Introduction

A vehicle in motion has a kinetic energy (E_{kin}) whose magnitude depends on the vehicle mass (m) and its speed (v) squared.

$$E_{kin} = \frac{m \times v^2}{2}$$

This energy has to be converted, wholly or partly, when the vehicle is to stop or reduce its speed. This is the purpose of the brake which by means of friction, converts the vehicle's kinetic energy into heat.

Acceleration and Deceleration

Acceleration is the term used for the **increase in speed** by a certain speed value in metres per second for each second (= m/s²). (Braking) deceleration is the term used for the **reduction in speed** by a certain speed value in meters per second for each second (= m/s²).

If this value is identical in each second, this is called **"uniform" acceleration or deceleration**.

The speed is computed using the following formula:

$$\text{speed} = \frac{\text{travel}}{\text{time}} \qquad v = \frac{s}{t} \qquad \text{in } \frac{m}{s}$$

Acceleration and deceleration are computed using the following formula:

$$\text{deceleration} = \frac{\text{speed}}{\text{time}} \qquad a = \frac{v}{t} \qquad \text{in } \frac{m}{s^2}$$

Maximum Braking Deceleration

The deceleration or braking cannot be increased infinitely. **A limit** is set by the theoretically achievable deceleration by acceleration due to **gravity (g)** at g = 9.81 m/s². The deceleration of a braking system, no matter how effective that may be, will hardly be able to achieve this value, let alone exceed it.

Another limit is the **frictional value between the tyre and the road surface** which is expressed by the **adhesion coefficient (k)**. Usually (there are exceptions) deceleration is greatest when the wheels do not lock during the braking process, i. e. that they just continue to turn. Any increase in the braking force would thus not automatically achieve greater braking performance but would instead result in locking of the wheels and thus a loss of steerability, and cause the vehicle to swerve.

Adhesion coefficient (k)

Depending on the road surface and its condition at the time (dry, wet), a certain adhesion coefficient (k) is obtained which determines the maximum achievable braking deceleration. It is computed as follows:

Max. attainable deceleration = gravity x adhesion coefficient

$$a_{max} = g \times k \qquad \text{in } \frac{m}{s^2}$$

The table below shows **adhesion coefficients k** on different road conditions:

Road Surface	dry	wet	
		clean	slippery
concrete, granite	0.7	0.6	approx. 0.4
tar macadam	0.6	0.5	approx. 0.3
asphalt	0.6	0.5	approx. 0.25
blue basalt cobbles	0.55	0.3	0.1 – 0.2
snow (hard-packed)	0.2	0.1	
black ice	0.1	0.01 to 0.1	

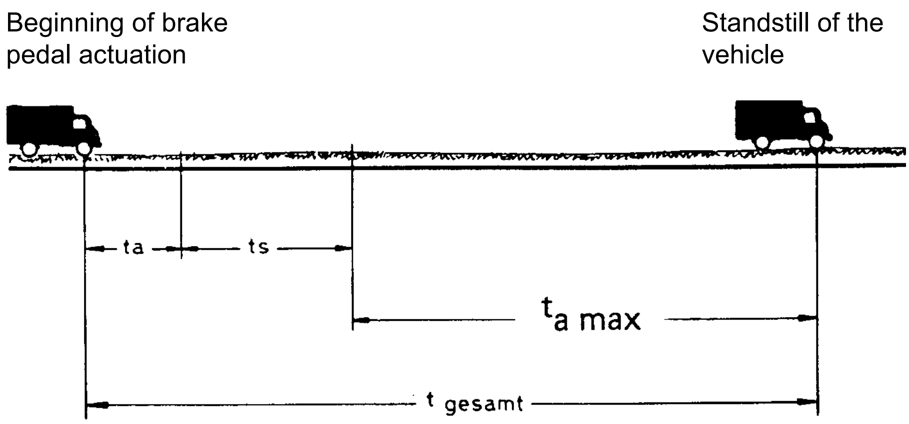
For braking on black ice, this means

$$a_{max} = 10\frac{m}{s^2} \times 0.1 = 1\frac{m}{s^2}$$

If, however, an adhesion coefficient of 0.6 is assumed (dry concrete), we have a maximum achievable value of 6 m/s².

The temporal sequence of a braking action

The maximum braking deceleration is not effective across the whole of the braking process, or during the total braking period, because from the moment the pedal is first pressed until maximum deceleration is reached, the process first passes through the response time t_a and the pressure build-up time t_s.



Beause of the symbolic illustration from the point of view of time run over the following time factors are shown (information in s).

The responds time (t_a)

Rather simplified, response time **(t_a)** is the term used for the time which elapses between actuation of the brake pedal and commencement of the braking performance.

The “pressure build-up time” (t_a)

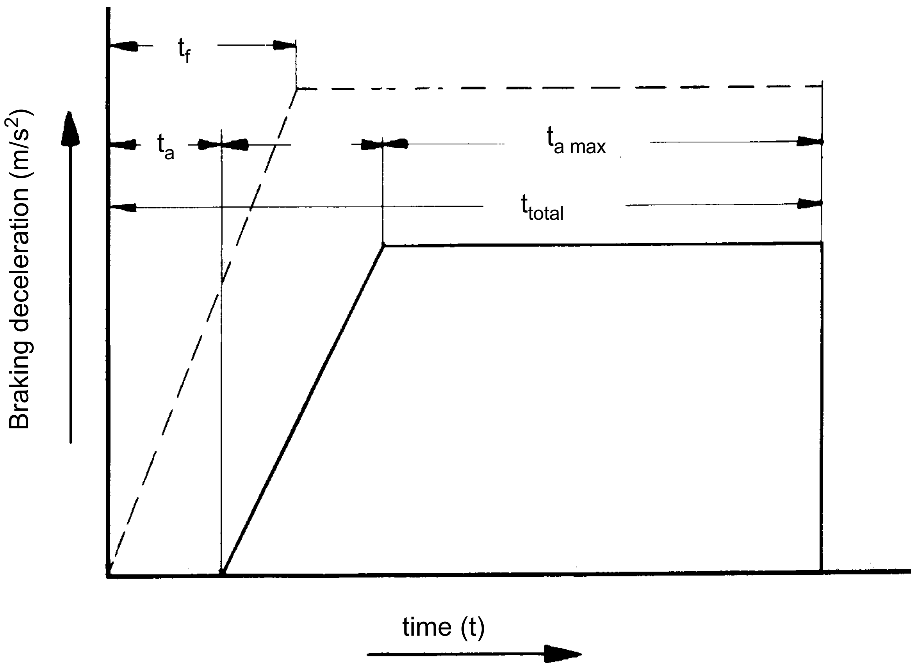
Again if we simplify this, pressure build-up time **(t_s)** is the term used for the time which elapses between commencement of the braking performance and the moment when maximum braking deceleration has been achieved.

Braking deceleration period ($t_{a\ max}$)

The term braking deceleration period **($t_{a\ max}$)** is used for the period between commencement of maximum braking deceleration **(a_{max})** and the moment when the vehicle has stopped.

Total Braking Period (t_{tot})

This is the period from actuation of the brakes until the vehicle has stopped. The driver’s thinking and reaction times are not being taken into account at this point.



The actuating period (t_f)

The length of the response and pressure build-up times of course depends on the length of the actuating period **(t_f)**.

By this we mean the period between commencement of the brake pedal or treadle being actuated and the moment its end stop has been reached.

The Braking Ratio (z)

In addition to braking deceleration there is another dimension for describing braking behaviour: the **braking ratio z**.

This is the percentage ratio of the braking forces generated, i. e. determined on the roller dynamometer, compared with the current weight force of the vehicle.

$$\textbf{braking rate in \%} = \frac{\textbf{vehicle's total braking forces}}{\textbf{vehicle's test weight}}$$

$$z = \frac{F}{G_p} \times 100\ \%$$

Relation between braking ration z and max. braking deceleration a_{max}

A relation between the max. braking deceleration amax and the braking ration z arises from the formula:

$$a_{max} = \frac{F \times g}{G_p} = z \times g$$

This means that there is a direct connection between (z) and (a_{max}) which allows the braking deceleration (a_{max}) achieved to be expressed as the percentual braking ratio (z), and vice versa.

This table shows the corresponding values

Braking Ratio (z)	Braking deceleration (a_{max})	
	exact	rounded up
10 %	0.981 m/s^2	1.0 m/s^2
20 %	1.962 m/s^2	2.0 m/s^2
30 %	2.943 m/s^2	3.0 m/s^2
40 %	3.924 m/s^2	4.0 m/s^2
50 %	4.905 m/s^2	5.0 m/s^2
60 %	5.886 m/s^2	6.0 m/s^2
70 %	6.867 m/s^2	7.0 m/s^2
80 %	7.848 m/s^2	8.0 m/s^2
90 %	8.829 m/s^2	9.0 m/s^2
100 %	9.810 m/s^2	10,0 m/s^2

Measuring of the deceleration or of the retardation

There are two possibilities

1. Determining the braking ratio z in % **using a brake test bench** (roller or plate dynamometer):

2. Determining the values in the course of deceleration in a road-test run **using a decelerometer** (recording or non-recording) Whilst a non-recording decelerometer will only display the level of maximum braking deceleration, a recording unit will also provide information on the response and pressure build-up times.

Testing the brakes in a road-test run is time-consuming and, bearing in mind traffic density as it is today, also dangerous. For this reason, it is mainly brake test benches (for commercial vehicles, usually roller dynamometers) which are used for testing braking systems according to Section 29 of the German Motor Vehicle Construction and Use Regulation.

Vehicles which, due to their design, cannot be tested on such test benches, must be tested on the road with a recording decelerometer.

Determination of the braking ratio on the test bench

On a roller dynamometer, the maximum braking forces per wheel are measured. When these braking forces are added and their total is expressed in percent and compared with the respective vehicle weight, we receive the percentual braking ratio of the vehicle by applying the formula we know already:

$$\mathbf{z} = \frac{\mathbf{F}}{\mathbf{G_p}} \times \mathbf{100\ \%}$$

Example: F = 96,000 N; Gp = 160,000 N

$$\mathbf{z} = \frac{\mathbf{96{,}000\ N}}{\mathbf{160{,}000\ N}} \times \mathbf{100\ \%} = \mathbf{60\ \%}$$

Certain minimum braking ratios are required which the **laden vehicle** must achieve when examined in accordance with Section 29 German Motor Vehicle Construction and Use Regulation (general inspections, special brake testing).

The large majority of vehicles is not, however, taken to have their brakes inspected when they are fully laden; usually they are either unladen, or perhaps partially laden.

Therefore, extrapolation has to be done to prove that the legal requirements are being complied with.

The reason is that when the vehicle carries no load and due to the insufficient wheel weight, only slight braking forces can be measured before anti-lock control becomes effective.

The braking force on a vehicle's wheels shows a linear increase with the input braking pressure. This applies to both vehicles with air brakes and with hydraulic braking systems.

On this basis, the brake forces measured on the unladen vehicle and the input pressures to the brake cylinders can be used to extrapolate the probable brake force when the vehicle is laden.

Projection

For extrapolation, Factor i is computed from the maximum braking pressure (p_N) for the braking system as stipulated by the vehicle manufacturer, and the input pressure (p) for the brake cylinders on the individual axles, taking into account the application pressure of 0.4 bar.

$$\mathbf{z} = \frac{\mathbf{F_1} \times \mathbf{i_1} + \mathbf{F_2} \times \mathbf{i_2} + \ldots \mathbf{F_n} \times \mathbf{i_n}}{\mathbf{G_z}} \times \mathbf{100\ \%}$$

G_z = vehicle’s permissible total weight (N)
z = retardation in %
F_1 = braking power of the first axle on which pressure p_1 was estimated in (N)
F_2 = braking power of the second axle on which pressure p_2 was estimated in (N)
F_n = braking force of the last axle in (N)

Formula

$$\mathbf{i_1} = \frac{\mathbf{p_N} - \mathbf{0.4}}{\mathbf{p_1} - \mathbf{0.4}}$$

The 0.4 bar take into account the wheel brake's application pressure.

$$\mathbf{i_2} = \frac{\mathbf{p_N} - \mathbf{0.4}}{\mathbf{p_2} - \mathbf{0.4}}$$

Index

p_N = the maximum braking pressure as stipulated by the manufacturers for the axle in question (positve pressure in bar) - see name plate. (If p_N is not shown, continue to use calculated pressure as before.)

p_1; p_2 = braking pressure being input into the wheel cylinders of the respective axle when the brakes are tested (positive pressure in bar).

Example

G_z = 220,000 N

G_z = 8,500 N
G_z = 6,000 N
F_3 = 6,000 N

p_n = 7.0 bar (in this case stipulated by the manufacturer, and for all axles)

p_1 = 2.0 bar
p_2 = 1.7 bar
p_3 = 1.7 bar

Searched for: z

$$i_1 = \frac{7.0\ \text{bar} - 0.4}{2.0\ \text{bar} - 0.4} = 4.1$$

$$i_1 \text{ and } i_3 = \frac{7.0\ \text{bar} - 0.4}{1.7\ \text{bar} - 0.4} = 5.1$$

$$z = \frac{8{,}500\ \text{N} \times 4.1 + 6{,}000\ \text{N} \times 5.1 + 6{,}000\ \text{N} \times 5.1}{220{,}000\ \text{N}} \times 100\ (\%) = 44.0\ \%$$

Thus the braking ratio z equals 44 %.

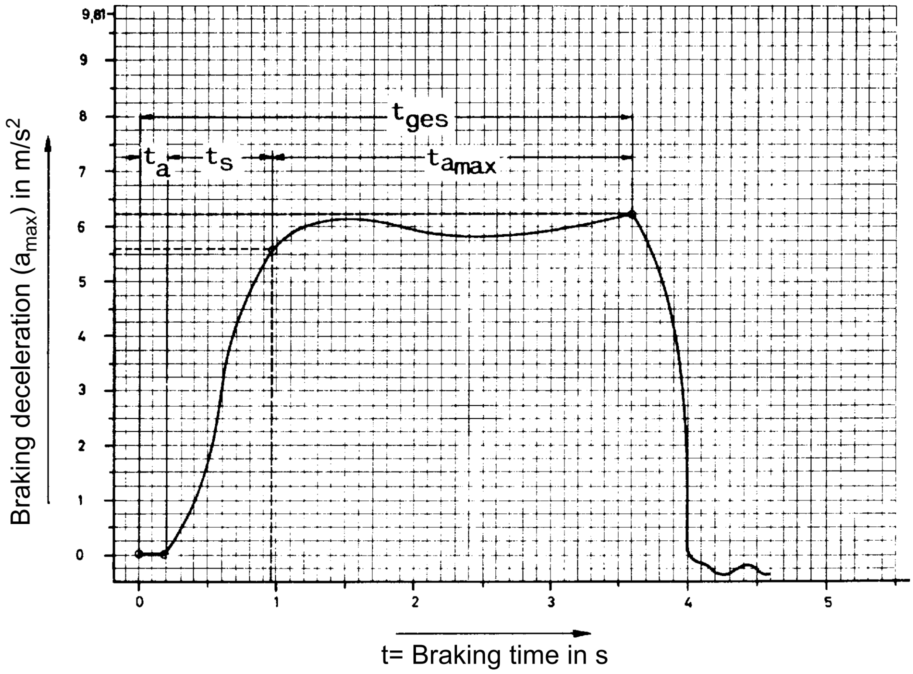
Determining Deceleration in a Road-Test Run:

If the braking ratio cannot be tested on a test bench, a recording decelerometer is used which produces a diagram of the braking process while the brakes are being actuated. This diagram shows both the level of the maximum deceleration and the variation in time of the braking process. Thus it also permits conclusions to be drawn on response and pressure build-up times.

The initial speed for testing brakes on the road - except for the sustained-action brake - should be between **45 and 50 km/h**. If it is not possible to attain this speed, the respective top speed must be used. In special cases, brakes can also be tested at higher initial speeds.

Example

The graph below shows the result of testing the braking performance as a ratio of the time.



Tests of trailer braking systems in a Road-Test Run

If the trailer's design does not permit it to be tested on the test bench, road-test runs have to be done with the tractor-trailer combination, braking the trailer only. For this purpose, the trailer must carry its total permissible weight.

The trailer's braking ratio is then computed as follows:

$$z_A = (z_Z - f_R)\frac{G_A + G_K}{G_A} + f_R \text{ (\%)}$$

Index

z_A = the trailer's braking ratio in %
z_Z = the braking ratio in % of the tractor-trailer combination, using the trailer's braking system only
G_A = the trailer's weight force (N)
G_y = the trailer's weight force (N)
f_y = allowance for rolling resistance (= 2%)

Manufacturer of the Braking System.................................

Manner of the Braking System...

Calculated pressure or maximum braking pressure for the vehicle / of every axle p_N .... / .... / .... / .... bar

test weight of the vehicle (P_M)............................ daN

permitted axle loads 1/2/3/4................................ daN

permitted total weight G_z (for trailers sum permitted axle loads: .... daN

Read values of the brake test bench

	Service Braking System						Parking brake Braking force (daN)	vehicle's weight/ axle loads (test weight) (daN)
	Braking powers (daN)			Cylinder pressure p (bar)	$i = \frac{p_N - 0{,}4}{p - 0{,}4}$	F × i		
	left	right	sum F					
Axle 1								
Axle 2								
Axle 3								
Axle 4								
Sum								

Braking ratio depending on the test weight (only if the test weight is known)

$$z_{PM} = \frac{F_1 + F_2 + \ldots F_n}{P_M} \times 100[\%]$$ = ... %

Braking ratio depending vehicle's permitted total weight (extrapolation)

$$z = \frac{F_1 \times i_1 + F_2 \times i_2 + \ldots F_n \times i_n}{G_z} \times 100[\%]$$ = ... %

Retardation with the Parking brake (depending on the permitted total weight)

$$z_{FBA} = \frac{F_{FBA}}{G_z} \times 100[\%]$$ = ... % *or:* Exceeding the blocking limit ❑

Difference of the Braking powers

$$\frac{\text{difference of the braking forces of an axle}}{\text{highest brake force of an axle}} \times 100 \leq \ldots[\%]$$

SBS: .... %

PBS .... %

One gets the weight force (N) for earth acceleration for g rounded on 10 m/s^2 by multiplication of the total assets (kg) by the factor 10.1 daN (10 N) strength about 1 kg mass corresponds with that.

Note:
For trailers or trailer vehicles of a similar design: instead of using the weight force, use the axle loads!