



**International
Standard**

ISO 23373

**Heavy commercial vehicles
and buses — Vehicle dynamics
simulation and validation — Tyre
model for lateral estimation
of heavy vehicle combinations
operated at dry paved road surface**

*Véhicules utilitaires lourds et bus — Simulation et validation de
la dynamique du véhicule — Modèle de pneu pour l'estimation
latérale des combinaisons de véhicules lourds exploités sur une
surface de route pavée sèche*

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Foreword

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

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

This document describes a generic tyre model intended for lateral stability performance estimations of commercial vehicle combinations operated at dry paved road surface.

Even though the recommended use is limited to moderate excitation levels, non-linear components of truck tyres are included to not underestimate risk levels, especially when it comes to loads with high centres of gravity. Hence the standard model calculates the lateral force from vertical force and slip angle input with a non-linear formula.

The tyre model in this document is inspired by a trigonometric formula for calculating steady-state lateral or longitudinal force under pure slip conditions, often referred to as the Magic Formula. This formula was introduced by HB Pacejka and colleagues in the 1980s.

The standard tyre model is however less complex compared to many tyre models based on the Magic Formula, for example, by neglecting the influence of camber inclination, asymmetry and combined longitudinal slip and sideslip. There are five characterizing parameters in the tyre model that describe the steady state properties of the tyre, and two parameters that describe its transient properties.

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Heavy commercial vehicles and buses — Vehicle dynamics simulation and validation — Tyre model for lateral estimation of heavy vehicle combinations operated at dry paved road surface

1 Scope

This document specifies a generic tyre model and model parameters for calculating lateral tyre forces, for use in lateral stability simulations of heavy commercial vehicle combinations with test cases according to ISO 14791. This tyre model is parameterized by easily understandable characteristics which can be estimated from tyre measurement data. If tyre data is not available, the parameters proposed in this document can be used.

One typical application area of this document is the comparing and ranking of various vehicle combination configurations with respect to on-road lateral and roll stability. Such an assessment is usually performed at close to constant speed levels typical for public roads, usually higher than 40 km/h. The tyre model, however, can be useful for both high- and low-speed manoeuvring.

This tyre model is relevant for representing the lateral performance of tyres on a vehicle combination when the longitudinal forces are insignificant, typically less than 10 % of the peak longitudinal friction utilization. The tyre model can be used for normal forces ranging from zero to twice the nominal normal force of the tyre. This tyre model has been developed for moderate lateral slip conditions; it is important that the model is used with care for scenarios where tyre slip angle exceeds 15°.

This tyre model is suitable for vehicle models operating in the yaw and roll plane which naturally include vertical load transfer between the wheels during manoeuvring. The tyre model can also be used in models with less complexity such as pure yaw plane models.

This document applies to heavy vehicles, including commercial vehicles, commercial vehicle combinations, buses and articulated buses as defined in ISO 3833 (trucks and trailers with a maximum weight above 3,5 tonnes and buses and articulated buses with a maximum weight above 5 tonnes, according to ECE and EC vehicle classification, categories M3, N2, N3, O3 and O4).

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 3833, *Road vehicles — Types — Terms and definitions*

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

ISO 15037-2, *Road vehicles — Vehicle dynamics test methods — Part 2: General conditions for heavy vehicles and buses*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3833, ISO 8855, ISO 15037-2 and the following 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 tyre slip angle

α
angle from the X_T axis to the normal projection of the tyre trajectory velocity vector on to the X_T - Y_T plane

[SOURCE: ISO 8855:2011, 5.2.12, modified — The figure and Notes to entry have been removed and the original term "slip angle" has been deleted.]

3.2 tyre normal force

F_{ZT}
component of the total force exerted on the tyre by the road in the direction of the Z_T axis

[SOURCE: ISO 8855:2011, 10.2.1, modified — This is used as a scalar in this document, not as a vector.]

3.3 tyre lateral force

F_{YT}
component of the tyre shear force vector in the direction of the Y_T axis

[SOURCE: ISO 8855:2011, 10.2.6, modified — This is used as a scalar in this document, not as a vector.]

3.4 nominal normal force

F_{ZT0}
nominal value of the *tyre normal force* (3.2) which is assumed to be equal to the rated load of the tyre according to its load index for single wheel fitment

Note 1 to entry: Single wheel fitment means that there is one tyre per side of a truck axle. A common alternative is dual fitment where there are two tyres per side of an axle.

3.5 tyre cornering stiffness

C_α
negative of the first derivative of *tyre lateral force* (3.3) with respect to *tyre slip angle* (3.1)

[SOURCE: ISO 8855:2011, 10.3.15, modified — The variable has been added and the Note to entry has been removed.]

3.6 nominal cornering stiffness

$C_{\alpha 0}$
tyre cornering stiffness (3.5) at the *nominal normal force* (3.4)

3.7 tyre cornering coefficient

C_n
ratio between the *tyre cornering stiffness* (3.5) and the *tyre normal force* (3.2)

Note 1 to entry: The tyre cornering coefficient is expressed as:

$$C_n = \frac{C_\alpha}{F_{ZT}}$$

3.8**nominal cornering coefficient** C_{n0} ratio between the *nominal cornering stiffness* (3.6) and the *nominal normal force* (3.4)

Note 1 to entry: The nominal cornering coefficient is expressed as:

$$C_{n0} = \frac{C_{\alpha 0}}{F_{ZT0}}$$

3.9**cornering coefficient gradient** C_{ng} rate of change of the *tyre cornering coefficient* (3.7) with respect to the *tyre normal force* (3.2) at the *nominal normal force* (3.4)

Note 1 to entry: The relation is described in 4.1.

Note 2 to entry: The parameter typically has a negative value.

3.10**tyre peak lateral friction** μ_y maximum value for the ratio between the *tyre lateral force* (3.3) and the *tyre normal force* (3.2) for a given tyre normal force**3.11****nominal peak lateral friction** μ_{y0} *tyre peak lateral friction* (3.10) at the *nominal normal force* (3.4)**3.12****peak lateral friction gradient** μ_{yg} rate of change of the *peak lateral friction* (3.10) with respect to the *tyre normal force* (3.2) at the *nominal normal force* (3.4)

Note 1 to entry: The relation is described in 4.1.

Note 2 to entry: The peak lateral friction gradient is a fixed value in the tyre model and typically has a negative value. The negative sign implies that the peak lateral friction decreases when the tyre vertical force increases.

3.13**shape factor** C

parameter in the tyre model which affects the shape of the force-slip curve of the tyre

3.14**nominal peak position** α_{p0} *tyre slip angle* (3.1) at which the peak lateral friction occurs at *nominal normal force* (3.4)**3.15****tyre longitudinal velocity** $\vec{v}_{XT}$ component of the tyre trajectory velocity in the X_T direction

[SOURCE: ISO 8855:2011, 5.1.7]

3.16

tyre lateral relaxation length

σ_y
delay of tyre lateral force (3.3) with respect to the tyre slip angle (3.1) expressed in travelled distance assuming a first order filter delay behaviour

Note 1 to entry: Given a step tyre slip angle input, the lateral relaxation length is the distance a tyre needs to travel for the tyre lateral force to build up to 63,2 % of its final value.

Note 2 to entry: The lateral relaxation length can be transformed into first order filter time constant by dividing the lateral relaxation length with tyre longitudinal velocity (3.15).

3.17

nominal lateral relaxation length

σ_{y0}
tyre lateral relaxation length (3.16) at the nominal normal force (3.4)

3.18

lateral relaxation length gradient

σ_{yg}
rate of change of the tyre lateral relaxation length (3.16) with respect to the tyre normal force (3.2) at the nominal normal force (3.4)

Note 1 to entry: The relation is described in 4.2.

Note 2 to entry: The lateral relaxation length gradient is a constant in the tyre model and typically has a positive value. The positive sign implies that the tyre lateral relaxation length increases when the tyre vertical force increases.

4 Tyre model formulae

4.1 Steady-state calculation

The steady-state lateral force, $F_{YT,SS}$, is calculated from the tyre slip angle, α :

$$F_{YT,SS} = -F_{ZT} \mu_y \sin \left[C \operatorname{atan} \left(\frac{C_n}{C \mu_y} \alpha \right) \right]$$

The tyre peak lateral friction, μ_y , at a given tyre normal force, F_{ZT} , is calculated using the nominal peak lateral friction, μ_{y0} , and the peak lateral friction gradient, μ_{yg} , as:

$$\mu_y = \mu_{y0} \left(1 + \mu_{yg} \frac{F_{ZT} - F_{ZT0}}{F_{ZT0}} \right)$$

The tyre cornering coefficient, C_n , at a given tyre normal force, F_{ZT} , is calculated using the nominal cornering coefficient, C_{n0} , and the cornering coefficient gradient, C_{ng} , as:

$$C_n = C_{n0} \left(1 + C_{ng} \frac{F_{ZT} - F_{ZT0}}{F_{ZT0}} \right)$$

The shape factor, C , can be obtained from the formula describing the relation between the tyre peak lateral friction, μ_{y0} , the peak position, α_{p0} , and the tyre cornering coefficient, C_{n0} , at nominal normal force:

$$\alpha_{p0} = \frac{C \mu_{y0}}{C_{n0}} \tan \left(\frac{\pi}{2C} \right)$$

However, the tyre lateral force will exhibit a peak only if $C > 1$. Another requirement is that $\frac{\mu_{y0}}{C_{n0}} < \frac{\pi}{2}$, so that the peak occurs before a tyre slip angle of 90° . If $C \leq 1$, the tyre force-slip curve will not have a peak; in that case the shape factor, C , can be obtained by fitting a curve to the tyre measurement data.

4.2 Transient properties

The tyre model transient properties are represented by the tyre lateral relaxation length which divided with the tyre longitudinal velocity results in a time constant used in a first order low-pass filter applied to the steady state calculation above. Thus, the tyre lateral force can be calculated by the differential formula:

$$\frac{\sigma_y}{\bar{v}_{XT}} \dot{F}_{YT} + F_{YT} = F_{YT,SS}$$

where $\dot{F}_{YT}$ is the first time-derivative of tyre lateral force, and the tyre lateral relaxation length is linearly dependent on the vertical load as:

$$\sigma_y = \sigma_{y0} \left(1 + \sigma_{yg} \frac{F_{ZT} - F_{ZT0}}{F_{ZT0}} \right)$$

The nominal lateral relaxation length value is approximately equal to the radius of the tyre. The tyre lateral relaxation length calculated by this formula will not vanish when the load approaches zero, e.g. in a close to rollover situation. This is due to the simplification in the load dependency description and is deemed to have a negligible effect since the tyre lateral force will be close to zero in such situations.

However, in simulations, low pass filtering the tyre slip angle rather than the tyre lateral force has the advantage that the tyre lateral force directly becomes zero when the tyre normal force vanishes. In that case the formula for the tyre lateral force can be written as:

$$F_{YT} = -F_{ZT} \mu_y \sin \left(C \operatorname{atan} \left(\frac{C_n}{C \mu_y} \alpha' \right) \right)$$

where the relaxed tyre slip angle, α' , is calculated from:

$$\frac{\sigma_y}{\bar{v}_{XT}} \dot{\alpha}' + \alpha' = \alpha$$

4.3 Standard values of the model parameters

If tyre data is not available, the standard values in [Table 1](#) can be used to represent a new (not worn) generic tyre on dry asphalt. Tyre parameters are provided for three tyre dimensions, as well as for an all-purpose tyre. The latter can be used for tyres with other dimensions. The parameters have been derived from tyre measurements on multiple truck tyres, and the process is described in detail in Reference [\[2\]](#).