
**Road vehicles — Heavy commercial
vehicles and buses — Calculation
method for steady-state rollover
threshold**

*Véhicules routiers — Véhicules utilitaires lourds et bus — Méthode de
calcul du seuil de renversement en régime permanent*

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics and chassis components*.

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

Introduction

The dynamic behaviour of a road vehicle is a most important aspect of active vehicle safety. Any given vehicle, together with its driver and the prevailing environment constitutes a closed-loop system which is unique. The task of evaluating the dynamic behaviour is therefore very difficult, since the significant interaction of these driver-vehicle road elements are each complex in themselves. A complete and accurate description of the behaviour of the road vehicle inevitably involves information obtained from a number of different tests.

Moreover, insufficient knowledge is available to correlate overall vehicle dynamic properties with accident prevention. A substantial amount of work is necessary to acquire sufficient and reliable data on the correlation between accident prevention and vehicle dynamic properties in general.

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Road vehicles — Heavy commercial vehicles and buses — Calculation method for steady-state rollover threshold

1 Scope

This document describes a method for calculating steady-state rollover threshold of heavy commercial vehicles and buses, not considering the effects of active control systems. The calculation method considers the main factors that influence the rollover threshold, namely the height of centre of gravity, the track, the tyre lateral stiffness, and all factors that affect the vehicle roll stiffness. The considered compliances (e.g. tyre deformation) have a considerable influence on the effective track, and consequently on the steady-state rollover threshold.

NOTE As an alternative to the described calculation method standard, the steady-state rollover threshold can be measured on a test track or with a tilt-table test as described in ISO 16333.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8855, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in in ISO 8855 and the following shall apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

steady-state rollover threshold

a_{srt}

maximum lateral acceleration that the vehicle can sustain in a steady state turn without rolling over

3.2

first lift-off lateral acceleration

a_{yf}

lateral acceleration, at which the first wheel lift-off occurs

3.3

total lift-off lateral acceleration

a_{yt}

lateral acceleration, at which theoretically all axles lift from the ground

3.4
track

b

distance between the contact centres on a single wheel axle, measured parallel to the Y axis, with the vehicle at rest on a horizontal surface

Note 1 to entry: For dual wheel axles, it is the distance between the points centrally located between the contact centres of the inner and outer dual wheels.

3.5
equivalent track

b_e

track (3.4) for a dual wheel axle

Note 1 to entry: For single wheel axles, equivalent track is equal to the track.

3.6
kingpin representative track

b_k

representative track (3.4) for the kingpin of a semitrailer, used for calculation of vehicle effective track (3.7)

3.7
vehicle effective track

b_v

average of the axles' equivalent tracks (3.5) normalized by the axle normal forces (3.21)

3.8
tyre lateral stiffness

C_{yt}

first derivative of tyre lateral force with respect to tyre lateral deformation, calculated for all tyres on each side of an axle

3.9
vehicle effective tyre lateral stiffness

C_{yv}

sum of tyre lateral stiffnesses (3.8) at all axles of the vehicle

3.10
tyre normal stiffness

C_{zt}

first derivative of the tyre normal force with respect to the change in loaded radius, calculated for all tyres on each side of an axle

3.11
roll stiffness distribution

$D_{k\phi}$

distribution of the vehicle roll stiffness (3.20) between the individual axles expressed as a percentage of the vehicle roll stiffness

3.12
centre of gravity height

H_{cg}

height of complete vehicle's centre of gravity above the ground plane

3.13
roll centre height

H_{rc}

height of suspension roll centre above the ground plane

3.14**sprung mass centre of gravity height** H_{sm}

height of centre of gravity of the sprung mass of the vehicle above the ground plane

3.15**axle roll stiffness** $K_{\varphi a}$ rate of change of the restoring couple exerted by an axle on the sprung mass with respect to the angular change about the X_V axis of a line joining the contact centres of the axle**3.16****suspension roll stiffness** $K_{\varphi s}$

rate of change of the restoring couple exerted by an axle suspension on the sprung mass with respect to the suspension roll angle of the axle

3.17**equivalent suspension roll stiffness** $K_{\varphi e}$ rate of change of the restoring couple exerted by an axle suspension on the sprung mass with respect to the angular change about the X_V axis of a line joining the contact centres of the axle**3.18****kingpin representative roll stiffness** $K_{\varphi k}$ representative roll stiffness for the kingpin of a semitrailer, used for calculation of *vehicle roll stiffness* ([3.20](#))**3.19****tyre-induced roll stiffness** $K_{\varphi t}$ contribution of *tyre normal stiffness* ([3.19](#)) to rate of change of the restoring couple exerted by an axle on the sprung mass with respect to the angular change about the X_V axis of a line joining the contact centres of the axle**3.20****vehicle roll stiffness** $K_{\varphi v}$ sum of the individual *axle roll stiffnesses* ([3.15](#))**3.21****axle normal force** N_a

normal force exerted on an axle

3.22**kingpin normal force** N_k

normal force exerted on the kingpin

3.23**total normal force** N_t

sum of normal forces exerted on all axles

3.24**dual wheel spacing** S_d

distance between the contact centres of the inner and outer dual wheels

3.25

unsprung mass weight

W_{um}

weight of the vehicle's unsprung mass

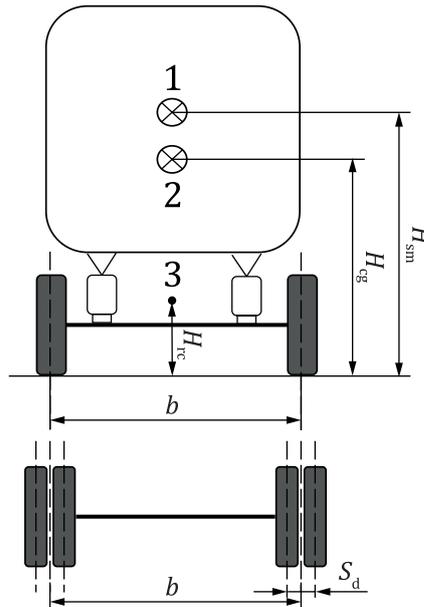
4 Properties

4.1 Vehicle properties used for calculation

For the calculation of the steady-state rollover threshold, the following variables are utilized:

- b_{ei} , where i is the axle number;
- b_i , where i is the axle number;
- b_k ;
- b_v ;
- C_{yti} , where i is the axle number;
- C_{yv} ;
- C_{zti} , where i is the axle number;
- $D_{k\phi i}$, where i is the axle number;
- H_{cg} ;
- H_{rci} , where i is the axle number;
- H_{sm} ;
- $K_{\phi ei}$, where i is the axle number;
- $K_{\phi k}$;
- $K_{\phi si}$, where i is the axle number;
- $K_{\phi ti}$, where i is the axle number;
- $K_{\phi v}$;
- N_{ai} , where i is the axle number;
- N_k ;
- N_v ;
- S_d ;
- W_{um} .

NOTE For the vehicle dimensions see [Figure 1](#).

**Key**

- 1 centre of gravity of the sprung mass
- 2 centre of gravity of the vehicle
- 3 suspension roll centre

Figure 1 — Vehicle dimensions**4.2 Required parameter accuracy**

The required accuracy for the parameters used in the calculation of the steady-state rollover threshold, are listed in [Table 1](#).

Table 1 — Required parameter accuracy

Variable	Required accuracy
Axle normal force, N_a	500 N
Unsprung mass weight, W_{um}	500 N
Track, b	5 mm
Roll centre height, H_{rc}	50 mm
Centre of gravity height, H_{cg}	50 mm
Sprung mass centre of gravity height, H_{sm}	50 mm
Suspension roll stiffness, $K_{\phi s}$	10 %
Tyre normal stiffness, per axle side, C_{zt}	10 %
Tyre lateral stiffness, per axle side, C_{yt}	10 %

NOTE If measurement data for estimating the value of C_{yt} do not exist, a value of 600 kN/m can be used, which represents a wide single tyre or dual tyres (lateral stiffness of 300 kN/m per tyre). Note that an infinite value of C_{yt} results in an estimated value equal to ECE R111 calculation method, see [Table A.1](#) for more examples.

5 Principle

Steady-state rollover threshold of a heavy commercial vehicle or bus is the maximum lateral acceleration that the vehicle could sustain in steady-state turning without rolling over. This document provides an analytical model for calculation of the steady-state rollover threshold, using suspension characteristics

and tyre characteristics data. Linear parameters are used for suspension and tyre characteristics. The method addresses the steady-state rollover threshold calculation of semitrailers and effects of kingpin connection, by introducing a representative roll stiffness and a representative track for the kingpin.

NOTE 1 Nonlinear effects of suspension, such as backlash and bump stop, and their influence on suspension roll stiffness are not considered.

NOTE 2 Kingpin is part of the normal coupling arrangement between a tractor and a semitrailer.

6 Calculation method

6.1 General

In the following the method for calculation of steady-state rollover threshold, as well as the required variables to do so, are provided.

6.2 Calculation of vehicle effective track

The equivalent track for an axle with dual wheels is calculated based on the track and the dual wheel spacing, as given in [Formula \(1\)](#):

$$b_e = \sqrt{b^2 + S_d^2} \quad (1)$$

NOTE For single wheel axles, the equivalent track is equal to the track.

By taking an average of the axles' equivalent tracks, normalized by the axles' normal forces, the vehicle effective track can be calculated by [Formula \(2\)](#):

$$b_v = \frac{\sum_{i=1}^n (b_{ei} N_{ai})}{N_t} \quad (2)$$

where the total normal force is sum of the individual axle normal forces, as given in [Formula \(3\)](#):

$$N_t = \sum_{i=1}^n N_{ai} \quad (3)$$

In case of semitrailers, the kingpin normal force should be included in the calculations, and a kingpin representative track should be introduced, as given in [Formula \(4\)](#):

$$b_k = \frac{\sum_{i=1}^n b_{ei}}{n} \quad (4)$$

Consequently, the total normal force and the vehicle effective track will be given by [Formula \(5\)](#) and [Formula \(6\)](#), respectively:

$$N_t = N_k + \sum_{i=1}^n N_{ai} \quad (5)$$

$$b_v = \frac{b_k N_k + \sum_{i=1}^n (b_{ei} N_{ai})}{N_t} \quad (6)$$

6.3 Calculation of vehicle roll stiffness

The equivalent suspension roll stiffness with respect to ground plane, can be calculated from suspension roll stiffness, using suspension roll centre height and sprung mass centre of gravity height, as given in [Formula \(7\)](#):

$$K_{\phi ei} = K_{\phi si} \left(\frac{H_{sm}}{H_{sm} - H_{rci}} \right)^2 \quad (7)$$

The tyre-induced roll stiffness is calculated from the tyre normal stiffness by [Formula \(8\)](#):

$$K_{\phi ti} = \frac{C_{zti} b_{ei}^2}{2} \quad (8)$$

Adding up the two above terms, the axle roll stiffness can be calculated by [Formula \(9\)](#):

$$K_{\phi ai} = \frac{K_{\phi ei} K_{\phi ti}}{K_{\phi ei} + K_{\phi ti}} \quad (9)$$

Consequently, the vehicle roll stiffness will be given by [Formula \(10\)](#):

$$K_{\phi v} = \sum_{i=1}^n K_{\phi ai} \quad (10)$$

In case of semitrailers, a kingpin representative roll stiffness should be introduced, using the kingpin normal force, as given in [Formula \(11\)](#):

$$K_{\phi k} = 4N_k \quad (11)$$

Consequently, the vehicle roll stiffness will be given by [Formula \(12\)](#):

$$K_{\phi v} = K_{\phi k} + \sum_{i=1}^n K_{\phi ai} \quad (12)$$

6.4 Calculation of vehicle effective tyre lateral stiffness

The vehicle effective tyre lateral stiffness is calculated by adding up the tyre lateral stiffnesses at all axles of the vehicle, as in [Formula \(13\)](#):

$$C_{y tv} = \sum_{i=1}^n C_{y ti} \quad (13)$$

6.5 Calculation of steady-state rollover threshold

The wheel lift-off at each axle happens when the overturning moment, M_o , becomes as large as the restoring moment, M_r . These moments can be calculated as given by [Formula \(14\)](#) and [Formula \(15\)](#), where $D_{k\phi i}$ is the roll stiffness distribution between the axles and W_{um} is the unsprung mass weight.

$$M_r = N_{ai} \left(\frac{b_{ei}}{2} - \frac{a_y N_{ai}}{C_{yti}} \right) \quad (14)$$

$$M_o = a_y \left(D_{k\phi i} N_t H_{cg} + \frac{(D_{k\phi i} (N_t - W_{um}) H_{sm})^2}{K_{\phi ai} - D_{k\phi i} N_t H_{sm}} \right) \quad (15)$$

The first lift-off lateral acceleration, at which the first axle lifts from the ground, can be calculated by [Formula \(16\)](#):

$$a_{yf} = \min_i \frac{N_{ai} \frac{b_{ei}}{2}}{\left(D_{k\phi i} N_t H_{cg} + \frac{(D_{k\phi i} (N_t - W_{um}) H_{sm})^2}{K_{\phi ai} - D_{k\phi i} N_t H_{sm}} + \frac{N_{ai}^2}{C_{yti}} \right)} \quad (16)$$

The total lift-off lateral acceleration is given by [Formula \(17\)](#):

$$a_{yt} = \frac{N_t \frac{b_v}{2}}{\left(N_t H_{cg} + \frac{((N_t - W_{um}) H_{sm})^2}{K_{\phi v} - N_t H_{sm}} + \frac{\left(\sum_{i=1}^n N_{ai} \right)^2}{C_{ytv}} \right)} \quad (17)$$

Linear interpolation between the first lift-off lateral acceleration and the total lift-off lateral acceleration gives the steady-state rollover threshold as given by [Formula \(18\)](#):

$$a_{srt} = a_{yt} - (a_{yt} - a_{yf}) \frac{N_{ai}}{N_t} \quad (18)$$

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