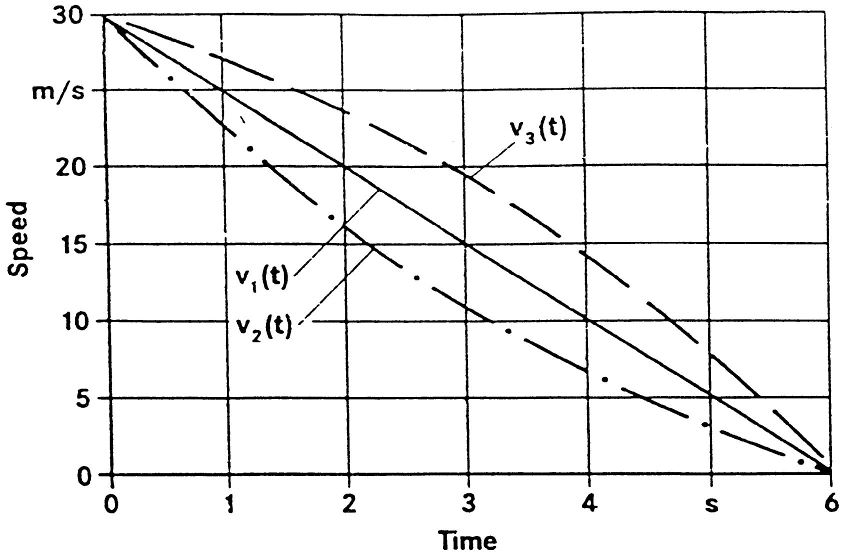

Figure 2 - Speed paths correlated to the decelerations in figure 1

Integration of the speeds over time gives the distance paths (figure 3):

$$s_1\,(t) = 30\ m/s \times t - 2{,}5/s^2 \times t^2 \qquad (5)$$

$$s_2\,(t) = 30\ m/s \times t - (8\ m/s^2 - 0{,}\overline{3}\ m/s^3 \times t) \times \frac{t^2}{2}$$

$$s_3\,(t) = 30\ m/s \times t - (2\ m/s^2 + 0{,}\overline{3}\ m/s^3\ x\ t) \times \frac{t^2}{2}$$

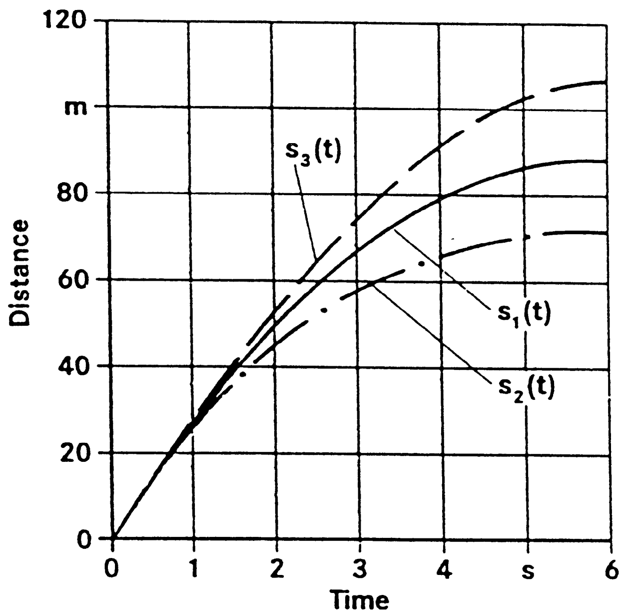

Figure 3 - Distance paths correlated to the decelerations in Figure 1

In the case of different decelerations a (t) with the same time-related mean value, major deviations in the braking distance are apparent (Figure 3):

$s_1 = 90$ m $\qquad s_2 = 72$ m $\qquad s_3 = 108$ m

If the deceleration paths correlated to Figure 1 are plotted against distance, the result is shown in Figure 4.

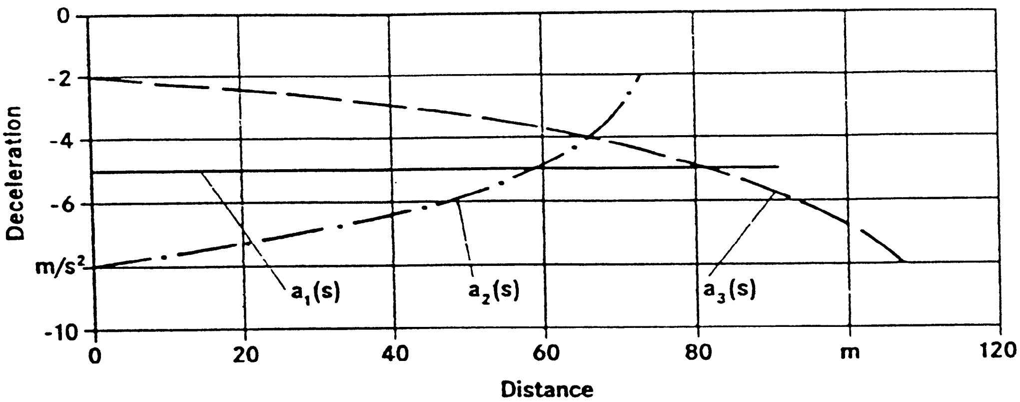

Figure 4 - Deceleration paths over distance based on the distances in Figure 3

With the help of the equation:

$$a_{msj} = -\frac{v_0^2}{2 \times s_j}, j = 1, 2, 3 \quad (6)$$

which represents a special case of the equation (11) developed in chapter 2, the results is as follows:

a_{ms1} = - 5,0 m/s² a_{ms2} = - 6,25 m/s² a_{ms3} = - 4,17 m/s²

It can be seen that the distance-related mean decelerations deviate from one another. Only in the case of a_{ms1} = - 5.0 m/s² the value is equal to the time-related value.

The previous discussions indicate that it is necessary to carefully interpret the mean fully developed deceleration, designated as d_m in equation (1). Particularly so because the legal requirements based on the current edition of ECE Regulation No. 13 allow the possibility of using the mfdd d_m in addition to evaluation of the stopping distance for approval tests.

2 Theoretical considerations

2.1 Basic equations

The physical derivation is required to help understand the second term s_D from equation (1) containing mfdd. Starting with the basic equations:

$$v(t) = \frac{ds}{dt} \tag{7}$$

and

$$a(t) = \frac{dv}{dt} \tag{8}$$

the following relationship can be obtained by eliminating the time differential dt in (8) by substitution using (7):

$$ds = \frac{1}{a(t)} \times v(t) \times dv \tag{9}$$

The question of a suitable definition of mfdd is equivalent to the question which representative constant deceleration rate $\bar{a}$ can describe a given deceleration process. Considering the difference between distance s_B at the start and distance s_E at the end of the evaluation period it can be obtained by integrating (9) within the associated speed limits v_B and v_E

$$\int_{s_B}^{s_E} ds = s_E - s_B = \frac{1}{\bar{a}} \times \int_{v_B}^{v_E} v(t) \times dv = \frac{v_E^2 - v_B^2}{2 \times \bar{a}} \tag{10}$$

or:

$$\bar{a} = \frac{v_E^2 - v_B^2}{2 \times (s_E - s_B)} \tag{11}$$

When the vehicle is braked to a full stop V_E goes to zero. Equating:

$$s_E - s_B = s_D \tag{12}$$

$$|\bar{a}| = d_m \tag{13}$$

and:

$$v_B = v \tag{14}$$

it follows from (10) or (11) the second term of (1). This clearly describes its physical background.

Corresponding to the literal sense of mfdd the same result can be obtained by calculating a mean value a_{ms} for the distance-dependent deceleration a(s) using the usual mathematical definition of a mean:

$$a_{ms} = \frac{1}{s_E - s_B} \times \int_{s_B}^{s_E} a(s) \times ds = \frac{1}{s_E - s_B} \times \int_{v_B}^{v_E} \frac{dv}{dt} \times v(t) \times dt \qquad (15)$$

This results in:

$$a_{ms} = \frac{v_E^2 - v_B^2}{2 \times (s_E - s_B)} \qquad (16)^{1)}$$

The representative deceleration $\overline{a}$ according to (11) and the mean value a_{ms} according to (16) are therefore identical. So it is proved that only a distance-related mean deceleration is in harmony with the stopping distance.

A time-related mean value a_{mt} between the times t_B at the beginning and t_E at the end of the evaluation period can also be calculated analogous to (15) according to the equation:

$$a_{mt} = \frac{1}{s_E - t_B} \times \int_{t_B}^{t_E} a(t) \times dt = \frac{1}{s_E - t_B} \times \int_{v_B}^{v_E} \frac{dv}{dt} \times dt \qquad (17)$$

This results in:

$$a_{mt} = \frac{v_E - v_B}{t_E - t_B} \qquad (18)$$

When the deceleration process is not constant, a_{mt} deviates from a_{ms} as it was already shown in the examples in the introduction. The following discussion describes the effects of the difference between a_{ms} and a_{mt} in greater detail.

2.2 Determination of the distance-related mean deceleration from a(t)

Before continuing with the derivation of the physical laws required for a comparative discussion of a_{ms} and a_{mt}, a few deficiencies in the previous discussion need to be cleared up. In equation (13) it was only possible to achieve the transition to d_m by using the absolute value of $\overline{a}$. This was necessary, because the legal regulations only allow the use of positive deceleration values, while deceleration rates have negative values in exact physical terms, as are obtained in equations (11), (16) and (18). Moreover substitution of v for v_B in equation (14) is critical, because legal regulations define v to be the testing velocity, whereby v_B as used below means the velocity at the start of the evaluation period.

1) The anticipated legislative text in ECE-R13 is based on this equation.