



BSI Standards Publication

Railway applications — Ride comfort for passengers — Measurement and evaluation

National foreword

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A list of organizations represented on this committee can be obtained on request to its committee manager.

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European foreword

This document (EN 12299:2024) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2025, and conflicting national standards shall be withdrawn at the latest by April 2025.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 12299:2009.

EN 12299:2024 includes the following significant technical changes with respect to EN 12299:2009:

- a) the Scope has been revised;
- b) Normative references have been updated;
- c) Clause 3, Terms and definitions has been updated;
- d) Clause 4, Symbols, units and abbreviations has been revised;
- e) Clause 5, General description has been revised;
- f) Clause 6, Mean comfort and continuous comfort have been revised;
- g) Clause 7, Comfort on curve transitions has been updated;
- h) Clause 8, Comfort on discrete events has been revised;
- i) Clause 9, Guide for the interpretation of the results has been updated;
- j) Annex B, Measurement techniques has been updated;
- k) Annex C, Weighting curves has been updated;
- l) new Annex D has been added;
- m) (previous) Annex D has been revised and renamed in Annex F;
- n) Annex E has been revised;
- o) (previous) Annex F has been revised and renamed in Annex G;
- p) Annex H has been renamed Annex I. New Annexes H, J and K added.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

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1 Scope

The purpose of this document is to provide methods for quantifying the ride comfort of a passenger in a rail vehicle in response to the track sections it is operated over.

The methods aim to quantify the effects of vehicle body motions on ride comfort and to make the assessment of passenger comfort predictable, repeatable, objective and meaningful.

The methods and comfort scales are validated for people of good health.

This document applies to passengers in rail vehicles operating on heavy rail networks.

This document applies to measurements of motions. It also applies to simulated motions. Guidance is provided on:

- which method described within the document should be used for different scenarios;
- typical values for different comfort levels;
- the application of simulation.

This document excludes health and safety issues, non-passenger carrying vehicles, vehicle homologation and safety, limit values, motion sickness, discomfort caused by accelerating and braking, design guidelines and measurement technology.

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.

EN 15663, *Railway applications — Vehicle reference masses*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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

passenger

person travelling in a rail vehicle, without specific activities related to the transport

3.2

ride comfort

complex sensation experienced by a passenger due to motions (vibrations, roll velocities and inertia forces etc.) transmitted through the rail vehicle body whilst running over track (see also 5.5)

3.3

interfaces

contact parts between the vehicle body or seat and the passenger with the function of sustaining and guiding the passenger and of transmitting the weight of the passenger to the vehicle body itself, e.g. floor-feet

3.4**mean comfort**

perceived comfort level, continuously adjusted, as evaluated through measurement on a long-time basis (at least some minutes)

3.5**continuous comfort**

level of accelerations, frequency weighted continuously evaluated as a set of RMS (root mean square) values in vertical, lateral and longitudinal direction over a short time period (typical 5 s)

3.6**comfort on curve transitions**

comfort evaluation, due to a perceived curve transition, expressed as percentage of passengers feeling uncomfortable

3.7**comfort on discrete events**

comfort evaluation, due to a perceived transient acceleration, expressed as percentage of passengers feeling uncomfortable

3.8**whole-body transmission**

motion transmitted to the whole body through the interfaces between vehicle body and passenger

3.9**indirect measurement**

measurement of motion environment by different motion quantities, such as acceleration or roll velocity

3.10**direct measurement**

measurement of actual passenger reactions, for example by asking passengers to fill in a questionnaire

3.11**vehicle assessment with respect to ride comfort**

identifying the vehicle's contribution to the ride comfort by relating the measured ride comfort to the condition of the track and operation condition

Note 1 to entry: conditions of track includes geometry, irregularities, turnout, bridges, etc.

Note 2 to entry: operation condition includes speed, cant deficiency, etc.

3.12**test section**

part of a rail line used for the passenger comfort test

3.13**test zone**

five-minute period, which is used for mean comfort evaluation

3.14**reference system**

local reference system for a vehicle body defined by:

Origin: on the floor of the vehicle body, in the central position between the two body-bogie centre pivots (existing or ideally defined)

Axis:

- x-axis: longitudinal
- y-axis: lateral
- z-axis: vertical

Roll motions (φ) are defined as rotation around the x-axis

For human body reference system, a right hand system is used with vertical direction defined upwards

Note 1 to entry: A more detailed definition of the reference system is given in Annex A.

3.15

heavy rail network

conventional rail network intended for intra- and interregional and/or international transportation

3.16

unit

generic term used to name the rolling stock. It may be composed of either one vehicle or several vehicles in a fixed formation

4 Symbols, units and abbreviations

Table 1 and Table 2 define the symbols, units and abbreviations used in this document.

Table 1 — Symbols and units – Part 1

Parameter	Symbol	Unit
General parameters		
Time	t	[s]
Time period	T	[s]
Integration variable	τ	[s]
Vehicle speed	V	[km/h]
Frequency	f	[Hz]
Frequency weighting curve for vertical direction	W_b	[-]
Frequency weighting curve for longitudinal direction (backrest)	W_c	[-]
Frequency weighting curve for lateral/longitudinal direction	W_d	[-]
Low-pass filter	W_p	[-]
n-tile	k	[-]

Parameter	Symbol	Unit
Percentile	n	[%]
Number of samples	N	[-]
Imaginary unit	i	[-]
Root mean square	RMS	[-]
Constants for passenger comfort on curve transitions and discrete events		
Constant in acceleration component in curve transitions	A	$[s^2/m]$
Constant in acceleration component in curve transitions	B	$[s^3/m]$
Constant in acceleration component in curve transitions	C	[-]
Constant in roll velocity component in curve transitions	D	$[s/rad]$
Constant in roll velocity component in curve transitions	E	[-]
Constant in acceleration component in discrete events	a	$[s^2/m]$
Constant in acceleration component in discrete events	b	$[s^2/m]$
Constant in acceleration component in discrete events	c	[-]
Transfer functions		
Cut-off frequencies, $n = 1,2,3,4,5,6$	f_n	[Hz]
Resonant quality factors, $n = 1,2,3,4$	Q_n	[-]
Gain	K	[-]
High pass transfer function	$H_h(f)$	[-]
Low pass transfer function	$H_l(f)$	[-]
Acceleration to velocity transfer function	$H_t(f)$	[-]
Upward gradient transfer function	$H_s(f)$	[-]

Table 2 — Symbols and units – Part 2

Parameter	Longitudinal axis	Lateral axis	Vertical axis
Translational accelerations in vehicle body [m/s²]			
Leading end of passenger compartment	–	$\ddot{y}_{EI}^*$	$\ddot{z}_{EI}^*$
Over leading bogie	–	$\ddot{y}_I^*$	$\ddot{z}_I^*$
Body centre	$\ddot{x}_M^*$	$\ddot{y}_M^*$	$\ddot{z}_M^*$
Over trailing bogie	–	$\ddot{y}_{II}^*$	$\ddot{z}_{II}^*$
Trailing end of passenger compartment	–	$\ddot{y}_{EII}^*$	$\ddot{z}_{EII}^*$
Translational weighted accelerations [m/s²]			
Seat, weighted W_c, W_b	$\ddot{x}_{D,Wc}^*$	–	$\ddot{z}_{A,Wb}^*$
Vehicle body, weighted W_d, W_b	$\ddot{x}_{P,Wd}^*$	$\ddot{y}_{P,Wd}^*$	$\ddot{z}_{P,Wb}^*$
Vehicle body, weighted W_p	–	$\ddot{y}_{P,Wp}^*$	–
Seat (Dossier, seat back in French, and Assise, seat pan in French), weighted W_c, W_d, W_b , RMS	$a_{XD}^{w_c}$	$a_{YA}^{w_d}$	$a_{ZA}^{w_b}$
Floor (Plancher in French), weighted W_d, W_b , RMS	$a_{XP}^{w_d}$	$a_{YP}^{w_d}$	$a_{ZP}^{w_b}$
Floor, weighted W_d, W_b , RMS, 50 th percentile	$a_{XP50}^{w_d}$	$a_{YP50}^{w_d}$	$a_{ZP50}^{w_b}$
Seat, weighted W_c, W_d, W_b , RMS, 95 th percentile	$a_{XD95}^{w_c}$	$a_{YA95}^{w_d}$	$a_{ZA95}^{w_b}$
Floor, weighted W_d, W_b , RMS, 95 th percentile	$a_{XP95}^{w_d}$	$a_{YP95}^{w_d}$	$a_{ZP95}^{w_b}$
One-second average	–	$\ddot{y}_{ls}(t)$	–
Two-second average	–	$\ddot{y}_{2s}(t)$	–
Peak to peak	–	$\ddot{y}_{pp}(t)$	–
One-second average, maximum absolute value	–	$ \ddot{y}_{ls} _{\max}$	–
Two-second average, absolute value	–	$ \ddot{y}_{2s} (t)$	–

Parameter	Longitudinal axis	Lateral axis	Vertical axis
Translational jerk in vehicle body [m/s³]			
One-second average	–	$\ddot{y}_{1s}(t)$	–
One-second average, maximum absolute value	–	$ \ddot{y}_{1s} _{\max}$	–
Angular velocity in vehicle body [rad/s]			
Body	$\dot{\phi}^*(t)$	–	–
Weighted W_p	$\dot{\phi}_{Wp}^*(t)$	–	–
One-second average	$\dot{\phi}_{1s}(t)$	–	–
One-second average, maximum absolute value	$ \dot{\phi}_{1s} _{\max}$	–	–
Comfort indexes [-]			
Mean comfort standard method	N_{MV}		
Mean comfort standard method, partial index	N_{MVx}	N_{MVy}	N_{MVz}
Mean comfort complete method, seated passenger (in French: VA = voyageur assis)	N_{VA}		
Mean comfort complete method, standing passenger (in French: VD = voyageur debout)	N_{VD}		
Continuous comfort	C_{Cx}	C_{Cy}	C_{Cz}
Comfort on curve transitions	P_{CT}, P_{CT-3s}		–
	P_{CT-Rol}	P_{CT-Lat}	–
Comfort on discrete events	–	P_{DE}	–

5 General description

5.1 General

The comfort of passengers in a rail vehicle is influenced by a number of different factors (temperature, noise, vibration, etc.). This document considers only that part of the comfort influenced by the vibrations and motions of the vehicle. This is described as ride comfort or as passenger comfort. The methods described in this document may also be used for vehicle evaluation with respect to ride comfort. This document defines as the standard method:

- a) the standard method for mean comfort evaluation, taking into account the effects of vibration exposure measured on the floor of the vehicle body.

This document also defines several methods for special applications:

- b) taking into account the short time effects of vibration exposure measured on the floor of the vehicle body as continuous comfort for the longitudinal, lateral, and vertical direction;
- c) taking into account the vibration exposure measured on the seat or other interfaces on ride comfort as the complete method for mean comfort evaluation;
- d) taking into account the effects of:
 - 1) discrete events (comfort on discrete events) and
 - 2) curve transitions (comfort on curve transitions)on ride comfort;
- e) taking into account the vibration exposure measured on the floor of the vehicle body for the purpose of vehicle assessment with respect to ride comfort.

5.2 Passenger exposure to vibrations

Rail transport exposes passengers to vibrations related to the dynamic motions of the vehicle body.

The motions of the vehicle body transmit their effects to the human body through the following interfaces:

- a) in the standing position:
 - 1) floor – feet
- b) in the seated position:
 - 1) headrest – head
 - 2) arm rest – arms
 - 3) seat – hips
 - 4) backrest – back
 - 5) floor – feet

The type of transmission is whole-body transmission which acts on the whole body through the interfaces.

5.3 Application

Table 3 lists the items included or excluded from this document.

Table 3 — Items considered by this document

Item	Included	Excluded
Effects of vibration exposure	— on ride comfort — on vehicle assessment with respect to ride comfort	— on health — on activities — on motion sickness
Vibration transfer	— on whole body through interfaces — through floor interface	— on single body part — on whole surface
Test procedure	— definitions — reference system — requirements — measurement and evaluation rules — guidance on reporting	— notes or attributes related to service quality and/or passenger expectation — limit values
Posture and activities of passenger	— standing — seated	— lying down — performing specific actions (reading, writing etc.)
Type of measurement	— indirect measurement, i.e. measurement of motion environment by different motion quantities	— direct measurements (by asking test subjects) — combined measurements

5.4 Characteristics of rail vehicle motions

The basic typical motion characteristics, referred to the type of measurement and evaluation, are:

- a) different properties, depending on the type of evaluation:
 - quasi-stationary (mean comfort);
 - non-stationary (comfort on curve transitions and comfort on discrete events);
- b) the frequency range of motions expected in rail vehicles includes, in the lateral direction:
 - up to 15 Hz: due to track characteristics, vehicle body sway and yaw modes at lower frequencies, and suspensions characteristics and vehicle body modes at higher frequencies;
- c) the frequency range of motions expected in rail vehicles includes, in the vertical direction:
 - up to 40 Hz: due to track characteristics, suspensions characteristics, wheel defects, vehicle body modes;

- d) the range of frequencies from 0 Hz (quasi-static) to 2 Hz for comfort on curve transitions and for discrete events.

5.5 Ride comfort

Ride comfort is the complex sensation, produced on the passenger by the vehicle body motions of the railway vehicle, transmitted to the whole body through the interfaces.

This sensation is classified as:

- a) average sensation, based on the vibration applied on a long-time basis (several minutes);
- b) quasi-static lateral acceleration due to curving;
- c) instantaneous sensation: a sudden change of the average sensation, due to a short-basis event (change of mean lateral acceleration level with possible oscillation, roll motion at significant velocity and lateral jerk).

The first type of sensation is taken into account in the mean comfort evaluation.

The second and the third type of sensation are taken into account in the comfort on curve transitions and in comfort on discrete events.

5.6 Direct and indirect measurements

The quantification of ride comfort for passengers is performed through indirect measurements, i.e. measuring and post-processing the relevant motion quantities. Other types of tests and evaluation, such as direct tests based on the assessment of the perceptions of tested passengers, and combined tests, including both direct and indirect tests, are not specified in this document. However, some guidance for direct tests is given in Annex G.

5.7 Summary table of procedures

The evaluation of ride comfort for passengers is taken into account in this document by:

- a) procedure for the quantification of comfort index “Mean Comfort” by the standard method (N_{MV}), see Clause 6;
- b) procedure for the quantification of comfort index “Mean Comfort” by the complete method (N_{VA} , N_{VD}), see Clause 6;
- c) procedure for the quantification of comfort index “comfort on curve transitions” (P_{CT}), see Clause 7;
- d) procedure for the quantification of comfort index “comfort on discrete events” (P_{DE}), see Clause 8;
- e) procedure for the quantification of continuous comfort (C_{Cx} , C_{Cy} , C_{Cz}), see Clause 6.

This document also provides guidelines for the specification for the vehicle performance regarding ride comfort, see Annex D, and requirements for assessment of vehicles with respect to ride comfort, particularly for the continuous comfort (CC) and the mean comfort standard method (N_{MV}), see Annex E. Motion quantities and position of measurement for the different comfort indices are listed in Table 4.

Table 4 — Motion quantities and measurement position for evaluation of ride comfort

	Mean comfort standard method	Mean comfort complete method		Continuous comfort	Comfort on curve transitions	Comfort on discrete events
Comfort index	N_{MV}	N_{VD}	N_{VA}	C_{Cx}, C_{Cy}, C_{Cz}	P_{CT}	P_{DE}
Motion quantities	Accelerations in three directions	Accelerations in three directions		Accelerations in three directions	Lateral acceleration, Lateral jerk, Roll velocity	Lateral acceleration
Measuring position	Floor	Floor	Floor and interfaces	Floor	Floor	Floor

All determining quantities are summarized in Annex I.

5.8 Application of comfort indices

The different procedures for ride comfort estimation and their applications are summarized in Table 5.

Table 5 — Specification of different comfort indices for evaluation of ride comfort and vehicle assessment with respect to ride comfort

	Mean comfort standard method	Mean comfort complete method	Continuous comfort	Comfort on curve transitions	Comfort on discrete events
Comfort index	N_{MV}	N_{VA}, N_{VD}	C_{Cx}, C_{Cy}, C_{Cz}	P_{CT}	P_{DE}
Passenger comfort	✓	✓	✓	✓	✓
Vehicle assessment	✓	—	✓	✓ (tilting vehicles)	—

For vehicle assessment, only the mean comfort standard method and the continuous comfort should be used. The mean comfort complete method is too complex for the application to assess an adequate amount of passengers/positions, so a vehicle assessment could not reasonably be performed using the complete method. The comfort on curve transitions and the comfort on discrete events are mainly influenced by the track layout and speed, as perception is dominated by the uncompensated lateral acceleration. Therefore, these methods are valid for the comfort estimation perceived by passengers, but not generally for vehicle assessment. For tilting trains, the comfort in curve transitions may also be used for the assessment of the tilting system if the requirements for vehicle assessment in Annex E are met.

Further applications, where it may be beneficial to use the different comfort indices, are shown in Table 6.

Table 6 — Guidance to use the different comfort indices for other applications

	Mean comfort standard method	Mean comfort complete method	Continuous comfort	Comfort on curve transitions	Comfort on discrete events
Comfort index	N_{MV}	N_{VA}, N_{VD}	C_{Cx}, C_{Cy}, C_{Cz}	P_{CT}	P_{DE}
Track layout	—	—	—	✓	—
Track monitoring	✓	—	✓	—	✓
Vehicle monitoring	✓	—	✓	✓ (tilting vehicles)	—

NOTE For monitoring of a vehicle or track section further methods than those presented in Table 6 can be beneficial.

6 Mean comfort and continuous comfort

6.1 General

Mean comfort is divided in two methods:

- the standard method taking into account the acceleration on the floor interface, giving a general assessment of the ride comfort along the vehicle;
- the complete method taking into account accelerations in the seat and on the floor interface, giving a detailed assessment of the ride comfort perceived by seated and standing passengers.

The standard method is a simplification of the more general complete method. The complete method is better correlated with the passenger's perception of comfort than the standard method.

The continuous comfort is a set of RMS values of the frequency weighted accelerations measured at floor level to evaluate the mean comfort. It can be considered as an intermediate evaluation step of the standard method. These methods can be applied on straight and curved lines.

Caution should be taken when applying these methods on curved track, as the effects of quasi-static lateral accelerations in curves are excluded by the frequency weighting filters. The methods are validated on predominantly straight lines.

The application of the standard method is constrained by the condition that the longitudinal acceleration should not be excessive.

When the complete method is used, the standard method should also be applied for reference purposes.

Subject of this clause is to specify:

- a) comfort (standard method and complete method) and continuous comfort;
- b) the parameters to be measured and the methods to be used to obtain the assessment values.

This clause constitutes an application document for the railway field covering the measurement, analysis and evaluation of acceleration, taking into account that mechanical vibration in a railway vehicle presents certain specific characteristics.

Application of this clause, on the basis of the measurement of certain accelerations, will permit an evaluation to be made of mean comfort and continuous comfort in a specified vehicle under specified service conditions.

Application of these methods will give comfort indexes or RMS values for the vehicle-track system. The separate influence of the vehicle and track cannot be assessed without further information on vehicle and seat characteristics, track layout and track geometry quality.

Application of these methods under the prescribed conditions may assist in the identification of causes of discomfort.

6.2 Basis of the method

Comfort is perceived in different ways by different people. It is therefore impossible to specify a unique assessment system which is valid for everybody.

As a result of this, the evaluation of mean comfort, made in this document, is based on the relationship between the accelerations measured in a vehicle and the mean comfort ratings given by a representative group of passengers for periods of 5 min.

NOTE The standard and complete methods are demonstrated and validated in the reports of the ERRI B153 Committee, particularly in RP10, RP12, RP13, RP 17 and DT219 (B153) (exists only in French).

6.3 Methodology

Evaluation of mean comfort and continuous comfort consists of:

- a) measuring the accelerations on the floor of the vehicle and for the complete method also on seat interfaces;
- b) digitisation together with appropriate anti-aliasing filters.

The computation is carried out through:

- c) frequency weighting of signals;
- d) calculation of sliding RMS values with window lengths of 5 s, resulting in continuous comfort.

The step size of moving the sliding window (sliding step) can be defined as:

- preferably the sampling interval $1/f_s$ (e.g. 0,002 s in case of sampling rate $f_s = 500$ Hz),
 - or a fraction of 5 s but not higher than 1 s,
 - or 5 s (e.g. for comparison with previous results).
- e) calculation of the 95th percentile and for the complete method also 50th percentile over a time period of 5 min;
 - f) calculation of the mean comfort index for each measuring point.

6.4 Test conditions

6.4.1 General

The general test conditions are described in this clause. The detailed conditions may vary depending on the application and should be considered in the specification of the test. The test conditions used shall be

documented in the test report, see 6.8. For the purpose of vehicle assessment with respect to ride comfort, the test conditions are further elaborated in Annex E.

6.4.2 Selection of test sections

The choice of the test sections should reflect representative operating conditions representative for the test vehicle are taken into account, for instance, track geometry and track quality.

The duration of the measurements for the evaluation of mean comfort shall be a multiple of 5 minutes. The minimum requirement shall be four test zones of 5 minutes. The four test zones may be separate, but each of them shall be taken from a continuous record. For vehicle assessment, acceptable modifications of this requirement are provided in E.4.

NOTE The record of the vehicle's position along the track during the test run enables investigation of periods of discomfort with respect to local track properties.

6.4.3 Test speed

Comfort shall be evaluated with the maximum operating speed of the vehicle on the test sections.

For mean comfort evaluation, the test speed should be kept constant with a tolerance of ± 5 km/h during the test zones of 5 min.

NOTE Depending on the purpose of the test, other test speeds might be useful.

6.4.4 Wheel-rail contact geometry

The comfort may be influenced by the wheel-rail contact geometry. This is especially important for the purpose of vehicle assessment, see also Annex E.

NOTE Requirements for the vehicle stability assessment are set out in EN 14363:2016+A2:2022, Clause 7.

6.4.5 Vehicle condition

The vehicle shall be tested in a specified condition including state of vehicle loading, wear of wheels, inflated air-suspension and activated tilting systems if applicable, etc.

NOTE Depending on the purpose of the test, other vehicle conditions might be useful.

The inter-vehicle couplings and gangways should be tightened as for normal service.

6.5 Parameters to be measured

6.5.1 General

Mean comfort and continuous comfort are calculated on the basis of accelerometer measurements. These measurements are carried out at different points on the floor and/or seat interfaces.

Annex B describes the measuring techniques.

6.5.2 Location of measuring points

The accelerations at a given point in a vehicle are closely dependent upon the location of that point. For this reason, the measurements shall be carried out at the longitudinal centre of the body and at both ends of the passenger compartment, at the seats most closely located to these positions. Figure 1 shows an example of the locations of these measuring points on the floor of a vehicle.

The following measuring points, as a minimum, shall be used:

- one point at each end of the passenger compartment;
- one point at the longitudinal centre (one point on each deck for double-deck vehicles).

Floor accelerometers shall be fixed to the floor as closely as possible to the vertical projection at the centre of the seat pan (preferably less than 100 mm from this point).

Additional measuring points may be used depending on the purpose of the test and to gain a better understanding of the characteristics of the vehicle.

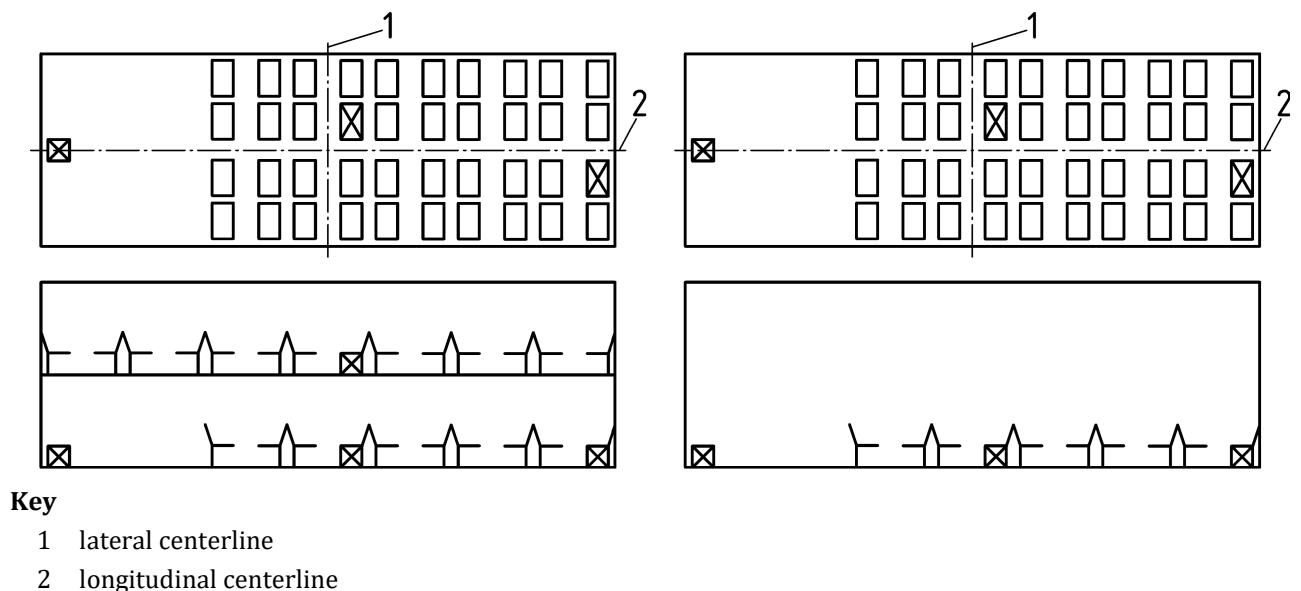


Figure 1 — Locations of measuring points; double deck and single deck passenger coaches

In case of application of the complete method, accelerometers shall additionally be placed on the seat pan and seat back.

6.5.3 Filtering

The measured signals shall be filtered using the weighting curves with tolerance bands specified in Annex C.

6.6 Definition of intermediate quantities

In the following clause the definitions of the intermediate quantities and RMS are given.

Symbols

N = Comfort index

The general expression of frequency weighted RMS-accelerations is:

$$a_{Ej}^{W_i}(t)$$

and the general expression of a percentile taken from a frequency weighted RMS-acceleration distribution is:

$$a_{Ejk}^{W_i}$$

where

- a RMS acceleration values, in m/s^2 , taken over 5 s
- W_i superscript index relates to the weighted frequency values in accordance with the weighting curve i
($i = \text{b, c, d}$):
 - b: vertical direction W_b
 - c: longitudinal direction (backrest), W_c
 - d: lateral/longitudinal direction, W_d
- E subscript index indicating the orientation of acceleration:
 - X: longitudinal direction
 - Y: lateral direction
 - Z: vertical direction
- j subscript indices related to measuring position
 - P: the floor interface
 - A: the seat pan interface
 - D: the seat back interface
- k : subscript index indicating the percentile used
 - $k = 95$ for the 95th percentile
 - $k = 50$ for the 50th percentile (or median)

NOTE 1 The weighting curve W_b deviates from W_k defined in ISO 2631-1. The weighting curve W_b defined in the present standard slightly deviates from the one defined in ISO 2631-4.

The k^{th} n-tile of N samples is the value that corresponds to a cumulative frequency of $N \cdot k / n$, and if $n = 100$ it is called percentiles. Therefore, for a collection of 60 samples (5 min of five-second RMS values) the 95th percentile is the 57th value and the 50th percentile is the 30th value.

There exist some percentile definitions, including implementation in standard software packages, which deviate from this. It is necessary to follow the provided definition, when calculating 50th and 95th percentile from a set of only 60 samples (like in case of N_{MV}). With increasing numbers of samples in a data set, the differences between the percentile definitions become less and less significant.

The five-second RMS values of the frequency weighted accelerations are calculated as:

$$a_{Xj}^{W_i}(t) = \left[\frac{1}{T} \cdot \int_{t-T}^t (\ddot{x}_{W_i}^*(\tau))^2 d\tau \right]^{0,5} \quad (1)$$

$$a_{Yj}^{W_i}(t) = \left[\frac{1}{T} \cdot \int_{t-T}^t (\ddot{y}_{W_i}^*(\tau))^2 d\tau \right]^{0,5} \quad (2)$$

$$a_{Zj}^{W_i}(t) = \left[\frac{1}{T} \cdot \int_{t-T}^t (\ddot{z}_{W_i}^*(\tau))^2 d\tau \right]^{0,5} \quad (3)$$

where

$$T = 5 \text{ s}$$

and t is equal to a multiple of the chosen sliding step of up to 1 s (or 5 s for historic compatibility).

NOTE 2 The RMS can alternatively be calculated in the frequency domain (based on FFT) rather than in the time domain. Flow diagrams for the numerical integration are shown in Annex H.

6.7 Definition of comfort indexes

6.7.1 Continuous comfort

On floor level, the RMS values of the frequency weighted accelerations are defined as:

$$C_{Cx}(t) = a_{XP}^{W_d}(t) \quad (4)$$

$$C_{Cy}(t) = a_{YP}^{W_d}(t) \quad (5)$$

$$C_{Cz}(t) = a_{ZP}^{W_b}(t) \quad (6)$$

The RMS values for the continuous comfort are functions of time.

6.7.2 Mean comfort standard method

Comfort formula:

$$N_{MV} = 6 \cdot \sqrt{\left(a_{XP95}^{W_d}\right)^2 + \left(a_{YP95}^{W_d}\right)^2 + \left(a_{ZP95}^{W_b}\right)^2} \quad (7)$$

If this formula is to be used for measurements carried out at more than one point of the vehicle, the value $a_{XP95}^{W_d}$ may be obtained from the centre of the vehicle.

Depending on the application, it can be useful to calculate the following partial comfort indexes:

$$N_{MVx} = 6 \cdot a_{XP95}^{W_d} \quad (8)$$

$$N_{MVy} = 6 \cdot a_{YP95}^{W_d} \quad (9)$$

$$N_{MVz} = 6 \cdot a_{ZP95}^{W_b} \quad (10)$$

6.7.3 Mean comfort complete method

Comfort formula for seated:

$$N_{VA} = 4 \cdot \left(a_{ZP95}^{W_b} \right) + 2 \cdot \sqrt{\left(a_{YA95}^{W_d} \right)^2 + \left(a_{ZA95}^{W_b} \right)^2} + 4 \cdot \left(a_{XD95}^{W_c} \right) \quad (11)$$

Comfort formula for standing:

$$N_{VD} = 3 \cdot \sqrt{16 \cdot \left(a_{XP50}^{W_d} \right)^2 + 4 \cdot \left(a_{YP50}^{W_d} \right)^2 + \left(a_{ZP50}^{W_b} \right)^2} + 5 \cdot \left(a_{YP95}^{W_d} \right) \quad (12)$$

6.8 Test report

The test report shall be sufficiently detailed so that the execution of the comfort test is comprehensible and that special occurrences can be identified. The level of detail depends on the purpose of the test. Annex F gives guidelines for the test report.

7 Comfort on curve transitions

7.1 General

The assessment of passenger comfort according to P_{CT} is useful in situations where curve transitions make a significant contribution to the passenger's perception of comfort. It gives a measure of the passenger comfort for an individual transition curve without evaluation of cumulative effects. It is suitable for use with heavy rail vehicles and at any speed.

The object is to specify:

- a) the conditions for carrying out running tests to assess comfort on curve transitions;
- b) the parameters to be measured and the methods to be used to obtain the assessment values.

NOTE Comfort on curve transitions evaluates the complete rail system. For vehicle assessment it is only applicable to tilting trains.

7.2 Basis of the method

The method is based on the technical report BRR TR DOS 017, also assumed as a calculation and experimental guideline by ERRI B176 Committee and applied, with some clarifications, in Italy and Switzerland for tilting system tests in 1991.

The method concerns measurements and evaluation of the comfort on curve transitions that are instantaneously perceived by the passengers as a sudden change to the average feeling of ride comfort. This perception is due to low-frequency behaviour on entry, reverse transitions and transitions with increasing lateral acceleration within compound curves. This type of feeling is perceived in different ways by different people. It is therefore impossible to specify a unique assessment, valid for everybody, based on direct tests. Transition curves with constantly decreasing magnitudes of lateral acceleration do not cause passenger discomfort.

As a result, the evaluation of comfort on curve transitions is based on the relationship between the average percentage of dissatisfied passengers and the most relevant magnitudes of lateral acceleration, lateral jerk, and roll velocity of the vehicle body.

The formula has been validated for transitions with increasing magnitude of lateral acceleration, where curvature and cant change linearly with respect to distance along the track, having a duration of at least