BS EN 14363:2016

BSI Standards Publication

Railway applications — Testing and Simulation for the acceptance of running characteristics of railway vehicles — Running Behaviour and stationary tests

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National foreword

This British Standard is the UK implementation of EN 14363:2016. It supersedes BS EN 14363:2005, BS EN 15686:2010 and BS EN 15687:2010 which are withdrawn

The UK committee draws users' attention to the distinction between normative and informative elements, as defined in Clause 3 of the CEN/CENELEC Internal Regulations, Part 3.

Normative: Requirements conveying criteria to be fulfilled if compliance with the document is to be claimed and from which no deviation is permitted.

Informative: Information intended to assist the understanding or use of the document. Informative annexes do not contain requirements, except as optional requirements, and are not mandatory. For example, a test method may contain requirements, but there is no need to comply with these requirements to claim compliance with the standard.

When speeds in km/h require unit conversion for use in the UK, users are advised to use equivalent values rounded to the nearest whole number. The use of absolute values for converted units should be avoided in these cases. Please refer to the table below for agreed conversion figures:

INS, RST and ENE speed conversions	
km/h	**mph**
2	1
3	1
5	3
10	5
15	10
20	10
30	20
40	25
50	30
60	40
80	50
100	60
120	75
140	90
150	95
160	100
170	105
180	110
190	120
200	125
220	135
225	140
230	145
250	155
280	175
300	190
320	200
350	220
360	225

The UK participation in its preparation was entrusted by Technical Committee RAE/1, Railway Applications, to Subcommittee RAE/1/-/8, Railway Applications - Vehicle/Track Interaction.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Compliance with a British Standard cannot confer immunity from legal obligations.

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Railway applications - Testing and Simulation for the acceptance of running characteristics of railway vehicles - Running Behaviour and stationary tests

Applications ferroviaires - Essais et simulations en vue de l'homologation des caractéristiques dynamiques des véhicules ferroviaires - Comportement dynamique et essais stationnaires

Bahnanwendungen - Versuche und Simulationen für die Zulassung der fahrtechnischen Eigenschaften von Eisenbahnfahrzeugen - Fahrverhalten und stationäre Versuche

This European Standard was approved by CEN on 19 September 2015.

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Contents

Page

European foreword

This document (EN 14363:2016) 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 September 2016, and conflicting national standards shall be withdrawn at the latest by September 2016.

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

This document supersedes EN 14363:2005, EN 15686:2010 [4], EN 15687:2010 [5].

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

It is not necessary to require further assessment of vehicles which have been already assessed under the conditions of previous standards in this field. Test results achieved under the conditions of the previous standards remain valid and can be used for the extension of acceptance of a vehicle or vehicle design according to this standard.

Prior to the first issue of this standard, national procedures were applied for vehicle acceptance, for example in Germany or UK. The underlying principles that were applied in these earlier standards are also incorporated in this standard. The fundamentals have not been changed but the formulation of the requirements has been made consistent. Therefore it is considered that also vehicles that were previously approved utilizing these earlier requirements have an equal status compared to vehicles that are approved according to this standard. This applies to the infrastructure and operating conditions that were considered in the earlier approval. This includes also a use as reference vehicle for extension of acceptance.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

Acceptable running characteristics of a railway vehicle (hereafter called vehicle) are essential for a safe and economic operation of a railway system. They are related to:

— the vehicle,

— the operating conditions,

— the characteristics of the infrastructure (track layout design and track quality) and

— the contact conditions of the wheel/rail interface.

The objective is to quantify the vehicle's performance under known representative conditions of operation and infrastructure.

This standard describes methods to assess the vehicle performance in the following areas:

— safety against derailment on twisted track (see 6.1);

— running safety under longitudinal compressive forces in s-shaped curves (see 6.2);

— evaluation of the torsional coefficient (see 6.3);

— determination of displacement characteristics (see 6.4);

— loading of the diverging branch of a switch (see 6.5);

— running safety in curved crossings (see 6.6);

— running safety, track loading and ride characteristics (see Clause 7).

The vehicle performance is assessed in two stages. Usually in the first stage the basic characteristics and low speed behaviour are investigated before first runs on the line under controlled operating conditions. In the second stage the running behaviour is assessed. The assessment of a vehicle according to the elements listed above can be performed either by physical testing, numerical simulation, calculation or comparison with a known solution (dispensation). Details about the requirements relating to the choice of the appropriate assessment method are given in this document.

The operational envelope (speed and cant deficiency) that the vehicle has been assessed for needs to be documented.

The establishment of this document was based on existing rules, practices and procedures. The following principles were applied:

— the railway system requires comprehensive technical rules in order to ensure an acceptable interaction of vehicle and track;

— the performance of new railway vehicles has to be evaluated and assessed before putting them into service;

— it is of particular importance that the existing level of safety and reliability is not compromised even when changes in design or operating conditions are demanded, e.g. by the introduction of higher speeds, higher vertical wheel forces, modification of the suspension, etc.

— it is possible to demonstrate compliance with the requirements of this standard by comparison of relevant parameters or by simulation if changes are made to the design or to the operating conditions;

— as the combination of all the target test conditions described is not always achievable, the compliance against the missing target test conditions can be demonstrated by other means.

Requirements on running safety under longitudinal compressive forces in S-shaped curves of certain vehicles are given in EN 15839, while EN 16235 specifies a method to get dispensation from on-track testing for vehicles equipped with established and standardized running gear, if certain conditions are fulfilled.

The informative Annexes A, B, C, D, E, F; Q, S, T and U contain requirements that have to be fulfilled when the annex is applied.

1 Scope

This European Standard defines the process for assessment of the running characteristics of railway vehicles for the European network of standard gauge tracks (nominally 1 435 mm).

In addition to the assessment of the running characteristics of vehicles for acceptance processes, this standard also defines quantities and dependencies that are not directly used for acceptance purposes. This information is for example intended for the validation of simulation models. It can also be used to define operating conditions outside the reference conditions to be used for the approval.

The assessment of running characteristics applies to vehicles which:

— are newly developed;

— have had relevant design modifications; or

— have changes in their operating conditions.

The assessment process is based on specified target test conditions (see 3.1) given in this document.

Experience over many years has demonstrated that vehicles complying with this standard can be operated safely on infrastructure with conditions more severe than the target test conditions, if the current general operating rules are applied. As an example it is generally current practice to restrict cant deficiency in curves below a certain radius. It may be necessary to adapt these operating rules, if a deterioration of the infrastructure conditions is observed. These operating rules are defined on a national basis. The procedure to evaluate these operating rules is out of the scope of this standard.

NOTE 1 There are margins included in the specified limit values and the statistical evaluation. They cannot be quantified, but they explain why vehicles can also be operated at full speed and cant deficiency in many cases outside of the target test conditions.

This standard also enables the demonstration of compliance against the target test conditions for the case that their combination is not achievable during tests. It is also possible to carry out the assessment of a vehicle for limited test conditions such as test zones 1 and 2 or reduced speed or reduced cant deficiency. In this case the approval of the vehicle shall be restricted accordingly.

NOTE 2 National regulations sometimes allow the increase or decrease of the values for speed, curve radius and cant deficiency for local operation based on safety considerations taking into account the local characteristics of the infrastructure (track layout, track structure, track geometrical quality and contact conditions). These local characteristics can be different from those included in the assessment for the vehicle acceptance.

NOTE 3 The methods of this standard can also be applied to gather information about the compatibility between the vehicle and infrastructure with conditions more severe than the target test conditions. The results of such investigations can be used to determine safe operating rules for such infrastructure conditions.

Where testing the vehicle demonstrates that the performance of a vehicle complies with the requirements of this standard when operating at maximum speed and maximum cant deficiency under infrastructure conditions that are more severe than the target test conditions, the obtained results are accepted and there is no need to carry out additional tests to fulfil the requirements defined in this standard.

This standard addresses four aspects:

1) Vehicles

The assessment of the running characteristics applies principally to all railway vehicles. The document contains acceptance criteria for all types of vehicles with nominal static vertical wheelset forces up to 225 kN (of the highest loaded wheelset of the vehicle in the assessed load configuration specified in 5.3.2). In addition for freight vehicles with nominal static vertical wheelset forces up to 250 kN the acceptance criteria are defined. The acceptance criteria given in this document apply to vehicles designed to operate on standard gauge tracks.

2) Infrastructure

In the acceptance process the range of curve radii is defined, for which the vehicle is assessed. A vehicle accepted according to the requirements of this standard is able to be operated on all standard gauge tracks complying with EN 13803-1 and EN 13803-2.

EN 14363 also gives guidance about the handling of geometric track quality associated with the assessment.

3) Conditions of the wheel rail interface

This standard contains requirements relating to the necessary range of equivalent conicity to be included in the assessment as target test conditions.

In some national systems, either parts or all, equivalent conicities are significantly higher than the target test conditions of this standard. These cases are outside the scope of this standard. Nevertheless the methodology defined in this standard for the proof of running stability can also be used for higher equivalent conicities.

NOTE 4 In these cases running safety is demonstrated by application of existing national requirements for high equivalent conicities during stability testing. Experience shows, that it is not necessary to include the maximum occurring values of equivalent conicity in such national requirements.

4) Operating conditions

The document requires the specification of the combination of admissible speed and admissible cant deficiency as well as the loading conditions for each type of vehicle.

NOTE 5 Recommended values of cant deficiencies for broad international approval are given in informative Annex H.

This standard is not directly applicable to:

— railways with different track layout, e.g. tramways, metros and underground railways;

— railways with non-standard gauge tracks;

but assessment can be conducted by analogy with this document, e.g. the test procedures described in this standard can be applied also to vehicles operated in networks with other track gauges (e.g. 1 524 mm and 1 668 mm). The related limit values and test conditions could be different. They are specified nationally taking into account track design and operating conditions.

The strength of the vehicle and mounted parts, passengers and train crew vibration exposure, comfort, load security and effects of cross wind are out of the scope of this standard.

This document includes the assessment of track loading quantities, the quantification of track deterioration or track fatigue is out of the scope of this standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13803-1, *Railway applications — Track — Track alignment design parameters — Track gauges 1435 mm and wider — Part 1: Plain line*

EN 13803-2, *Railway applications — Track alignment design parameters — Track gauges 1 435 mm and wider — Part 2: Switches and crossings and comparable alignment design situations with abrupt changes of curvature*

EN 13848-1, *Railway applications — Track — Track geometry quality — Part 1: Characterisation of track geometry*

EN 13848-2, *Railway applications — Track — Track geometry quality — Part 2: Measuring systems — Track recording vehicles*

EN 13848-5:2008+A1:2010, *Railway applications — Track — Track geometry quality — Part 5: Geometric quality levels — Plain line*

EN 14033-1, *Railway applications — Track — Railbound construction and maintenance machines — Part 1: Technical requirements for running*

EN 15273-1, *Railway applications — Gauges — Part 1: General — Common rules for infrastructure and rolling stock*

EN 15273-2, *Railway applications — Gauges — Part 2: Rolling stock gauge*

EN 15302:2008+A1:2010, *Railway applications — Method for determining the equivalent conicity*

EN 15663:2009, *Railway applications — Definition of vehicle reference masses*

EN 15746-1, *Railway applications — Track — Road-rail machines and associated equipment — Part 1: Technical requirements for running and working*

EN 15839 *Railway applications — Testing for the acceptance of running characteristics of railway vehicles — Freight wagons — Testing of running safety under longitudinal compressive forces*

EN 15954-1, *Railway applications — Track — Trailers and associated equipment — Part 1: Technical requirements for running and working*

EN 15955-1, *Railway applications — Track — Demountable machines and associated equipment — Part 1: Technical requirements for running and working*

EN 16235, *Railway application — Testing for the acceptance of running characteristics of railway vehicles — Freight wagons — Conditions for dispensation of freight wagons with defined characteristics from on-track tests according to EN 14363*

3 Terms and definitions

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

3.1
target test conditions
conditions specified in this standard for the performance of on-track tests

3.2
bogie yaw resistance
torque around the vertical axis between bogie and vehicle body required to rotate a bogie while supporting a vehicle body

3.3
unsprung mass
mass of a wheelset including all components that are attached to it and which are not suspended by the primary suspension or the wheelset guidance, e.g. brake discs, gear wheels, bearings, axle boxes plus half of the primary suspension mass, half the mass of suspension links and if applicable the unsuspended part of the traction equipment

Note 1 to entry: Sometimes it will be necessary to regard different wheelsets of a running gear separately.

Note 2 to entry: Sometimes it will be necessary to include or exclude parts which are separately suspended with regard to the problem in question, e.g. magnetic brakes.

3.4
primary suspended mass
mass between primary and secondary suspension of a running gear with two vertical suspension stages, i. e. the bogie frame together with all components attached to it, e.g. braking equipment, antennas, pipes and cables plus half of the primary and secondary suspension mass, half the mass of suspension links and traction rods and if applicable the primary suspended part of the traction equipment

Note 1 to entry: Sometimes it will be necessary to include or exclude parts which are separately suspended with regard to the problem in question, e.g. magnetic brakes.

3.5
secondary suspended mass
mass supported by the secondary suspension of a running gear, i. e. the mass of the relevant part of a vehicle body with all components attached to it, e.g. upper bolster or adapter beam plus half of the secondary suspension mass, half the mass of suspension links and traction rods and if applicable the secondary suspended part of the traction equipment

3.6
bogie mass
mass of the bogie which rotates against the vehicle body around the vertical axis during the entrance into curves

Note 1 to entry: In most cases this mass is similar to the sum of the unsprung masses and the primary suspended mass of a running gear with two or more wheelsets.

3.7
yaw moment of inertia of whole running gear
moment of inertia of the mass of the running gear which rotates against the vehicle body around the vertical axis during the entrance into curves

3.8
displacement characteristics
combination of lateral and roll displacements of a vehicle when subjected to cant excess or deficiency

3.9
running behaviour
behaviour of a vehicle or running gear with regard to the interaction between vehicle and track covering the specific terms running safety, track loading and ride characteristics

3.10
running characteristics
characteristics of a vehicle or running gear with regard to running behaviour, safety against derailment in twisted track and under longitudinal compressive forces in S-shaped curves, torsional coefficient of a vehicle body, displacement characteristics, loading of the diverging branch of a switch and running safety in curved crossings

3.11
equivalent conicity
tan γ_e
is equal to the tangent of the cone angle tan γ_e of a wheelset with coned wheels whose lateral movement has the same kinematic wavelength as the given wheelset and is the relevant parameter of contact geometry on straight track and on large radius curves

Note 1 to entry: See also EN 15302.

3.12
radial steering index
q_E
ratio between curve radius R_E negotiable without longitudinal creepage and the actual curve radius R of the track section and it describes the radial steering capability of a free wheelset in a track section as the relevant parameter of contact geometry on small and very small radius curves

3.13
operation envelope
given by the combinations of speed and cant deficiency for which the vehicle is intended to be operated

Note 1 to entry: See informative Annex H.

3.14
conventional technology vehicle
vehicles which are operated under normal operating conditions and correspond completely or in those construction parts which are relevant to the running behaviour to the proven state of the art

3.15
special vehicle
vehicle which is designed for maintenance, inspection or renewal of infrastructure elements or for special transport purposes which fleets are operated with a low global mileage (for the whole fleet) compared to normal railway vehicles including, but not necessarily restricted to the following list:

— maintenance vehicles:
  — on-track machines (see EN 14033);
  — cranes and matching wagons;
  — road rail machines (see EN 15746-1);
  — demountable machines (see EN 15955-1);
  — trailers (see EN 15954-1);
— monitoring and inspection vehicles, including:
  — track inspection vehicles;
  — catenary inspection vehicles;
— special transport vehicles, including:
  — transformer transporter;
  — crucible transporters.

Note 1 to entry: Trolleys as described in EN 13977 have no requirements in EN 14363 according to their hand-operation. Additional information is given in 7.1 and in informative Annex S.

3.16
reference vehicle
vehicle that has the same fundamental design concept as the vehicle to be assessed and that has been tested and approved according to this standard or to an equivalent standard

3.17
engineering change
change to the design of the vehicle that potentially varies the performance of the vehicle, when evaluated according to this standard

4 Deviations from requirements

If deviating from some points of the requirements of this standard for a particular assessment, these deviations shall be reported and explained. Then the influence on the assessment of the vehicle in terms of the acceptance criteria shall be evaluated and recorded. The outcome of this study shall be considered as an integral part of the requirements of this standard when applied to the assessment process of the vehicle, as long as evidence can be furnished that safety is at least the equivalent to that ensured by complying with these rules.

5 Test requirements

5.1 Measuring uncertainty

The different methods applied today for assessment of measuring uncertainty, are at least as strict as the requirements used when the limit values for the vehicle assessment were established. The limit values already include a margin for measuring uncertainty and no additional adjustment of the result or the limit value shall be made.

NOTE The measuring methods (equipment and processing) used today generally have the capability of achieving a measuring uncertainty at least as good as those in use, when the limit values for the vehicle assessment were established.

The appropriate equilibrium conditions of measured wheel/rail forces (quasi-static sum of Y and sum of Q forces) and inertia forces (uncompensated acceleration multiplied with mass) shall be checked. Maximum deviations from regression against cant deficiency and speed shall be reported. Sections with large deviations from the expected results shall be excluded from the evaluation if they cannot be explained by physical effects.

5.2 Test extent

5.2.1 General

For a vehicle designed to be operated under conditions assumed by the track layout given in EN 13803-1 and EN 13803-2 the test extent is given in the Clause 6 and Clause 7 of this standard and if necessary complemented by 5.2.2.

5.2.2 Fault modes

For the purposes of this standard, it is assumed, that potentially catastrophic failures of conventional mechanical parts are managed by the design and maintenance regime of the vehicle.

If an analysis of the requirements from the maintenance regime and operation condition show that the vehicle needs to be operated in a failure condition, assessment of running safety shall be performed according to this standard.

Running safety shall be demonstrated by tests, simulation or a combination of both. The extent of the test procedure and/or the simulation cases shall be defined by reference to the analysis. The aim of this testing is to assess the behaviour when operating in the investigated failure condition and testing can be restricted to the relevant test zones.

NOTE 1 Possible fault modes to be considered include but are not limited to failures of active suspension systems, tilt systems, air suspension, yaw dampers.

It is assumed that a failure will be repaired before a second one occurs and it is therefore not necessary to look at combinations so that, unless the analysis indicates a need for it (e.g. physical coupling), no superposition of different fault modes needs to be considered.

For the fault modes it is sufficient to assess only the criteria of running safety and only up to maximum speed (V_{adm}) and maximum cant deficiency (I_{adm}). The test speed range and test cant deficiency range as in Table 2 shall be adapted to appropriate ranges.

If running safety cannot be demonstrated for a relevant fault mode, limiting criteria for a safe operation shall be determined and possible measures for supervision and/or mitigation shall be defined to reduce the criticality of the fault mode.

NOTE 2 Safety requirements for supervision systems and compensating measures and requirements for reliability and availability of such systems are not handled in this document.

5.3 Test vehicle

5.3.1 Selection and status of the vehicle

The test vehicle shall be selected from a design type:

— according to the principle of random selection from identical stock; or

— by taking account of specific vehicle or running gear characteristics.

It shall be representative of the series production of a vehicle type. The results of testing of running behaviour refer to the actual status of the test vehicle during the test. The status of the test vehicle shall be determined and shall correspond to the desired status of the design series to be tested with respect to:

— the vehicle parameters relevant to running characteristics (Table U.1 gives guidance to select relevant characteristics); as well as

— the construction and maintenance status.

In this context, evidence (test reports, technical specifications, letter declaring conformity, etc.) shall be provided to show whether the values of the most important vehicle parameters for running behaviour are within the construction and maintenance tolerances.

Vehicles are generally tested in their new condition according to this standard. The specified tests and the associated limit values include a margin for the normal variation of vehicle parameters. It is not required to test all conceivable conditions.

5.3.2 Loading conditions

For testing the vehicle in empty and/or loaded condition the following definitions apply:

— empty: Between dead mass and operational mass in working order as defined in EN 15663 except that it is not necessary to test with worn parts subject to wear (e.g. discs, brake pads, wheels, etc.);

— loaded: design mass under normal payload as defined in EN 15663.

Apart from this rule the loaded condition of passenger vehicles of long distance and high speed trains to be operated without obligatory seat reservation shall include 160 kg/m^2 (2 $persons/m^2$) in standing areas instead of 0 kg/m^2.

NOTE 1 Vehicles of long distance and high speed trains are considered, if necessary, for the loading conditions with and/or without seat reservation in certain test conditions.

NOTE 2 For some vehicles it might be sufficient to test in a single appropriate intermediate load case and follow for the evaluation the method of extension of approval according to informative Annex U, e.g. for a special vehicle a variation from −15 % to +10 % (according to informative Annex S) of the tested nominal static vertical wheelset force is allowed.

It is acceptable that during the tests consumables are reduced (e.g. due to fuel consumption) in a range that is normal for the operation of the vehicle. For locomotives, only test results with a load above the operational mass in working order according to EN 15663 are acceptable.

For some vehicles, collection, transport and distribution of various items (ballast, track components, weed killer liquid…) may result in a large variable mass. For such vehicles the following rules shall be applied:

— fuel used for a vehicle's own propulsion and other items quoted in Table 2 of EN 15663:2009 shall be taken into account as “consumables”; for Clause 4 of EN 15663:2009, the vehicle is not considered as a freight vehicle, meaning that the design mass of consumables is considered greater than the operational mass of consumables;

— all items used in the working process, which can be collected and/or distributed or spread along the railway track, shall be considered as “payloads”.

— if a certain load condition is only applicable in working mode or travelling mode as described in EN 14033-2 (max. speed ≤ 60 km/h), then this load condition does not need to be considered for on-track testing according to this standard.

5.3.3 Distribution of static wheel forces

The distribution of the (vertical) wheel and wheelset forces is a fundamental parameter to describe the vehicle status during the test programme. To determine the wheel forces in the load cases used for testing as described in 5.3.2, they shall be measured directly in at least one load case. Other load cases may be calculated taking into account the masses of consumables and payload.

It is recommended to measure the vertical wheel forces of the test vehicle in all load cases used for testing.

The vehicle mass and the wheelset forces shall be reported together with the determined vertical wheel forces and ratios of vertical force difference according to the following formulae:

Vehicle mass:

$$m_{\text{veh}} = \frac{\sum_{j=1}^{n}(Q_{j1} + Q_{j2})}{g}$$

Vertical wheelset force:

$$P_{F0,j} = Q_{j1} + Q_{j2}$$

Maximum vertical wheelset force of the vehicle:

$$P_{F0,\max} = \max(Q_{j1} + Q_{j2}) \text{ for } j = 1,n$$

where

n is the number of wheelsets in the vehicle.

Ratio of vertical wheel force difference per wheelset related to the vertical wheelset force of the wheelset:

$$\Delta q_j = \frac{|Q_{j1} - Q_{j2}|}{P_{F0,j}}$$

NOTE It is intended to specify the measuring procedure for static vertical wheel and wheelset forces in the new standard prEN 15654–2 (Railway applications — Measurement of vertical forces on wheels and wheelsets — Part 2: Test in workshop for new, modified and maintained vehicles), that will be published later than this standard.

5.4 Assessment of test result

For vehicle assessment the target test conditions should be achieved. If not all of the target test conditions are achieved, the test results shall be interpreted or adjusted using one or more methods described in this standard (e.g. multiple regression in normative Annex R or simulation in informative Annex T). All deviations from the target test conditions shall be documented.

NOTE If an attempt is made to close gaps (between the target and the achieved test conditions) that are too big, this may lead to unreliable results and make it difficult to maintain the required confidence in the vehicle being able to respect the limit values.

5.5 Documentation of test

The test shall be documented with sufficient detail that the execution of the test is comprehensible and that special occurrences can be identified. This includes all necessary information to assess the test results, as a minimum:

— name of the test organization and test leader;

— date and time of the test;

— weather conditions;

— description of the vehicle design with its relevant parameters;

— status of the tested vehicle;

— description of the test facilities or test routes;

— description of measuring equipment;

— description of evaluation method;

— results from plausibility checks from instrumented wheelsets;

— special circumstances associated with the performance of the test;

— test results.

6 First stages assessment

6.1 Safety against derailment on twisted track

6.1.1 General

The assessment methods described in this clause are intended to ensure that vehicles can run safely on twisted tracks. The existence of twist in railway tracks is fundamental. This is a result of transition layout between levelled track and canted track as well as cross level deviations (maintenance limits). When running through twisted tracks there is an increased risk of derailment because of the risk of initiating flange climbing as a result of reduced vertical wheel force and high lateral forces. The vertical wheel forces are influenced by the following effects:

— twist on bogie wheel base;

— twist on bogie centre distance or axle distance for non-bogie vehicles;

— torsional hysteresis;

— eccentricity of centre of gravity;

— twist of the bogie and vehicle body as a result of tolerances or vehicle design;

— eccentricity of the centre of gravity due to cant excess – this influence is eliminated in the test;

— roll torque of the lateral axle box forces.

NOTE 1 It is assumed that the reduction in the guiding forces in larger curve radii has a stronger influence on the safety against derailment than the higher unloading of the guiding wheel due to the higher allowed cant excess in these radii.

The assessment methods for proving safety against derailment create an artificial and extreme situation for the vehicles.

This sub clause specifies three testing methods to investigate the derailment performance of vehicles while negotiating twisted track. All three methods are derived from work by ORE (later ERRI) and subsequently reported in documents prepared by the B55 groups of ORE. The objective of the test methods is common but the methods that are described below are independent and shall not be directly compared. In addition the values and conditions referred to in each method shall only apply to that method; it is not possible to directly compare test conditions and numerical results between the test methods.

The test conditions specified in the three methods detailed below for the assessment of safety against derailment on twisted track do not represent the worst conditions which could occur. Nevertheless, experience over many years has demonstrated that vehicles that comply with the assessment criteria specified in this sub clause operate safely on European Railways. This assessment shall be carried out for initial acceptance of all vehicles using one of the methods described below.

Method 1 represents a vehicle negotiating track with a 150 m radius curve with defined twist in the track. The assessment criterion is the wheel lift Δz.

Method 2 determines the guiding forces between wheel and rail as a vehicle negotiates a 150 m radius curve without twist. It measures separately the change in vertical wheel force when the vehicle is subjected to twisted track. The assessment criterion is the ratio of guiding force and vertical wheel force on the outer wheel $(Y/Q)_a$. This method includes the possibility of approval by calculation based on previous test results of a reference vehicle.

NOTE 2 ORE B55, Rp.8 [6] gives a lot of models and parameters for freight- and special vehicles that can be used to describe a reference vehicle.

Method 3 determines the bogie yaw resistance (X-factor) when negotiating the minimum radius curve specified for the vehicle. It measures separately the change in vertical wheel force $\Delta Q/Q$ when the vehicle is subjected to twisted track. The assessment criterion is the X-factor together with the wheel unloading $\Delta Q/Q$. Where it is not possible to demonstrate the simultaneous acceptable performance of both criteria using Method 3 (phase 1), validated computer simulations according to informative Annex B may be used.

The three test methods result in safe operation of the vehicles when the track twist including design twist and cross level is maintained in accordance with the rules given in EN 13848-5:2008+A1:2010, 8.6.

NOTE 3 The requirements for assessment of safety against derailment on twisted track of special vehicles operated in degraded working track are given in EN 14033–2.

For the extension of acceptance the assessment by calculation or testing is only necessary if the modification of the parameters might increase the risk of derailment.

NOTE 4 The most important factors influencing the safety against derailment are given in A.1.

A dispensation from tests and calculations of the safety against derailment is allowed for freight wagons, if the parameters and running gear types match with those that have shown results compliant with the limit value in published tests or calculations and the nominal wheel flange angle is 70°.

NOTE 5 Parameters and running gear types that meet the required criteria are included in the tabulated results given in Appendix A, Appendix B and Appendix C of UIC 530–2:2008 [12] available on the UIC-website http://www.uic.org.

6.1.2 Signal processing

The assessed signal for wheel lift Δz shall be low-pass filtered with a cut-off frequency between 5 Hz and 1 Hz depending on the speed in order to eliminate the detection of very short duration of wheel climbing occurrences.

If the Y and Q-forces are measured continuously with instrumented wheelsets, the signals shall be filtered as described in Table 5 for on-track testing.

6.1.3 Rail test conditions

Tests according to Methods 1 and 2 shall be done under nominally dry conditions in order to consider high friction forces between wheel and rail.

Information used in the determination of the rail conditions shall be gathered by measuring:

— Y_i and Q_i on the inner leading wheel;

— angle of attack α; and

— average vertical wheel force Q_0 of the leading wheelset;

and evaluated as described below.

During tests, the coefficient τ shall be at least 80 % of the value expected for dry rails. Therefore, the condition:

$$\left(Y/Q\right)_{\mathrm{i}} \geq 0{,}8 \cdot \tau_{\mathrm{dry}} + \gamma$$

as a function of the angle of attack shall be respected. In the above formula the contact angle of the tread γ at the contact point on the inner rail shall be inserted.

The coefficient τ_{dry} represents the ratio of the lateral friction force and the vertical force. For pure lateral creepage the coefficient τ_{dry} for dry rail conditions is defined as follows (see A.3):

$$\left(\frac{1}{\tau_{\text{dry}}}\right)^n = \left(\frac{1}{a}\right)^n + \left(\frac{1}{b \cdot \alpha}\right)^n$$

where

$$a = \frac{Q_0^2 - 242{,}5\, Q_0 + 57\,150}{100\,000}$$

$$b = \frac{Q_0^2 - 242{,}5\, Q_0 + 21\,950}{100}$$

$$n = 0{,}005\, Q_0 + 2{,}2$$

angle of attack α in rad and static vertical wheel force Q_0 in kN.

If the actual mean vertical wheel force on the inner rail during the test differs from Q_0 it is permitted to use this value in the above formulae.

The maximum values of τ_{dry} are obtained for the maximum values of α.

NOTE These formulae were determined with a wheel diameter of 1 m and static vertical wheel forces between 40 kN and 112,5 kN. For the application in this standard, they are deemed to be valid also outside these conditions.

If the angle of attack is replaced with the total creepage (lateral and longitudinal creepage), this formula describes the friction /creepage diagram for dry track.

If during the tests a coefficient higher than 100 % of τ_{dry} occurred, the tests may be repeated.

To determine friction during tests, the measurement of the angle of attack is necessary.

The method is not appropriate if the angle of attack is very small (e.g. below 0,0015 rad). In the case of bogies with a low angle of attack determination of the friction conditions is to be done by measuring on a leading wheelset of a vehicle which generates a higher angle of attack.

6.1.4 Vehicle test conditions

6.1.4.1 General

For methods 1 and 2 the effects of the running direction and the direction of curvature shall be analysed taking the vehicle design and the distribution of vertical wheelset forces in the vehicle into consideration. The test conditions and the wheelsets to be tested shall be determined for the worst case as a result of this analysis.

EXAMPLE For single vehicles with two wheelsets or bogies, the two outer wheelsets should be analysed in the leading position, unless the vehicle is symmetrical; then testing of one wheelset could be sufficient.

For all methods all the relevant connections between body and bogie of the vehicle which influence the assessment quantities shall be correctly attached. If it is necessary to remove dampers for a correct shimming in method 1, the effect on the vertical wheel forces shall be studied taking into account the low test speed. The result of this study shall be respected in the final assessment of the test results.

Single vehicles which are a part of a trainset may be tested separately. It shall be demonstrated that the test condition represents the forces and moments that exist when the vehicle is installed in the train set.

As long as the coupling forces and moments are lower or equal to the forces and moments between vehicles equipped with standard buffers and draw gear at their ends, vehicles may be tested separately.

6.1.4.2 Loading conditions

Vehicles shall be tested in the empty condition (see 5.3.2).

If the suspension is nonlinear, safety against derailment shall be tested in the worst combination of load and stiffness (e.g. this will occur for a two-rate spring at the smallest loading point above the application point of the second stiffness where, at full vehicle test twist, the relieved second stiffness just remains in contact/operation).

6.1.4.3 Conditions for vehicles with air springs

Safety against derailment shall be tested with inflated and deflated air springs.

For deflated cases, the most critical situation shall be tested (usually all bogies deflated).

With inflated air spring the vertical wheel force distribution may be changed by the response time of the levelling system. The type of the levelling system has an important influence (e.g. 4-point levelling, 3-point levelling and 2-point levelling), informative Annex A gives some additional information.

The effect of the levelling system's response time shall be investigated. During the test the effects of the levelling system shall be measured by including breaks in the test procedure to enable the system to stabilize.

6.1.4.4 Conditions for bogie vehicles with more than two axles per bogie

For methods 1 and 2 vehicle test twist for a bogie is related to the outer wheel base of the bogie. Twist displacements of intermediate wheelsets shall be interpolated.

6.1.4.5 Conditions for articulated vehicles

In the case of articulated vehicles where adjacent vehicle-bodies are suspended on a common running gear or articulation, the influence of inter-vehicle constraints shall be analysed in order to determine their significance. The test conditions and the wheelsets to be tested shall be determined as a result of this analysis. Intermediate running gear or bogies shall also be tested. It could be necessary to test more than one vehicle body at the same time.

A.5 gives some additional information and examples.

6.1.4.6 Conditions for vehicles with more than two suspension levels

The word suspension is used to indicate freedom between adjacent bodies which may or may not include springs or dampers. A.6 shows an example of such an arrangement, many other different types exist.

The relevant vehicle test twists for the individual suspension levels shall be defined by analogy to the rules given for bogie vehicles for each test method. A.6 gives an example for the vehicle illustrated.

6.1.4.7 Conditions for vehicles with steered wheelsets

For vehicles including mechanisms which steer the wheelsets, the track conditions (e.g. S-curves) may lead to angles of attack which are larger than those obtained on the test track. This shall be considered in the tests for methods 1 and 2. The worst conditions occurring in operation with regard to the angle of attack shall be determined. Normally, in full curves the angles of attack and therefore the guiding forces are low. However, in transitions or reverse curves the steering mechanism may generate adverse angles of attack.

In order to get the highest guiding forces during the test, these additional angles of attack shall be simulated by suitable methods (e.g. by removing the steering mechanism and fixing the wheelsets to this angle of attack).

For vehicles with self-steering wheelsets or other running gear which show a major influence of wheel/rail contact geometry on the steering effect and the resulting angle of attack, appropriate investigations (e.g. forced angle of attack, variation of wheel/rail geometry) shall be carried out.

6.1.5 Test methods

6.1.5.1 Method 1: Test on twisted test track

6.1.5.1.1 General

The safety against derailment shall be determined by measuring the wheel lift of the outer wheel of the leading wheelset when running through a curved twisted test track. The $(Y/Q)_a$ values shall be measured, $(Y/Q)_{a,max}$ be calculated and the results shall be reported but $(Y/Q)_{a,max}$ is not an assessment quantity.

6.1.5.1.2 Test conditions

The vehicle test twist values shall be applied as follows:

— for bogie test twist:

$$g_{\text{lim}}^{+} = 7$$ if $2a^{+} \leq 4$ m and

$$g_{\text{lim}}^{+} = \frac{20}{2a^{+}} + 2,0$$ if $2a^{+} > 4$ m

with $2a^{+}$ as the bogie wheel base in m and g^{+}_{lim} in ‰.

— for vehicle body test twist:

$$g_{\text{lim}}^{*} = 7$$ if $2a \leq 4$ m and

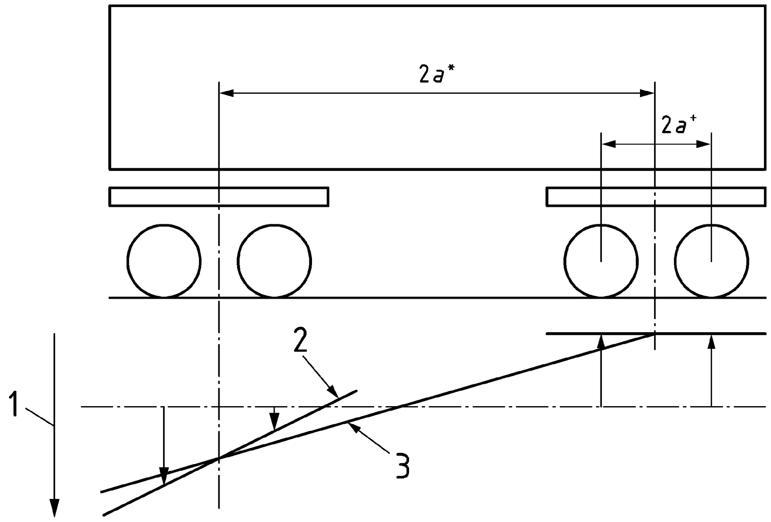
$$g_{\text{lim}}^{*} = \frac{20}{2a} + 2,0$$ if 4 m $< 2a \leq 20$ m

$$g_{\text{lim}}^{*} = 3$$ if 20 m $< 2a \leq 30$ m

$$g_{\text{lim}}^{*} = \frac{90}{2a}$$ if $2a > 30$ m

with $2a$ as the longitudinal dimension of twist in m (for single vehicles the longitudinal dimension of twist equals $2a^{*}$, the distance between centre pivots for vehicles with bogies or the distance of the wheelsets for non-bogie vehicles) and g^{*}_{lim} in ‰.

For bogie vehicles the twist due to the bogie wheel base $2a^{+}$ and the twist due to the bogie centre distance $2a^{*}$ shall be combined as shown in Figure 1.

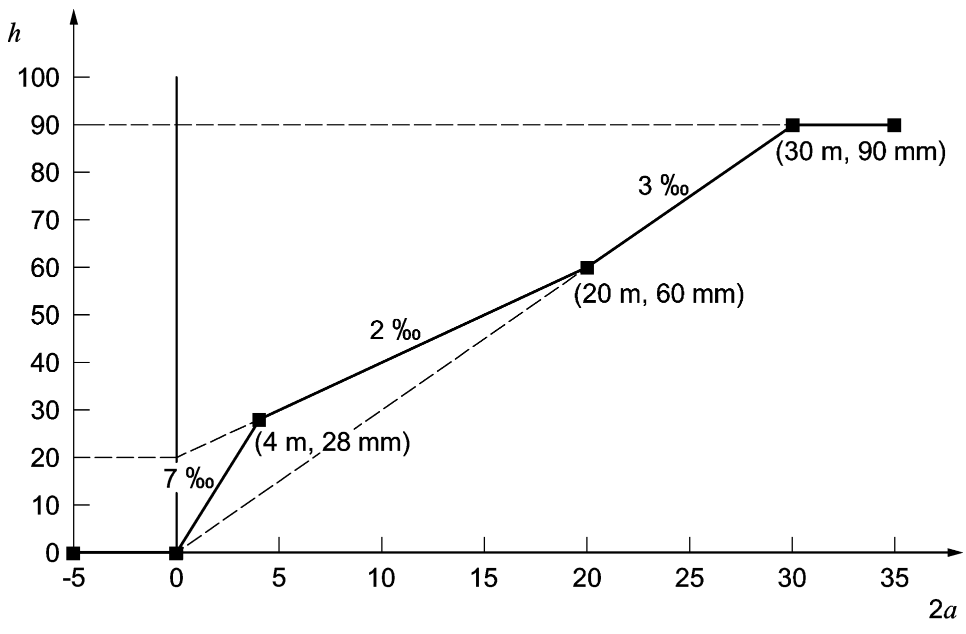


Key

1 vertical displacement
2 bogie test twist
3 vehicle body test twist

Figure 1 — Combination of bogie and vehicle body test twist

Figure 2 shows the test twist values depending on length dimensions $2a^+$ and $2a^*$. The maximum vertical height difference from twist shall be 90 mm which corresponds to a twist value of 3 ‰ at 30 m. For lengths greater than 30 m the vertical height difference from twist shall be 90 mm.



Key

h twist height
2*a* twist length

Figure 2 — Test twist values and twist heights

For articulated vehicles the influence of bodies and bogies that are not being tested shall also be considered and actions shall be taken to identify these influences. Where appropriate, these influences shall be removed by physical means (for example by shims) or the influence mitigated by other means (for example by calculation to demonstrate the consequence on the performance) or minimized to a justifiable level.

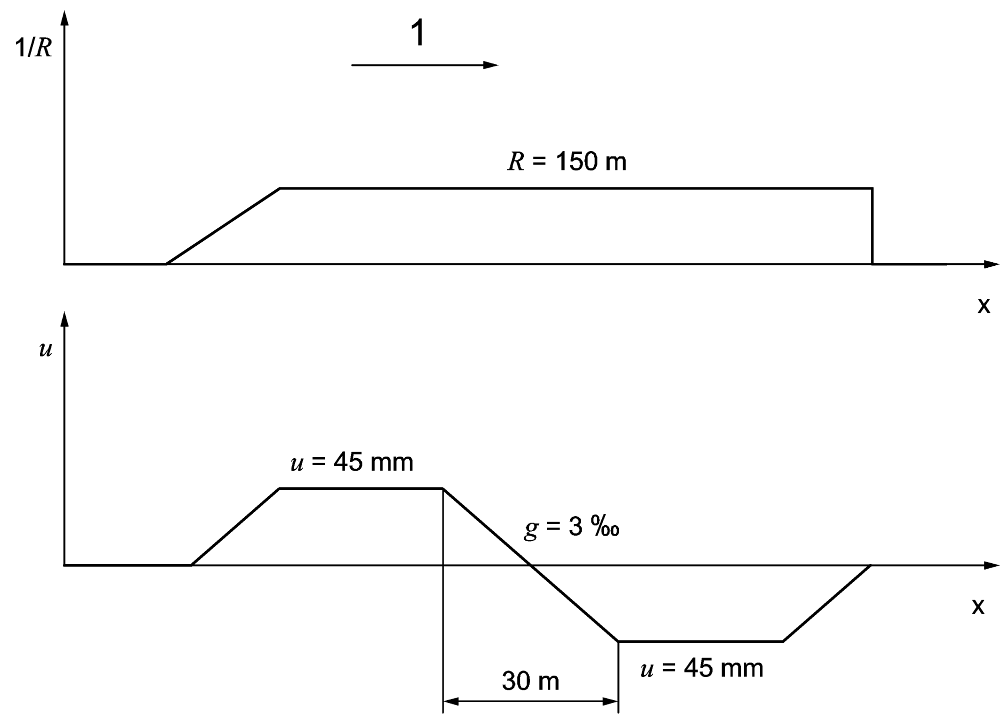
The objective is to apply the correct test twist to the vehicle. The condition of the test track shall be determined; using the measured track condition (twist, length of twist, cant, length of constant cant) any necessary adjustments to the vehicle (for example by the use of shims) to achieve the required test twist conditions shall be determined and reported. The achieved test twists (g^+, g^*) in the most critical position shall not deviate by more than 10 % from the intended values (g^+_{lim}, g^*_{lim}).

The influence of longitudinal forces in the train set shall be minimized. The vehicle shall not be braked. The speed shall be constant and not exceed 10 km/h.

Tests shall be carried out successfully a minimum of 3 times.

6.1.5.1.3 Track features

Figure 3 contains an example for installing a test track with characteristics described below.



Key

$1/R$	curvature
u	cant
1	running direction
x	track coordinate

Figure 3 — Example for general layout of test track

Tests shall be done on a test track with the following characteristics:

— nominal curve radius R = 150 m;

— nominal gauge in the range between 1 440 mm and 1 465 mm along the test track, variations of ± 5 mm around the nominal value are accepted.

— test track shall not exceed a tolerance for mean to peak alignment of 10 mm; section of twisted track with constant curvature and a nominal twist of 3 ‰;

— the twist is realized by varying the height of the outer rail from a positive to a negative cant. It is also permitted to use a horizontal track centre line by lowering and lifting both rails; the actual cant shall be measured at each rail fastening position and documented;

— sudden changes of contact geometry, gauge and curvature within the tolerances shall be avoided inside the measuring area. If sudden changes of contact geometry, gauge or curvature are included together with friction values at the upper end of the acceptable range, the test can be too severe and the test may be repeated.

Test conditions as described in 6.1.3 (dry rail conditions) shall be fulfilled for the inner rail. For the outer rail the test shall be carried out with wheel flange and rail in a dry condition and no residual lubrication shall be present. This shall be documented.

6.1.5.1.4 Vehicle condition

The test shall be planned to ensure that the direction of running and track curvature are in such a way that the wheel with the lowest vertical wheel force of a tested wheelset is tested in the leading position running on the outer rail of the curve. This may include additional shims in the suspensions. The aim is to make sure that the lower vertical wheel force is located at the most unfavourable position. The achieved vertical wheel force distribution shall be verified.

It is not necessary to test at the maximum permitted vertical wheel force difference.

For vehicles with air suspension the vertical wheel force distribution in the inflated and the deflated condition is different. This may lead to different requirements for shimming. If it can be demonstrated by the measured Y and Q forces, that one suspension condition is less critical with a sufficient margin (10 % difference between the two results of $(Y/Q)_a$), then the shimming for the more critical condition with respect to wheel climbing is acceptable for both conditions.

If the actual twist of the test track is smaller than the test twist specified in 6.1.5.1.2, the missing twist shall be included within the vehicle, e.g. by including shims in the springs in an appropriate way. Justification of the method of shimming that is used shall be documented. This shall demonstrate that the effect of the shimming achieves the same effects as would be achieved if the required twist was applied at the track level. A.7 contains suggestions for calculating the thickness of the shims depending on their location.

The nominal flange angle of the design wheel profile of the vehicle used for the test shall be ≤ 70°. If the vehicle is normally equipped with a profile with a nominal flange angle > 70°, a special profile with a flange angle of 70° shall be used for testing.

NOTE On new wheelsets or after machining the actual values of flange angles that are achieved may vary by the extent allowed by the tolerances defined in the specification for the wheel profile.

If the vehicle to be investigated was not only transferred to the test site but was already operated for a certain distance, it is required that the flange angle of the wheel profile or the contact angle during a theoretical wheel climbing is ≤ 71°. If the wheel flange angle is above this value, the test may be regarded as valid in the conditions stated in 6.1.5.1.6. The wheel profiles used for the test shall be measured at the beginning of these tests and documented.

It is not required to reprofile wheels during the test. Measurement of flange angle before starting the test is sufficient.

6.1.5.1.5 Measurement

The following values shall be measured:

— lateral forces on the inner and outer wheel of the tested wheelset Y_i, Y_a;

— vertical wheel forces on the inner and outer wheel of the tested wheelset Q_i, Q_a;

— angle of attack of a leading wheelset α (see 6.1.3);

— wheel lift $\Delta z = (z - z_0)$ of the guiding wheel of the tested wheelset.

The reference value z_0 is obtained with the wheelset on a straight track; wavelengths below 2 m shall be excluded from the signal. Forces shall be measured either by:

— appropriate devices on the rail; or

— appropriate devices on the vehicle.

In the case of rail measurements the measuring positions have to fulfil the following conditions as shown in Figure 4:

— measuring positions shall be within the twisted part of the track;

— in zone 2 where the track twist first influences the whole vehicle the distance between two measuring sections shall not be greater than 1,5 m;

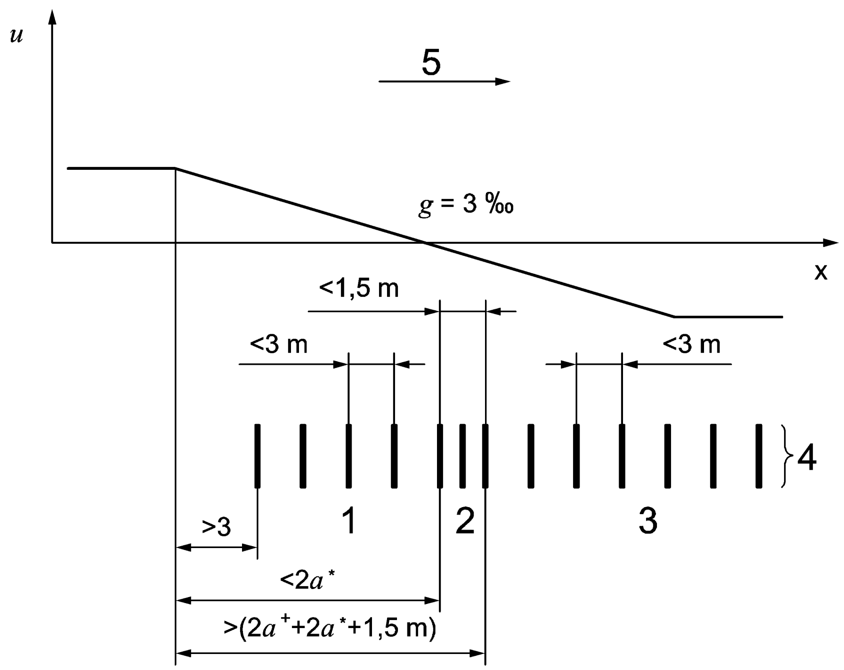
— in the other areas of the twisted track the distance between two measuring sections shall not be greater than 3 m.

NOTE For testing articulated trains, it is useful to extend zone 2 towards the end of the twisted section in order to cover also the area where the maximum wheel unloading occurs.

For each measuring section the value of $(Y/Q)_a$ of the leading wheelset shall be recorded. Wheel lift of the outer wheel of the leading wheelset Δz shall be recorded continuously.

To determine the friction conditions $(Y/Q)_i$ and α have to be evaluated as mean values of all measuring sections or of a continuous recorded signal.

If vehicle based measurement is used, the processing of measuring signals shall be done by analogy to the above conditions.



Key

1 zone 1
2 zone 2
3 zone 3
4 measuring points
5 running direction
u cant
x track coordinate

Figure 4 — Track based measuring positions to be used in method 1 in the twisted curve

6.1.5.1.6 Assessment

Assessment is made for the maximum value Δz_{max} of wheel lift of the outer wheel of the tested wheelset. The limit value is $\Delta z_{max} \leq \Delta z_{lim}$ = 5 mm, this shall be achieved on the three separate tests.

This limit value is defined for typical combinations of wheel and rail profiles such as S1002 according to EN 13715 and 49E1, 54E1 or 50E6 according to EN 13674-1. For other profiles, this limit can be adapted, if the contact point reaches the part of the flange with the angle of 70° at wheel lifts only above 5 mm.

The three successful tests are not necessarily consecutive test runs. However, if two consecutive tests fail, despite valid test conditions, the vehicle shall be rejected.

When the flange angle is above the value specified in 6.1.5.1.4, the test run shall be considered as successful if both following conditions are achieved:

— $\Delta z_{max} \leq \Delta z_{lim}$ = 5 mm;

— $(Y/Q)_{a,max} \leq (Y/Q)_{a,lim}$ = 1,2.

If wheel lift is higher than the limit, additionally $(Y/Q)_a$ on the outer rail shall be checked. If $(Y/Q)_a$ is below the value 1,12 (value corresponding a friction value of 0,4 and flange angle of 70°) the test shall be repeated.

NOTE If a wheel lift occurs at low values of $(Y/Q)_a$, this is an indication of excessive friction on the outer rail.

6.1.5.1.7 Reporting

Additionally to the general reporting according to 5.5 for each test condition that was part of the test programme the following details shall be included:

— the actual detail of the track features of the test site at the time of the test, including reference to the point identified in 6.1.5.1.3;

— shims applied as specified in 6.1.5.1.2 and 6.1.5.1.4;

— speed of passage through the test site;

— Y/Q for inner and outer rails at all measuring positions;

— maximum value of Δz.

6.1.5.1.8 Dispensation

Based on the test results of a reference vehicle (see 3.16) dispensation from testing is possible, either if:

— the influence of the changes to the vehicle compared to the reference vehicle is demonstrated and this shows that the acceptance criteria will not be exceeded;

or if:

— a calculation of guiding forces and vertical wheel forces of the reference vehicle under method 1 test conditions demonstrates credible results when compared with measurement results; and

— calculations for the reference vehicle and the assessed vehicle are made under method 2 test conditions to quantify the influence of the parameter change; and

— the calculated result of $(Y/Q)_a$ for the assessed vehicle under the conditions of method 2 testing (see 6.1.5.2) remains 10 % below the limit value (in a deflated suspension condition the 10 % margin does not apply); and

the calculated result of the assessed vehicle under the conditions of method 2 testing does not increase by more than 1/3 of the margin between the calculated result of the reference vehicle and the limit value.

6.1.5.2 Method 2: Test on twist test rig and flat test track

6.1.5.2.1 General

In method 2 the risk of flange climbing is assessed by the ratio of the horizontal guiding force Y and vertical wheel force Q. The assessment is carried out in two stages:

1) The measurement of the reduction of the vertical wheel force $Q_{a,}$ on a test rig which simulates twisted track

2) The measurement of the guiding force Y_a on an appropriate test track.

The calculation of the ratio $(Y/Q)_a$ is based on the test results.

6.1.5.2.2 Measurement of the reduction of the vertical wheel force

6.1.5.2.2.1 General

An appropriate test rig shall be used on which at least the supports of the wheelsets of one running gear may be lifted and/or lowered. With this the twist of the track on running gear wheel base as well as on running gear centre distance can be simulated.

6.1.5.2.2.2 Test conditions

The following values shall be used on the twist test rig:

— for bogie test twist:

$$g^{+}_{\lim} = 7 - \frac{5}{2a^{+}} \qquad \text{if } 2a^{+} < 4 \text{ m}$$

$$g^{+}_{\lim} = \frac{15}{2a^{+}} + 2,0 \qquad \text{if } 2a^{+} \geq 4 \text{ m}$$

with $2a^{+}$ as the bogie wheel base in m and $g^{+}_{\lim}$ in ‰.

— for vehicle body test twist:

$$g^{*}_{\lim} = 7 - \frac{5}{2a} \qquad \text{if } 2a < 4 \text{ m and}$$

$$g^{*}_{\lim} = \frac{15}{2a} + 2,0 \qquad \text{if } 4 \text{ m} \leq 2a \leq 20 \text{ m}$$

$$g^{*}_{\lim} = 3 - \frac{5}{2a} \qquad \text{if } 20 \text{ m} < 2a \leq 30 \text{ m}$$

$$g^{*}_{\lim} = \frac{85}{2a} \qquad \text{if } 2a > 30 \text{ m}$$

with $2a$ as the longitudinal dimension of the vehicle (distance between centre pivots for single bogie vehicles or wheelsets for non-bogie vehicles) in m and $g^{*}_{\lim}$ in ‰.

For bogie vehicles the twist on the bogie wheel base $2a^{+}$ and the twist on the bogie centre distance $2a$ shall be combined as shown in Figure 1. This combination can be performed during the test as described in A.9.3 or by calculation using separate test results as described in A.9.4.

6.1.5.2.2.3 Measurements

The displacements of the wheels shall be measured continuously during the twist test. Additionally the vertical wheel forces Q_{jk} of all wheels shall be measured by suitable devices.

By testing the vehicle on the test rig the following vehicle parameters are evaluated:

— $Q_{0,j}$ average vertical wheel force for each wheelset on level track (twist g = 0);

— ΔQ_{jk} deviation of vertical wheel force from Q_0 due to the combined bogie and body twist and eccentricity of centre of gravity including friction and tolerances;

— $Q_{jk,\min}$ minimum vertical wheel force due to the combined bogie and body twist and eccentricity of centre of gravity including friction and tolerances (see A.9.4.4).

A.8 and A.9 contain guidelines for testing and evaluation.

6.1.5.2.3 Measurement of the guiding force

6.1.5.2.3.1 General

The guiding forces of the outer wheels are determined in a flat, curved track.

6.1.5.2.3.2 Test conditions

Tests shall be done on a test track with the following characteristics:

— flat curve (without twist and cant);

— nominal curve radius R = 150 m;

— no transition between straight and curved track;

— nominal gauge in the range between 1 440 mm and 1 465 mm; along the test track, variations of ± 5 mm around the nominal value are accepted.

— test track shall not exceed the following tolerances for mean to peak longitudinal level: 10 mm and mean to peak alignment: 10 mm;

— sudden changes of contact geometry, gauge and curvature within the tolerances shall be avoided inside the measuring area. If sudden changes of contact geometry, gauge or curvature are included together with friction values at the upper end of the acceptable range, the test can be too severe and the test may be repeated

Direction of running and direction of curvature shall be in such a way that the wheel with the lowest vertical wheel force of the extreme wheelset is in the leading position running on the outer rail of the curve. This may include additional shims in the suspension.

Test conditions concerning the state of the rail as described in 6.1.3 (dry rail conditions) shall be fulfilled.

The influence of longitudinal forces in the train set shall be minimized. The vehicle shall not be braked. The speed shall be constant and not exceed 10 km/h.

Tests shall be done a minimum of 3 times.

6.1.5.2.3.3 Measurements

Forces may be measured by:

— appropriate devices on the rails; or

— appropriate devices on the vehicles.

The following values shall be measured:

— lateral forces on the inner and outer wheels of the tested wheelset Y_i, Y_a;

— vertical wheel force on the inner wheel of the tested wheelset Q_i;

— angle of attack of a leading wheelset α (see 6.1.3);

— if the results are used for comparison between calculation and measurement, the vertical wheel force on the outer wheel Q_a shall be measured in addition.

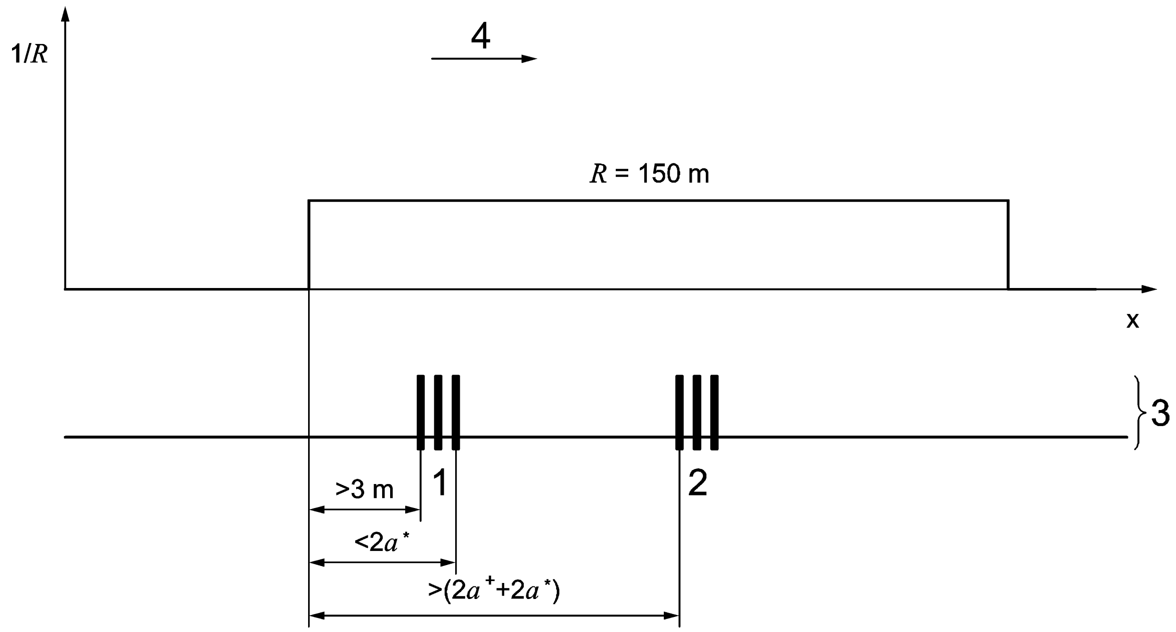
In the case of rail measurements the measuring positions shall fulfil the following conditions:

— at least 3 measuring positions shall be in zone 1 - at the beginning of the curve area between 3 m and up to $2a^*$ from the start of the curve. This ensures that the yaw between body and bogie is still taking place;

— at least 3 measuring positions shall be within zone 2 in a curve area where the angle around the vertical axis between bogie and body remains constant.

NOTE For the investigation of intermediate bogies of articulated trains it might be necessary to take into account also the guiding forces at the curve exit. In that case either the curve can be instrumented at the exit in the same manner as in zone 1 or the vehicle can be run also in the reverse direction.

Figure 5 shows an example of the measuring position in a 150 m radius curve.



Key

1	zone 1	4	running direction
2	zone 2	$1/R$	curvature
3	measuring points	x	track coordinate

Figure 5 — Track based measuring positions for determination of *Y* and *Q* in the flat curve

For each measuring position the values of Y_{ja} and Y_{ji} of the tested wheelset j shall be recorded. The mean values $Y_{ja,\text{mean}}$ and $Y_{ji,\text{mean}}$ of the measuring positions shall be evaluated separately for zone 1 and zone 2. The assessment is done with the higher of these two mean values.

For the evaluation of Y_i the direction of forces shall be noted (in most cases opposite to Y_a).

To determine the friction conditions $(Y/Q)_i$ and α shall be evaluated as mean values of all measuring positions or of a continuous recorded signal.

If vehicle based measurement is used the results shall be analysed in an equivalent way to the above conditions.

6.1.5.2.4 Assessment

Safety against derailment shall be analysed for the tested wheelsets of the vehicle. The following formula shall be evaluated for each tested wheelset:

$$\left(\frac{Y}{Q}\right)_{j,a} = \frac{Y_{j,\mathrm{a,mean}}}{Q_{jk,\min} + \Delta Q_{j,H}}$$

where

$Y_{j,\mathrm{a,mean}}$ is the higher of the mean values of the lateral guiding force evaluated for zone 1 and zone 2 by the tests described in 6.1.5.2.3.3.

$Q_{jk,\min}$ is the smallest vertical wheel force evaluated by twist test described in 6.1.5.2.2.3 (see also A.9.4.4)

$\Delta Q_{j,\mathrm{H}}$ is the change of the vertical wheel force due to the moment of the sum of lateral wheel forces: $\Delta Q_{j,H} = \left(Y_{j,\mathrm{a}} + Y_{j,\mathrm{i}}\right)\frac{h}{2b_{\mathrm{A}}}$

where

h is the effective height above rail of the primary lateral suspension

$2b_{\mathrm{A}}$ is the lateral distance of wheel/rail contact points (normally 1 500 mm)

A vehicle is considered to be safe against derailment if the condition:

$(Y/Q)_{j,\mathrm{a}} \leq 1{,}2$

is fulfilled for a flange angle of 70° (this corresponds to μ = 0,36 from A.2).

For lower flange angles β the limit value is calculated by:

$$\left(\frac{Y}{Q}\right)_{a,\lim} = \frac{\tan\beta - 0{,}36}{1 + 0{,}36 \cdot \tan\beta}$$

A.2 shows some background information for the evaluation parameter $(Y/Q)_{\mathrm{a}}$ and the limit value.

NOTE The limit value $(Y/Q)_{\lim}$ = 1,2 for a flange angle of 70° is based on statistical investigations described in ORE B55 [6]. It is identical with the Nadal's criterion for a flange angle of 70° and a wheel/rail friction coefficient of 0,36. In spite of the fact that this limit value has not been derived from the Nadal's formulae, and the friction coefficient between wheel and rail during the test should according to 6.1.3 be higher than 0,36, the Nadal's formula is accepted as a physical relationship between the flange angle, wheel/rail friction coefficient and the limit value of the safety against derailment due to wheel climbing. Hence, the Nadal's formula is used here for a recalculation of the limit value for flange angles lower than 70°. The value of wheel/rail friction coefficient of 0,36 used for this limit value recalculation, however, does not represent the real friction coefficient present during the test. Consequently, the formula above is not the limit value according to Nadal as often used in measurements and computations, but only a conversion formula to adjust the limit value identified in ORE B55 for flange angles lower than 70°.

6.1.5.2.5 Reporting

Additionally to the general reporting according to 5.5, for both test stages and each test condition that was part of the test programme the following details shall be documented:

— for each test condition performed according to 6.1.5.2.2.2 details about the applied twist;

— for each test condition performed according to 6.1.5.2.3.2 details about the curve;

— shims, if applied;

— speed of passage through the test curve;

— Y/Q for inner and if available also for outer rails in the test curve;

— for each test condition performed, the results of the measurements according to 6.1.5.2.2.3 (vertical wheel force and twist on test rig);

— for each test condition performed, the results of the measurements according to 6.1.5.2.3.3 (forces in flat curve).

6.1.5.2.6 Dispensation

Based on the test results of a reference vehicle (see 3.16) dispensation from testing is possible, either if:

— the influence of the changes to the vehicle compared to the reference vehicle is demonstrated and this shows that the acceptance criteria will not be exceeded;

or

— calculation of safety against derailment for the reference vehicle when compared with the tested values demonstrates credible results; and

— using the same calculation method, the calculated result $(Y/Q)_a$ for the assessed vehicle remains 10 % below the limit value (in a deflated suspension condition the 10 % margin does not apply); and

— the calculated result $(Y/Q)_a$ does not increase by more than 1/3 of the margin between the test result and the limit value.

6.1.5.3 Method 3: Test on twist test rig and yaw test rig

6.1.5.3.1 General

The risk of flange climbing is assessed in one or two phases.

In phase 1 two tests are carried out:

1) The measurement of the reduction of the vertical wheel force Q_a on a test rig which simulates twisted track.

2) The measurement of bogie yaw resistance generated as a vehicle negotiates the smallest radius of curvature that the vehicle is designed to go through.

Where it is not possible to demonstrate an acceptable performance using phase 1, validated computer simulations according to informative Annex B may be used. This is the second phase. Phase 2 cannot be used unless the tests of phase 1 have been done. The results of phase 1 are used to validate the work carried out in phase 2. If phase 2 also fails, either method 1 or method 2 shall be used.

Method 3 shall only be used under the following conditions:

— conventional technology vehicle as defined in 3.14 and

— vehicles with two two-axle bogies per vehicle body or articulated train with two-axle bogies, where the test location can accommodate and test a sufficient number of vehicle bodies to produce reliable results and

— flange angles of wheels between 68° and 70°.

6.1.5.3.2 Measurement of the reduction of the vertical wheel force

6.1.5.3.2.1 General

An appropriate test rig shall be used on which at least the supports of the two wheelsets of one bogie may be lifted and/or lowered. With this the twist of the track on bogie wheel base as well as on bogie centre distance can be simulated.

6.1.5.3.2.2 Test conditions

The following values shall be used on the twist test rig:

— for bogie test twist:

$$g_{\text{lim}}^{+} = 6{,}67 \qquad \text{if } 2a^{+} < 5{,}45 \text{ m and}$$

$$g_{\text{lim}}^{+} = \frac{20}{2a^{+}} + 3{,}0 \qquad \text{if } 2a^{+} \geq 5{,}45 \text{ m}$$

with $2a^{+}$ as the bogie wheel base in m and g_{lim}^{+} in ‰.

— for vehicle body test twist:

$$g_{\text{lim}}^{*} = \frac{20}{2a^{*}} + 3{,}0$$

with $2a^{*}$ as the longitudinal dimension of the vehicle (distance between centre pivots) in m and g_{lim}^{*} in ‰.

Tests shall be done as a combined body and bogie twist test as shown in Figure 1 and as described in A.9.3.

NOTE This type of test is identical with the test used in method 2 but with different twist conditions.

It is permissible to undertake the test by just lifting wheels, rather than also lowering wheels, provided that the defined twists are imposed over the bogie and body.

6.1.5.3.2.3 Measurements

The displacements of the wheels shall be measured continuously during the twist test. Additionally the vertical wheel forces Q_{jk} of the wheels experiencing the greatest percentage of unloading shall be measured by suitable devices.

6.1.5.3.3 Measurement of bogie yaw resistance

6.1.5.3.3.1 General

The test described in this clause is intended to evaluate body-to-bogie yaw torque which is generated by the passage of the vehicle through curves.

6.1.5.3.3.2 Test conditions

The tests shall be carried out on a test rig that shall be capable of determining the torque required to rotate the bogie up to at least the maximum body-bogie yaw angle. The characteristics of the test rig including its friction behaviour should be considered.

Tests shall be carried out in both directions of yaw rotation up to at least a body/bogie yaw angle of:

$$\Delta\psi^*_{\text{test}} = \frac{2a^*}{2 \cdot R_{\min}} + \frac{0,020}{2a^+}$$

NOTE 1 The formula includes a difference of the lateral displacements of the wheelsets of 20 mm due to the wheelset-track clearance in addition to the yaw angle determined by the minimum curve radius $R_{\min}$ specified for the vehicle.

The test shall be continued beyond the zero yaw angle to enable the hysteresis loop to be closed.

A mean yaw velocity of 1°/s shall be achieved over at least ± 75 % of the yaw angle amplitude.

NOTE 2 It is possible to achieve higher yaw velocities than this value. This will occur at smaller yaw angles. A combination of the maximum yaw angle and velocity is considered as unrealistic.

For vehicles with air springs tests shall be done in the inflated and deflated condition.

6.1.5.3.3.3 Measurements

Body-bogie yaw angle $\Delta\psi^*$ and yaw-moment M_z required to rotate the bogie shall be measured continuously and recorded in a diagram $M_z = f(\Delta\psi^*)$. Figure 6 shows an example of a bogie-rotation diagram.

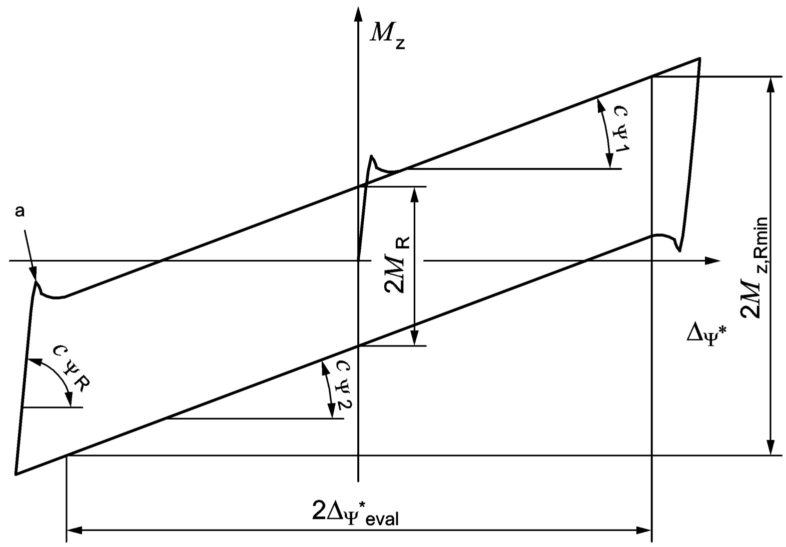


Figure 6 — Bogie-rotation diagram

M_R is the yaw hysteresis magnitude and results from friction and damping in the system.

The mean slope

$$c_\psi = \frac{c_{\psi 1} + c_{\psi 2}}{2}$$

is the yaw stiffness of the secondary suspension. If rotation is achieved by sliding of friction faces between body and bogie then c_ψ becomes zero.

The series stiffness $c_{\psi R}$ of the friction or damping element may be essential for the understanding of the dynamic behaviour of a vehicle.

The feature “a” in Figure 6 may be caused by characteristics of the test rig including inertia of turntable and bogie and is to be neglected.

6.1.5.3.4 Assessment

The results for phase 1 shall be determined. For acceptance both criteria shall be respected simultaneously.

The analysis of the suspension performance when negotiating twisted track (see 6.1.5.3.2) shall be done for the end wheelsets of the vehicle for each wheel using the wheel unloading factor $\Delta Q/Q_0$

where

Q_0 is the average vertical wheel force for the tested wheelset on level track (twist $g^0 = 0$)

ΔQ is the deviation from Q_0 at maximum twist condition

The following criterion shall be respected:

$$\frac{\Delta Q}{Q_0} \leq 0,6$$

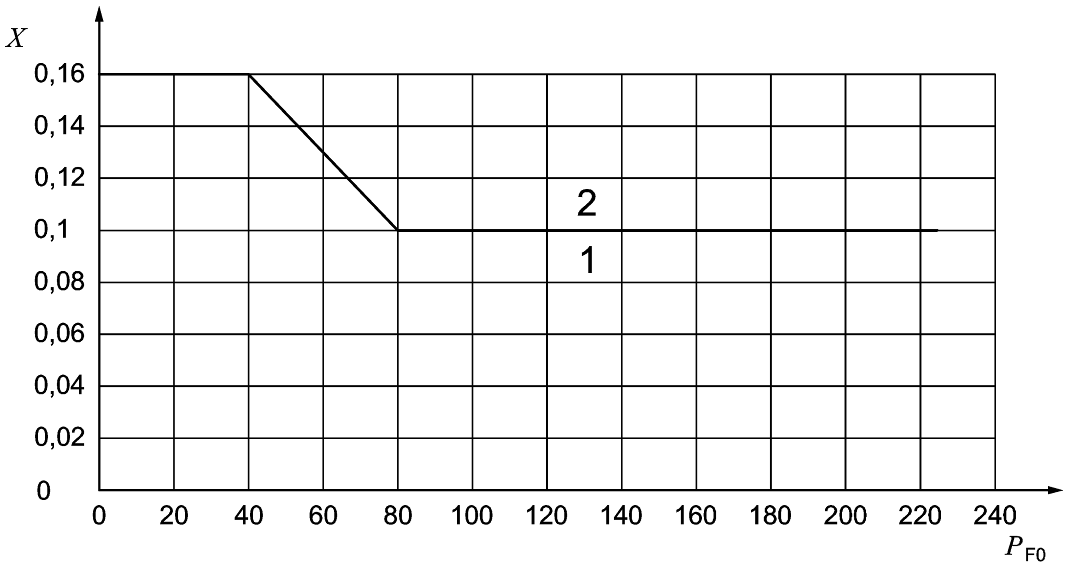
Based on the results of the measurement of bogie yaw resistance in small radius curves (see 6.1.5.3.3), the bogie *X*-factor shall be computed from the formula

$$X = \frac{M_{z,R\,min}}{2a^{+}P_{F0}}$$

where

$M_{z,Rmin}$ is the yaw moment required to rotate the bogie relative to the body (excluding gauge clearance) evaluated for

$$\Delta\psi^{*}_{eval} = a^{*} / R_{min}$$



Key

1	permissible
2	not permissible
X	'*X*' Factor
P_{F0}	nominal static vertical wheelset force in kN

Figure 7 — Maximum permissible factor *X* for freight vehicles

The following criterion shall be respected:

$X \leq 0,1$ for passenger vehicles and locomotives, for freight vehicles it shall be below the limits shown in Figure 7.

6.1.5.3.5 Reporting

Additionally to the general reporting according to 5.5 when the vehicle has successfully passed phase 1, for both tests, the following shall be reported:

— for each test condition, that was part of the test programme, details including reference to the points identified in 6.1.5.3.2 (twist test) and 6.1.5.3.3 (bogie rotation test);

— for each test condition, that was part of the test programme, results of the measurements made as detailed in 6.1.5.3.2.3 (twist test) and 6.1.5.3.3.3 (bogie rotation test).

In the event that phase 1 is not successfully passed then phase 2 is available to be used. Additionally, in this case the following shall be reported:

— the requirements detailed in B.1;

— the simulated track conditions according to B.3;

— the conditions of B.4;

— the output requirements of B.5.

6.2 Safety against derailment under longitudinal compressive forces in S-shaped curves

It is recognized that longitudinal forces within trains have the potential to increase the risk of derailment when negotiating S-shaped curves. This risk is regarded as low for conventional trains but for certain freight wagons and train operation methods the risk can be higher. In the case of at-risk freight wagons within the scope of EN 15839 the procedure defined in EN 15839 shall be used. In the case of special vehicles EN 14033-1 specifies conditions for dispensation from EN 15839. However, this risk should be considered when non-conventional configurations are developed.

6.3 Evaluation of the torsional coefficient of a vehicle body

The torsional coefficient of the vehicle body is only to be determined if it is needed for the assessment according to 6.1 or 6.2 or for purposes of model validation.

The torsional coefficient c^*_t is a basic parameter of a vehicle related to the safety against derailment under longitudinal compressive forces and influences also the safety against derailment in twisted tracks together with the suspension system. It is defined by the following formula:

$$c_t^* = M_t / \left(\frac{\vartheta}{l} \right) = (M_t / \vartheta) \cdot l \tag{1}$$

where

M_t is the torsional moment

ϑ is the angle of torsion

l is the longitudinal distance between supports

To determine the torsional coefficient value of a vehicle body, different methods of testing can be used. Methods are given in the informative Annex C.

NOTE The torsional coefficient of a bogie frame c^+_t is defined in the same way.

6.4 Determination of displacement characteristics

The determination of displacement characteristics are related to the requirements of EN 15273 and are included as informative Annex D.

6.5 Loading of the diverging branch of a switch

This standard does not specify any requirements for the assessment of vehicle behaviour in switches and crossings. Where there is a national requirement for evaluation of the vehicle behaviour in switches and crossings, informative Annex F presents a methodology and associated background to provide a consistent approach.

6.6 Running safety in curved crossings for vehicles with small wheels

This standard does not specify any requirements for the assessment of vehicle behaviour in curved crossings. Where there is a national requirement for evaluation of the behaviour of a vehicle with small wheels in curved crossings, informative Annex E presents a methodology and associated background to provide a consistent approach.

7 Second stage – dynamic performance assessment

7.1 General

All new or modified vehicles shall be checked with regard to their dynamic characteristics to evaluate the running safety, the track loading and the ride characteristics of the vehicle. An assessment may be carried out for the initial acceptance of the vehicle type or it may be for an extension of acceptance. The assessment is based on the evaluation of the performance of the vehicle while running on the track on a sample of track sections (curves with different radii and straight tracks) with defined assessment conditions. Then a statistical analysis of the assessed parameters is performed and the results are compared with limit values. If the conditions described in this sub clause are fulfilled, this gives the foundation for the type approval for the lifetime of the vehicle or the whole fleet of vehicles.

The initial assessment of the dynamic performance of a vehicle type shall generally be verified by on-track tests. The conditions for carrying out this process are given in this sub clause. In certain circumstances the tests may be supplemented by simulation (see informative Annex T) or other means, e.g. when the combination of the target test conditions cannot be achieved during the test.

An extension of acceptance for vehicles that are of the same basic design, or that have gained acceptance and subsequently undergone engineering change, is possible. This assessment shall be carried out either by means of a partial on-track test or by simulation of an on-track test or a combination of both. The procedure (test extent and measuring method) to be applied for the partial on-track test (including dispensation from test) is defined in informative Annex U. The possible application of simulation is described in informative Annex T.

For multiple units, the individual vehicles may have different parameters (e.g. forces, stiffness). In this case, selected vehicles may be used as reference vehicles. All other vehicles are regarded as vehicles with extension of acceptance due to changes of vehicle parameters. Therefore, the allowable differences in vehicle parameters, as given in U.3.2, determine the extent of measurements and tests.

For freight wagons equipped with established or standardized running gear as described in EN 16235, a dispensation from Clause 7 requirements (on-track testing) is granted if the requirements described in EN 16235 are fulfilled.

When planning on-track tests, the admissible speed V_{adm} and the admissible cant deficiency I_{adm} for the vehicle have to be selected. The chosen values determine the future use of the vehicle.

It may be necessary to test a vehicle for more than one combination of V_{adm} and I_{adm} as shown in informative Annex H.

For convenience standardized values for I_{adm} should be used for acceptance as given in informative Annex H.

NOTE 1 Using values equal to or higher than the maximum limiting values stated in EN 13803–1 will give the least restrictions for future operation. For national operation, other values of operational parameters may be a better choice. In many European countries operation within the standard timetables requires a minimum performance of the vehicles (see informative Annex H).

It is not necessary for acceptance to distinguish between admissible cant deficiencies which differ by no more than 2 %. This is the difference e.g. resulting from inaccuracy converting cant deficiency to uncompensated lateral acceleration using $g = 10\ m/s^2$ instead of $g = 9,806\ m/s^2$.

In case of a deactivation of a tilting system, the cant deficiency is to be reduced, e.g. to the maximum allowed values for conventional vehicles. In consequence the vehicle shall also be tested under these operational conditions.

NOTE 2 It is recognized that locomotives or power heads, which are operated with cant deficiencies higher than used for conventional trains without a tilting system (e.g. SJ-X2000) exist.

NOTE 3 Reasons for limiting operating conditions could be restricted capabilities of vehicle design or restricted availability of suitable test tracks.

As the target test conditions of equivalent conicities for stability testing are depending on the speed, it may also be necessary to test vehicles with high admissible speeds for more than one combination of speed and equivalent conicity.

Test procedures are based on the classification of the test vehicle into:

— locomotives, multiple units (EMU, DMU) and passenger coaches;

— freight wagons;

— special vehicles.

In 3.15 special vehicles are defined as such according to their use. However, their testing requirements are based on their design characteristics. Informative Annex S describes basic principles to be applied to special vehicles, before considering general test requirements of the present Clause 7.

Vehicles with maximum admissible speed $V_{adm} \leq 60$ km/h are granted dispensation from dynamic performance assessment.

7.2 Choice of measuring method

7.2.1 General

On-track tests can use the two different measuring methods:

— normal measuring method;

— simplified measuring method.

Figure 8 gives an overview of the assessment quantities used in both measuring methods.

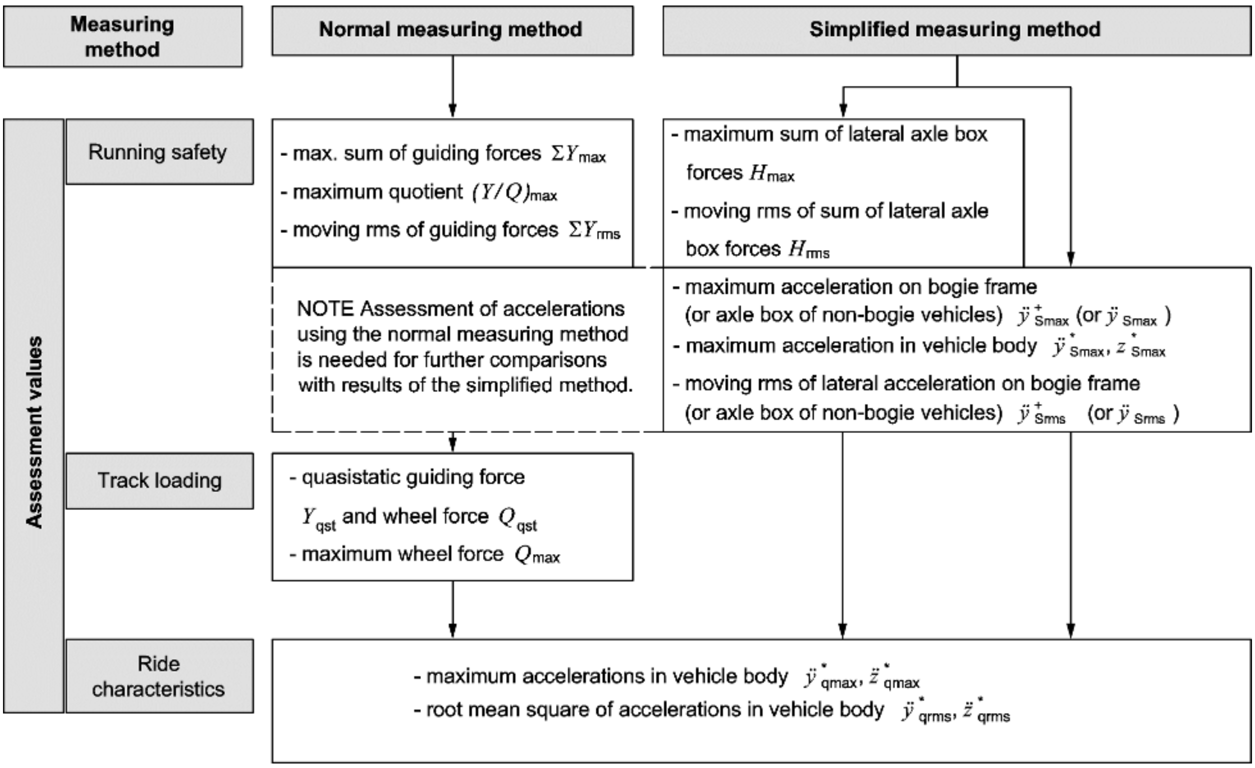


Figure 8 — Measuring methods and assessment quantities

On-track test with normal measuring method includes the assessment of:

— running safety;

— track loading;

— ride characteristics of the vehicle;

with direct measured forces between wheel and rail and accelerations in the running gear and in the vehicle body.

On-track test with simplified measuring method includes the assessment of:

— running safety;

— ride characteristics of the vehicle;

with measured accelerations at the bogie frame and accelerations in the vehicle body. In some cases lateral forces between wheelset and axle box are also measured. If the simplified method is applicable, it is assumed that the vehicle will comply with track loading limit values, without needing a direct assessment of the associated quantities.

For initial acceptance the simplified measuring method is only applicable if the base conditions in 7.2.2 are fulfilled.

For an extension of an acceptance state additional conditions for the use of the simplified measuring method are given in informative Annex U including the indication of required axle box force measurement. They are dependent upon the test methods of the initial and the new acceptance as well as on the results achieved during the initial acceptance and the modifications of relevant parameters.

7.2.2 Base conditions for the use of the simplified measuring method and measurement of axle box forces

In general the simplified measuring method may be applied to conventional technology vehicles, if all of the conditions in Table 1 are fulfilled:

Table 1 — Base conditions for the use of a simplified measuring method

Running gear type one of the following:	
— single wheelsets; — bogie with two wheelsets $2a^{+} \leq 3{,}3$ m; — bogie with three or more wheelsets with spacing between outer wheelsets ≤ 4,5 m with additional measurement of lateral axle box forces H.	
Vehicle configuration one of the following:	
Single vehicles — with two single wheelsets; — with two bogies.	
Articulated vehicles consisting of two or more vehicle bodies, with the following possible arrangements of running gears per vehicle body — up to two single wheelsets; — up to two bogies.	
Nominal static vertical wheelset force P_{F0} (for all vehicles)	≤ 200 kN [a]
Maximum admissible speed of the vehicle V_{adm}	
vehicles with single wheelsets	≤ 100 km/h
freight wagons with bogies	≤ 120 km/h

other vehicles with bogie mass $m^{+} > 10$ t	≤ 120 km/h
other vehicles with bogie mass $m^{+} > 10$ t and additional measurement of lateral axle box forces H	≤ 160 km/h
other vehicles with Bogie Mass $m^{+} \leq 10$ t and $(P_{F0} \cdot V_{\mathrm{adm}}) \leq 34\,000$ [kN km/h] [a]	≤ 200 km/h
Admissible cant deficiency I_{adm}	
freight wagons	≤ 130 mm
multiple units with nominal static vertical wheelset forces $P_{F0} \leq 170$ kN [a] and $V_{\mathrm{adm}} \leq 160$ km/h	≤ 165 mm
other vehicles	≤ 150 mm
[a] P_{F0} is the nominal static vertical wheelset force of the highest loaded wheelset of the vehicle in the assessed load configuration (see 5.3.2).	

7.2.3 Simplifications for separate stability testing

If stability testing is performed separately, the application of the simplified measuring method is sufficient as the method is consistent with the normal measuring method.

NOTE This permits the required high conicity condition to be achieved also by modification of the wheel profile on a running gear without instrumented wheelsets and to keep normal profiles on the instrumented wheelsets. For testing stability the instrumentation of running gear (or in the case of a vehicle with single axle running gear, with instrumentation on the vehicle body) is sufficient.

If a vehicle is equipped with an instability monitoring system based on established standards, results collected by this system may be used to demonstrate running stability.

7.3 Performing on-track tests

7.3.1 General

The running conditions during tests (and also for numerical simulations) shall include defined combinations of:

— speed;

— cant deficiency;

— curve radius.

Therefore, the assessment is carried out on different test zones. In each test zone, the test conditions for track and operation differ with regard to the ranges of test parameters to be examined. To allow a statistical evaluation of test results, the test lines are divided into track sections. The measured results from the track sections in which the required test parameters were fulfilled are allocated to the corresponding test zone. If multiple regression is used (see normative Annex R) all track sections in curves form together the basis for the statistical evaluation calculated at different target values specified for the different test zones.

Table 2 defines the test zones and the associated ranges of values for track layout. In the first part it also gives the objective of the testing and anticipated vehicle dynamic behaviour. In a second section the target test conditions for track layout, track quality, wheel/rail contact and operation (speed and cant deficiency) are defined. These target test conditions shall be complied with as far as possible in on-track testing of running characteristics. A third section specifies the requirements for the track sections.

NOTE As it was found in the DYNOTRAIN project, that the nominal rail inclination has no influence on test results, testing on two networks is no longer necessary, if profiles representative for the service of the vehicle are used during testing. In that case the range of contact conditions varies sufficiently for the statistical evaluation due to variations of gauge and rail shape on test lines.

As the effects of aerodynamic forces are outside the scope of this document they shall not have a significant influence on the tests. This should be assumed unless there are reasonable grounds to believe otherwise.

Table 2 — Target conditions for test zones and track sections

		Test zone				
		Stability	**1**	**2**	**3**	**4**
	Description	**Tangent track and very large radius curves** [a]		**Large radius curves**	**Small radius curves**	**Very small radius curves**
Test objectives	Objective	Testing the vehicles running stability	Testing in the area of the vehicles admissible speeds	Testing the combinations of the vehicles admissible speeds and cant deficiencies	Testing in the area of the vehicles admissible cant deficiency Including track sections with contact geometry that creates adverse steering conditions for a wheelset in test zone 4	
	Anticipated vehicle dynamic behaviour	Highest probability of unstable running behaviour	There are no or only low quasi-static guiding forces or accelerations, but larger dynamic content in all assessment quantities	Superposition of quasi-static and dynamic contents of all assessment quantities	Larger quasi-static guiding forces, vertical wheel forces and accelerations, dynamic content generally decreases	
Target test conditions	Curve radius	—			400 m ≤ R ≤ 600 m [f]	250 m ≤ R < 400 m [f]
	Mean value of curve radius of all track sections R_m	—			500 m (±50 m) [b, c, f]	300 m (+50 m – 20 m) [b, c, f]
	Test speed V [d]	$V_{adm} \le 100$ km/h: $V = V_{adm}$ +10 km/h 100 km/h < $V_{adm} \le 300$ km/h: $V = 1{,}1 \cdot V_{adm}$ [g, f] $V_{adm} > 300$ km/h: $V = V_{adm}$ + 30 km/h		$V_{adm} \le V \le 1{,}1 \cdot V_{adm}$ [g, f]	$V \le 1{,}1 \cdot V_{adm}$	
	Tolerance of evaluation range [d, e]	±5 km/h		±5 km/h	+5 km/h	
	Test cant deficiency I (evaluation range) [d]	$I \le 40$ mm [f]		0,70 [h] $\cdot I_{adm} \le I \le 1{,}15 \cdot I_{adm}$ [f]		

Target test conditions	Distribution of test speed	For multiple regression only: At least 3 sections with $V_{adm} \leq 100$ km/h: $V \geq V_{adm} + 5$ km/h 100 km/h < $V_{adm} \leq 300$ km/h: $V \geq 1,1 \cdot V_{adm} - 5$ km/h $V_{adm} > 300$ km/h: $V = V_{adm} + 25$ km/h		—	—
	Distribution of test cant deficiency	—		— one dimensional evaluation: at least 20 % of track sections $1,05 \cdot I_{adm} \leq I \leq 1,15 \cdot I_{adm}$ — two dimensional evaluation: at least 3 track sections $1,05 \cdot I_{adm} \leq I \leq 1,15 \cdot I_{adm}$ — multiple regression: at least 3 track sections with each of the following conditions: — $I \geq I_{adm}$ and $R \leq 350$ m — $I \geq I_{adm}$ and $R \geq 500$ m — $I \geq I_{adm}$ and $V \geq V_{adm}$	
	Geometric track quality target level according to informative Annex M	—	90 % value of distribution for longitudinal level and alignment above lower limit of target test range *TL90* in speed range of V_{adm}, see M.4 with Table M.3 [i,j] Possibly exclude exceptional track sections with single defects > *QN3*, see Table M.4	90 % value of distribution for longitudinal level and alignment above lower limit of target test range *TL90* in speed range of V_{adm}, see M.4 with Table M.3 [j] Possibly exclude exceptional track sections with single defects > *QN3*, see Table M.4	90 % value of distribution for longitudinal level and alignment above lower limit of target test range *TL90* in speed range 80 < $V \leq 120$ km/h, see M.4 with Table M.3 [j] Possibly exclude exceptional track sections with single defects > *QN3*, see Table M.4

Target test conditions	Requirements for wheel rail contact geometry [k], see also normative Annex O, normative Annex P, informative Annex Q and EN 15302	for at least 3 times 100 m track lengths (not overlapping): [l] — for $V \leq 120$ km/h: $\tan \gamma_e \geq 0{,}40$ — for 120 km/h $< V \leq 300$ km/h: $\tan \gamma_e \geq 0{,}534 - V/900$) (rounded to two decimal digits) — for $V > 300$ km/h: $\tan \gamma_e \geq 0{,}20$ Possibly exclude track sections with exceptional values of conicity outside the expected range of operation	— the majority of conditions shall be representative of normal service — avoid a narrow range of contact geometry conditions (equivalent conicities) — possibly exclude track sections with exceptional values of conicity outside the expected range of operation — some sections with $\tan \gamma_e < 0{,}05$ and $(TG\text{-}SR) \geq 7$ mm [r] shall be included in the statistical assessment to cover low frequency body motions [n]	—	—	avoid a narrow range of contact geometry conditions (radial steering index) [m]
	Wheel rail friction conditions [o]	Dry rails	Dry rails in at least 80 % of the track sections			
	Length of track section L_{ts} [p]	—	$V_{adm} \leq 160$ km/h: 100 m 160 km/h $< V_{adm} \leq 220$ km/h: 250 m $V_{adm} > 220$ km/h: 500 m		100 m	70 m
Track sections	Minimal number of track sections $n_{ts,min}$ [q]	—	25 for each test zone For multiple regression: a total of 100 in test zone 1 and a total of 200 in test zones 2 to 4			
	Minimal total length of track sections $\Sigma L_{ts,min}$	—	10 km	5 km	—	—
	Maximum speed variation within each track section	10 km/h	10 km/h	10 km/h	5 km/h	5 km/h

[a] Some track section with curves of very large radius should be included in test zone 1.

[b] Test zone 4 shall include track sections with a curve radius below 300 m and track sections with a curve radius above 350 m.

[c] For national and multinational restricted operation the range of conditions for the test zones may be varied. In this case associated quantities (e.g. R_{m}) shall be adapted.

[d] In failure mode (see 5.2.2) it is sufficient to investigate the vehicle only up to the admissible values of speed and cant deficiency. The ranges for evaluation shall be adapted accordingly.

[e] The intention of the tolerance is not to change the target test speed but to allow for a natural variation around the target test speed.

[f] For multiple regression all results of curved track (R > 250 m) shall form the basis for the evaluation of the estimated values in test zone 2, 3 and 4. Target values for the evaluation are for test zone 4: (R = 350 m, $I = 1{,}1 \cdot I_{\mathrm{adm}}$), for zone 3: ($R$ = 550 m, $I = 1{,}1 \cdot I_{\mathrm{adm}}$), for test zone 2: ($V = V_{\mathrm{adm}}$, $I = 1{,}1 \cdot I_{\mathrm{adm}}$) and for test zone 1: $V = V_{\mathrm{adm}}$, $I = 0$. The requirement for mean curve radii in test zones 3 and 4 is replaced by these target values.

[g] For multiple regression in test zone 1 and 2 test results with lower speeds down to max (60, $V_{\mathrm{adm}}/2$) can also be included.

[h] For multiple regression, test results with lower cant deficiencies (all sections with I > 40 mm) shall also be included, for two dimensional evaluation including lower cant deficiencies can improve the reliability of the analysis.

[i] In test zone 1 compliance with *TL90* is not mandatory (see M.4).

[j] For multiple regression the target values *TL50* shall be used and the target ranges *TL90* are not relevant (see M.4).

[k] For independently rotating wheels there are no requirements for wheel rail contact geometry.

[l] If lower in-service values of equivalent conicity are ensured by the characteristics of the network and the maintenance regime of the wheelsets, stability testing may be performed for these lower maximum equivalent conicities. This shall be documented.

[m] If the vehicle allows testing with the simplified measuring method with accelerations only, no requirements for contact geometry apply.

[n] If higher in-service values are ensured by the characteristics of the network and the maintenance regime of the wheelsets, the requirement for the minimum equivalent conicity can be adapted. This shall be documented.

[o] The coefficient of friction between flange and gauge corner does not influence the measured wheel rail forces. However, flange lubrication equipment may spread lubrication substance to the running surface, if not adjusted correctly, and that may reduce the lateral wheel rail forces. Therefore tests shall be conducted with deactivated on-board lubrication systems on all vehicles in the test train.

[p] Tolerance for the length of the individual track section: ± 20 %. The minus tolerance shall only be used if it permits additional track length to be included in the analysis.

[q] $n_{\mathrm{ts,min}}$ is the minimum required number of unique sections in the evaluation range of speed and cant deficiency.

[r] In the WG10 it is under discussion to increase this value to an achievable extent.

7.3.2 Test zones and track sections

Each track section used for the statistical evaluation shall have a certain length L_{ts} depending on the speed and/or the curve radius. Speed and cant deficiency shall remain approximately constant over the entire length of a track section. Therefore, track sections with speed deviations outside the range given in Table 2 shall be excluded from the evaluation.

It is permitted to use the same track section in zones 2 and 3 (or 4) when it meets the requirements for both, speed and cant deficiency for zone 2 and radius and cant deficiency for zone 3 (or 4).

NOTE In some cases (low maximum speed) zone 2 may cover the range of radii of zone 3. Experience shows that when V_{adm} is 100 km/h to 120 km/h test zones 2 and 3 often more or less coincide. In these cases evaluation on zone 3 is not necessary.

Track sections can be sequential or not, however, they may not overlap and have to fulfil the geometric requirements. The combination of non-consecutive parts to form one track section is not permitted.

To allow an assessment of test results in transition curves, separate track sections shall be defined which include the transition curve itself plus a suitable part of the surrounding track to take transient effects into account. Due to the changing test parameters in these track sections, a statistical evaluation is not performed.

The track sections are determined using the following process:

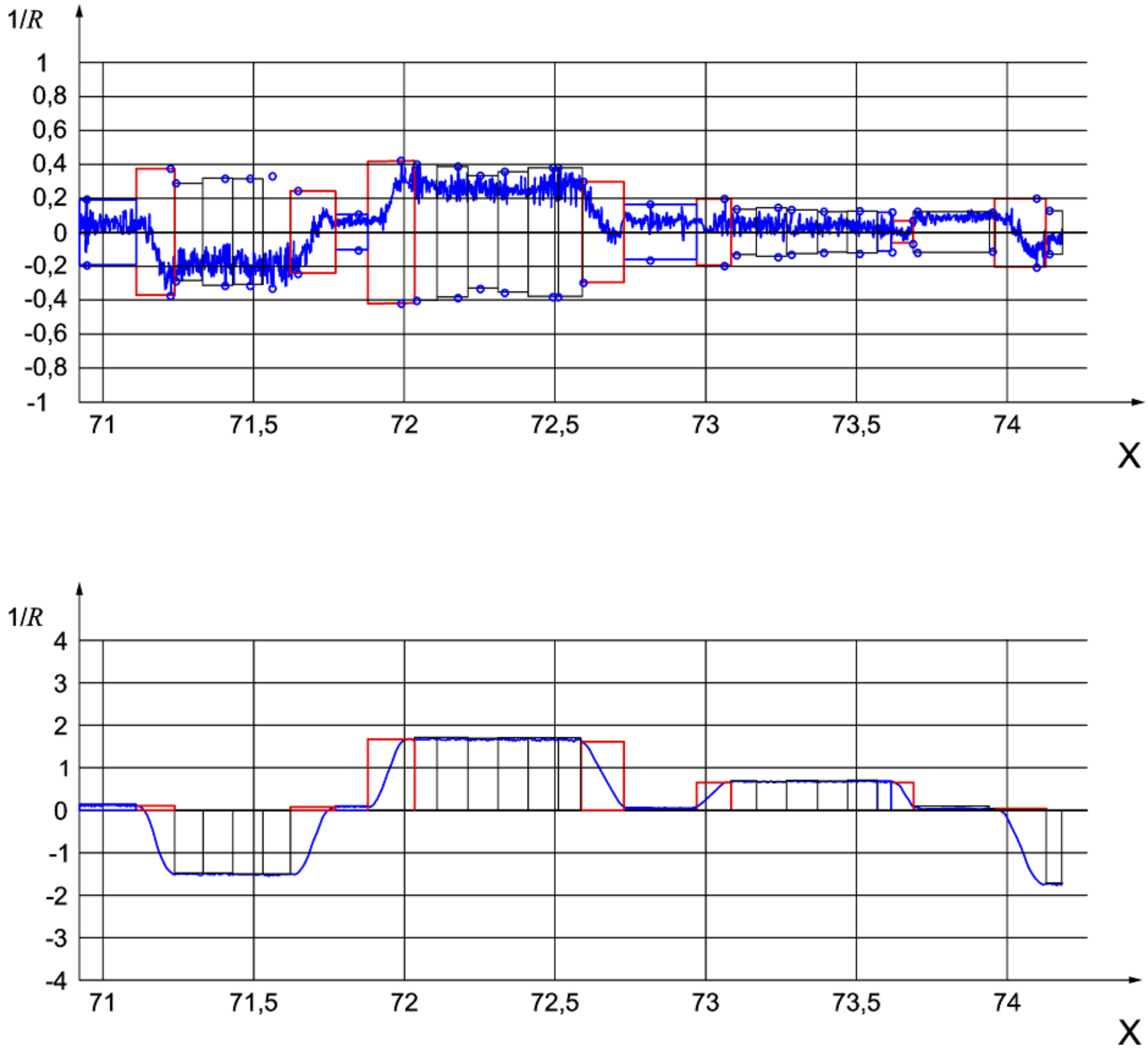
— select potential straight track sections and curved track sections to be used for statistical evaluation;

— select transition sections only adjacent to curves that contain curved track sections used for evaluation in test zones 2, 3 and 4;

— taking into account the vehicle length, a track length of up to 20 m on either side of the constant curvature may be included in the transition (to address transient effects);

— there should be no gap between the first section in the full curve and the preceding transition.

Figure 9 shows a typical arrangement of track sections on a test line.



Key

1/*R*	curvature of test track with track sections [1/m]
X	line kilometre

Figure 9 — Arrangement of track sections on a line

7.3.3 Extent of tests

For complete on-track tests (e.g. for initial acceptance) the combinations of the following test conditions:

— test zones;

— loading condition (see 5.3.2):

  — empty;

  — loaded;

shall be reviewed, the critical combinations shall be identified and included in the test programme.

EXAMPLE Usually stability testing needs only to be performed in the empty condition.

Using the same approach as for fault modes (5.2.2) it shall also be determined whether the partially occupied or partially loaded vehicle with unsymmetrical load distribution is the most unfavourable condition. This applies especially to freight vehicles with two stage suspension. If a partial load condition is found to be unfavourable, this condition shall be included in the assessment.

Vehicles that are tested on high-speed lines with $V_{adm} \geq 250$ km/h shall be tested additionally on lines with maximum line speed in the range from 160 km/h to 230 km/h. If one-dimensional analysis or simple regression is applied, these tests shall be separately analysed according to the requirements of test zone 1 and test zone 2 with a V_{adm} according to the maximum line speed. If multiple regression is applied, these test results shall be included in the analysis and an additional target value V_{adm} and track geometry level *TL50* according to the maximum line speed (see M.4) shall be applied.

NOTE The aim of this additional test is to include also track sections with a lower track quality typical of conventional lines.

The on-track tests shall be completed by tests in fault modes where appropriate (see 5.2.2). The extent of these tests shall be defined after an analysis of the critical conditions.

Vehicles intended to be operated outside the normal operating conditions (e.g. with higher speeds or cant deficiencies) or which are equipped with active systems that modify the vehicle response significantly shall be subjected to an analysis to determine whether additional testing is necessary, e.g. specific tests in transition curves between reverse curves or transition curve between two full curves in the same direction.

7.3.4 Test operation

The speed *V* and the cant deficiency *I* shall be defined for the test runs by taking account of:

— the intended operation envelope of the vehicle, see informative Annex H;

— the permissible local speeds of the test tracks or the speeds approved for test operation;

— the requirements for the test zone.

NOTE 1 Especially for high speed trains it is often not possible or necessary to include the combination of maximum speed and maximum cant deficiency in the test programme. This will define the proven operation envelope.

In principle, the test vehicle should be positioned in the test train in its usual position. If the coupler system is expected to introduce significant external forces on the test vehicle, then loose couplers should be considered.

The magnitude of tractive and braking effort applied may influence the track forces. The significance of this effect shall be considered in the assessment and the test conditions.

NOTE 2 The normal test conditions with constant or maximum speed do not require high tractive or braking effort. Only when operating on tracks with a high gradient significant forces may influence the results depending on the tractive characteristic.

7.4 Measured quantities and measuring points

Table 3 shows all measured parameters and measuring points used for on-track tests. They are defined in the vehicle coordinate system according to Figure G.1.

The choice of bogies to be instrumented shall cover the variety of running gear and its application, considering their influence on the dynamic performance of the vehicle, such as:

— type (powered, non-powered, various designs, etc.);

— location (end or intermediate, leading or trailing, etc.);

— nominal static vertical wheelset force.

Forces at wheel/rail contact or axle box forces shall be measured on each wheelset of instrumented bogies or each wheelset of a non-bogie vehicle. However, the number of measuring wheelsets to be used can be reduced when the vehicle or trainset is symmetrical and the tests are performed in both running directions. Figure I.1 provides examples of possible configurations.

Deviations from relevant parameters of the vehicle due to instrumentation shall be assessed (e.g. unsuspended mass of instrumented wheelset).

Table 3 — Measured quantities and measuring points

Reference point of measurement [a]	Direction	Symbol	Unit	Purpose of measurement
Forces between wheel and rail				
Guiding force Y				
Wheelset j, right wheel	lateral	Y_{j1}	kN	Normal measuring method: Running safety Track loading
Wheelset j, left wheel	lateral	Y_{j2}	kN	
Vertical wheel force Q				
Wheelset j, right wheel	vertical	Q_{j1}	kN	Normal measuring method: Running safety Track loading
Wheelset j, left wheel	vertical	Q_{j2}	kN	
Forces at bogie				
Lateral axle box force H				
Wheelset j, right suspension [b]	lateral	H_{j1}	kN	Simplified measuring method (where required): Running safety
Wheelset j, left suspension [b]	lateral	H_{j2}	kN	
Accelerations				
Accelerations of wheelset $\ddot{y}$				
Axle box wheel 11 (or 12)	lateral	$\ddot{y}_{11}$	m/s²	Simplified measuring method [c] (only single axle running gear): Running safety (including stability)
Axle box wheel 21 (or 22)	lateral	$\ddot{y}_{21}$	m/s²	
Accelerations of bogie frame above the outer wheelsets $\ddot{y}^+$				
Bogie frame, above wheel 11 (or 12)	lateral	$\ddot{y}^+_{11}$	m/s²	Simplified measuring method [c] (only bogie vehicles): Running safety (including stability)
Bogie frame, above wheel 21 (or 22)	lateral	$\ddot{y}^+_{21}$	m/s²	

Reference point of measurement [a]	Direction	Symbol	Unit	Purpose of measurement
Accelerations on the floor of vehicle body $\ddot{y}^*$, $\ddot{z}^*$				
Vehicle body, above running gear I	lateral	$\ddot{y}^*_{\mathrm{I}}$	m/s²	Simplified measuring method without *H*-force measurement [c]: Running safety All measuring methods: Ride characteristics
Vehicle body, above running gear II	lateral	$\ddot{y}^*_{\mathrm{II}}$	m/s²	
Vehicle body, above running gear I	vertical	$\ddot{z}^*_{\mathrm{I}}$	m/s²	Simplified measuring method [c]: Running safety All measuring methods: Ride characteristics
Vehicle body, above running gear II	vertical	$\ddot{z}^*_{\mathrm{II}}$	m/s²	
Centre of vehicle body (only recommended)	lateral	$\ddot{y}^*_{\mathrm{M}}$	m/s²	All measuring methods: Ride characteristics (Recommended only for long vehicles and double deck vehicles where major acceleration levels could be observed.)
	vertical	$\ddot{z}^*_{\mathrm{M}}$	m/s²	
Influencing quantities				
Speed	—	*V*	km/h	
Cant deficiency	—	*I*	mm	

[a] The measured quantities and measuring points described in this table are related to vehicles with two running gear. On vehicles with differing wheelset arrangements the measuring points shall be adapted accordingly.

[b] Lateral axle box forces may be recorded also as sum per wheelset, H_1 and H_2.

[c] It can be useful to measure these quantities when carrying out the normal measuring method to enable comparison with other wheelsets and for extension of acceptance.

7.5 Assessment quantities and limit values

7.5.1 General

Assessment quantities for running behaviour are measured directly, derived from other measurements or generated by the use of simulation. They are used to assess the interaction between vehicle and track and mainly describe the wheel/rail system or are closely related to it. Table 4 summarizes all assessment quantities generally used together with their limit values. It shall be investigated whether the estimated values from the statistical evaluation in the test zones 1 to 4 respect these limit values.

The reported measuring results from the transition curves shall be compared with the limit values. Any values exceeding the limit shall be investigated and where appropriate justified, e.g. taking into account track geometry.

NOTE 1 The given limit values reflect international operation and are derived from UIC. For national or multinational operation these limits may be varied. Differing limit values may be possible or necessary because of track conditions differing from those used by UIC as the basis. Examples are systems with slab track, systems with stronger rails or special conditions on mountain lines. Also track geometric quality different from those defined in normative Annex M can necessitate differing limit values.

Table 4 — Summary of assessment quantities and limit values

Assessment quantity L = to be compared with limit value; D = to be documented, but not to be compared with the limit value		**Test method**			**Limit values**		
		Normal	Simplified *H*-Force	Simplified acceleration	**Locomotives, Traction units, passenger vehicles**	**Freight wagons with bogies**	**Freight wagons with single axles**
Running safety							
Sum of guiding forces of left and right wheel	$\Sigma Y_{j,\max}$ $(Y_{j1} + Y_{j2})$	L	—	—	k_1 (10 kN + P_{F0}/3) k_1 = 1,0	k_1 (10 kN + P_{F0}/3) k_1 = 0,85	
Derailment coefficient	$(Y/Q)_{j,a,\max}$	L	—	—	0,80 [a]		
Lateral axle box force	$H_{j,\max}$	—	L	—	k_2 (10 kN + P_{F0}/3) k_2 = 0,90	k_2 (10 kN + P_{F0}/3) empty: k_2 = 0,75; loaded: k_2 = 0,80	
Lateral acceleration on bogie frame above axle box	$\ddot{y}^{+}_{j,\max}$ (only bogie vehicles)	(D) [b]	(D) [b]	L	12 m/s² – (m^+ / 5 t) · m/s²		—
Lateral acceleration on vehicle body above running gear	$\ddot{y}^{*}_{m,S,\max}$	D	D	L	Test zone 1, 2: 3,0 m/s² [c] Test zone 3: 2,8 m/s² [c] Test zone 4: 2,6 m/s² [c]	3,0 m/s² [c]	P_{F0} ≤ 60 kN: 4,0 m/s² [c] 60 kN < P_{F0} < 200 kN: 4,43 m/s² – (P_{F0} /140 kN) · m/s² [c] P_{F0} ≥ 200 kN: 3,0 m/s² [c]
Vertical acceleration on vehicle body above running gear	$\ddot{z}^{*}_{m,S,\max}$	D	L	L	3,0 m/s² single suspension or deflated air spring: 5,0 m/s²	5,0 m/s² [d]	

Assessment quantity L = to be compared with limit value; D = to be documented, but not to be compared with the limit value		Test method			Limit values		
		Normal	Simplified H-Force	Simplified acceleration	**Locomotives, Traction units, passenger vehicles**	**Freight wagons with bogies**	**Freight wagons with single axles**
Running safety – Stability							
	$\Sigma Y_{j,\mathrm{rms}}$	L	—	—	k_1 (10 kN + P_{F0}/3) / 2 (=$\Sigma Y_{j,\mathrm{max,lim}}$ / 2)		
	$H_{j,\mathrm{rms}}$	—	L	—	k_2 (10 kN + P_{F0}/3) / 2 (=$H_{j,\mathrm{max,lim}}$ / 2)		
	$\ddot{y}^{+}_{j,\mathrm{rms}}$ (only bogie vehicles)	(D) [b]	(D) [b]	L	[12 m/s² – (m^+ / 5 t) · m/s²] / 2 (= $\ddot{y}^{+}_{j,\mathrm{max,lim}}$ /2)		—
	$\ddot{y}_{j,\mathrm{rms}}$ (only single axle vehicles)	(D) [b]	(D) [b]	L	—	—	5,0 m/s² (preliminary value)
Running safety – Overturning criterion							
Overturning parameters	κ (For test conditions with I_{adm}>165mm)	L	—	—	1,0	—	

Assessment quantity L = to be compared with limit value; D = to be documented, but not to be compared with the limit value		**Test method**			**Limit values**		
		Normal	Simplified H-Force	Simplified acceleration	**Locomotives, Traction units, passenger vehicles**	**Freight wagons with bogies**	**Freight wagons with single axles**
Track loading							
Quasi-static guiding force	$Y_{j,\mathrm{a,qst}}$	(L) [e]	—	—	60 kN		
Quasi-static vertical wheel force	$Q_{j,\mathrm{a,qst}}$	L	—	—	$P_{F0} \leq 225$ kN: 145 kN 225 kN < $P_{F0} \leq 250$ kN: 155 kN		
Max. vertical wheel force	$Q_{j,\mathrm{a,max}}$	L	—	—	Test zones 1 and 2: $V_{\mathrm{adm}} \leq 160$ km/h: MIN(90 kN + Q_0; 200 kN) 160 km/h < $V_{\mathrm{adm}} \leq 200$ km/h: MIN(90 kN + Q_0; 190 kN) 200 km/h < $V_{\mathrm{adm}} \leq 250$ km/h: MIN(90 kN + Q_0; 180 kN) 250 km/h < $V_{\mathrm{adm}} \leq 300$ km/h: MIN(90 kN + Q_0; 170 kN) $V_{\mathrm{adm}} > 300$ km/h: MIN(90 kN + Q_0; 160 kN) Test zones 3 and 4: MIN(90 kN + Q_0; 200 kN) For all test zones with $V_{\mathrm{adm}} \leq 100$ km/h and 225 kN < $P_{F0} \leq 250$ kN: MIN(90 kN + Q_0 ;210 kN)		
Quasi-static rail load parameter [f] $\lvert Y_{\mathrm{a,qst}} \rvert$ + 0,83 $Q_{\mathrm{a,qst}}$	$B_{j,\mathrm{a,qst}}$	D	—	—	—		
Max guiding force [f]	$Y_{j,\mathrm{a,max}}$	D	—	—	—		
Max rail load parameter [f] $(\lvert Y \rvert + 0{,}91 \cdot Q)_{\mathrm{max}}$	$B_{j,\mathrm{a,max}}$	D	—	—	—		
Rail surface damage quantity (see J.3)	T_{qst}	(D) [g]	—	—	—		

Assessment quantity L = to be compared with limit value; D = to be documented, but not to be compared with the limit value		**Test method**			**Limit values**		
		Normal	Simplified *H*-Force	Simplified acceleration	**Locomotives, Traction units, passenger vehicles**	**Freight wagons with bogies**	**Freight wagons with single axles**
Ride characteristics							
Maximum accelerations in the vehicle body $\ddot{y}^*_{q,max}$ and $\ddot{z}^*_{q,max}$ are used for assessing the non mandatory ride characteristics of the vehicle; see informative Annex L for detailed information.							
Description of test conditions							
"Friction", ratio leading wheelset in zone 4	$(Y/Q)_i$	D	—	—	—		

$_j$ = wheelset number

$_m$ = running gear number

$_a$ = wheel on the outer rail of a curve

$_i$ = wheel on the inner rail of a curve

L = to be compared with limit value

D = to be documented, but not to be compared with the limit value

[a] In transition curves it is recognized that higher values than 0,8 may be encountered. The maximum limit value of 1,2 shall be respected, where 0,8 is exceeded. Each case shall be investigated and justified.

[b] Only to be documented if running gear is equipped with acceleration sensors. For a better understanding of the vehicle behaviour this instrumentation is recommended.

[c] In some cases for partial on-track tests with the simplified measuring method a modified limit value shall be calculated. Details are given in informative Annex U.

[d] This limit value is known to be a problem for empty freight vehicles in test zones 1 and 2. Deviations from this limit value have to be justified.

[e] For the application of this limit value see also 7.6.3.2.6

[f] Background information is given in informative Annex J.

[g] Only to be documented if T_x forces are measured.

NOTE 2 The limit $\Sigma Y_{max,lim}$ has been derived from the maximum guiding force values of a wheelset which a track is able to withstand without any permanent lateral displacement for the following conditions:

— ballasted track;

— track with timber sleepers, with a distance between sleepers of 0,65 m;

— rails with a weight of 46 kg per metre;

— track bed has been recently tamped.

The factors k_1 and k_2 scale the limit value for the conditions shown in the table above. To take account of greater variations in geometrical dimensions and of the state of maintenance of the vehicle, smaller factors k_1 and k_2 are assumed for freight wagons. Exceptions are permissible in well-founded individual cases.

NOTE 3 For vehicles with very short spacing of wheelsets the influence of the adjacent wheelsets increases the limit value $\Sigma Y_{j,max}$ a track is able to endure without displacement. It is possible to use extended calculation methods which take this fact into consideration.

NOTE 4 The $(Y/Q)_i$ on the inner rail is assumed to represent the friction in the interface between curve inner wheel and rail in very small curve radii for understanding or correcting other measured quantities. The following is assumed:

— the contact angle between curve inner wheel and rail is small;

— the friction coefficient is similar between curve inner and curve outer wheels and rails.

The friction coefficient represented in this way is often under-estimated since:

— it assumes that the creep force is saturated (that the creepage is large enough to release the full friction coefficient);

— the influence of the longitudinal component of the creep force is neglected.

NOTE 5 The conditions of vehicle, track, operation and environment as well as the measuring and assessment procedure have an effect on the assessment quantities. The random occurrence of these influences or conditions characterizes the assessment quantities as stochastic variables.

7.5.2 Running safety

The derived quantities ΣY_{max} and $(Y/Q)_{a,max}$ are the criteria for running safety. The value ΣY_{max} is used for assessing compliance with regard to the safety against track shifting. The ratio $(Y/Q)_{a,max}$ of the leading wheel is the criterion for safety against derailment resulting from the climbing of the wheel flange onto the rail.

Under specified conditions (see 7.2.2 and informative Annex U) an assessment of running safety on a simplified basis is possible using:

— accelerations at the bogie $\ddot{y}^+_{S,max}$ together with the accelerations in the vehicle body $\ddot{y}^*_{S,max}$ and $\ddot{z}^*_{S,max}$; or

— the sum of lateral axle box forces H_{max} together with the vertical accelerations in the vehicle body $\ddot{z}^*_{S,max}$

The lateral vehicle body acceleration $\ddot{y}^*_{S,max}$ should be evaluated in order to enable an easy extension of acceptance later.

Stability of the vehicle is assessed on basis of a moving rms value of sum of guiding forces ΣY_{rms}, sum of lateral axle box forces H_{rms}, lateral accelerations at the bogie $\ddot{y}^+_{rms}$ or lateral accelerations on wheelsets $\ddot{y}_{rms}$ depending on the used measuring method.

For test conditions with I_{adm} > 165 mm additionally the overturning criterion:

$$\kappa = \frac{\sum_{bogie} Q_{jA} - \sum_{bogie} Q_{jB}}{\sum_{bogie} Q_{jA} + \sum_{bogie} Q_{jB}}$$

for each bogie where wheel/rail forces are measured shall be evaluated as a parameter of running safety in the normal measuring method. A indicates the wheels of one vehicle side and B the wheels of the other side. For the statistical evaluation of κ see R.6.

7.5.3 Track loading

The quasi-static vertical wheel force $Q_{a,qst}$, the maximum vertical wheel force Q_{max} and the quasi-static guiding force $Y_{a,qst}$ form the basis for the assessment of track loading. The limit values for these parameters are specified in Table 4.

Where the quasi-static guiding force was normalized according to 7.6.3.2.6, the normalized result $Y_{a,nf,qst}$ shall be used instead of $Y_{a,qst}$.

NOTE 1 The specified limits are not running safety relevant limits but are to be considered in relation to the load/mechanical strength and the wear of the superstructure.

In addition the following parameters shall be documented:

— combined rail loading quantity $B_{qst} = Y_{a,qst} + 0{,}83\ Q_{a,qst}$ (using the normalized value $Y_{a,nf,qst}$ instead of $Y_{a,qst}$ if the quasi-static guiding force was normalized, see J.3)

— $B_{max} = (|Y| + 0{,}91\ Q)_{max}$ (see J.3);

— maximum guiding force $Y_{a,max}$;

— rail surface damage quantity T_{qst} (see informative Annex K), if T_x forces were measured.

NOTE 2 The additional parameters B_{qst}, B_{max}, $Y_{a,max}$ and T_{qst} can help determine appropriate operating and vehicle conditions (cant deficiency, speed, friction conditioning, payload) depending on track layout, track design, track quality and track maintenance strategy. Limit values for B_{qst}, B_{max}, $Y_{a,max}$ and T_{qst} are not defined in this standard.

7.5.4 Ride characteristics

The values for ride characteristics are presented as good practice values for accelerations and are not safety or obligatory limits. Values of good practice are given in informative Annex L. More information about the character of the stated values is also given in this annex.

7.6 Test evaluation

7.6.1 Overview

Figure 10 shows the evaluation process of measured data: After digitising, filtering, calculation of percentiles and their grouping and conversion, a statistical analysis is performed for the relevant percentiles to receive estimated results for the specified target test conditions of the test zones.

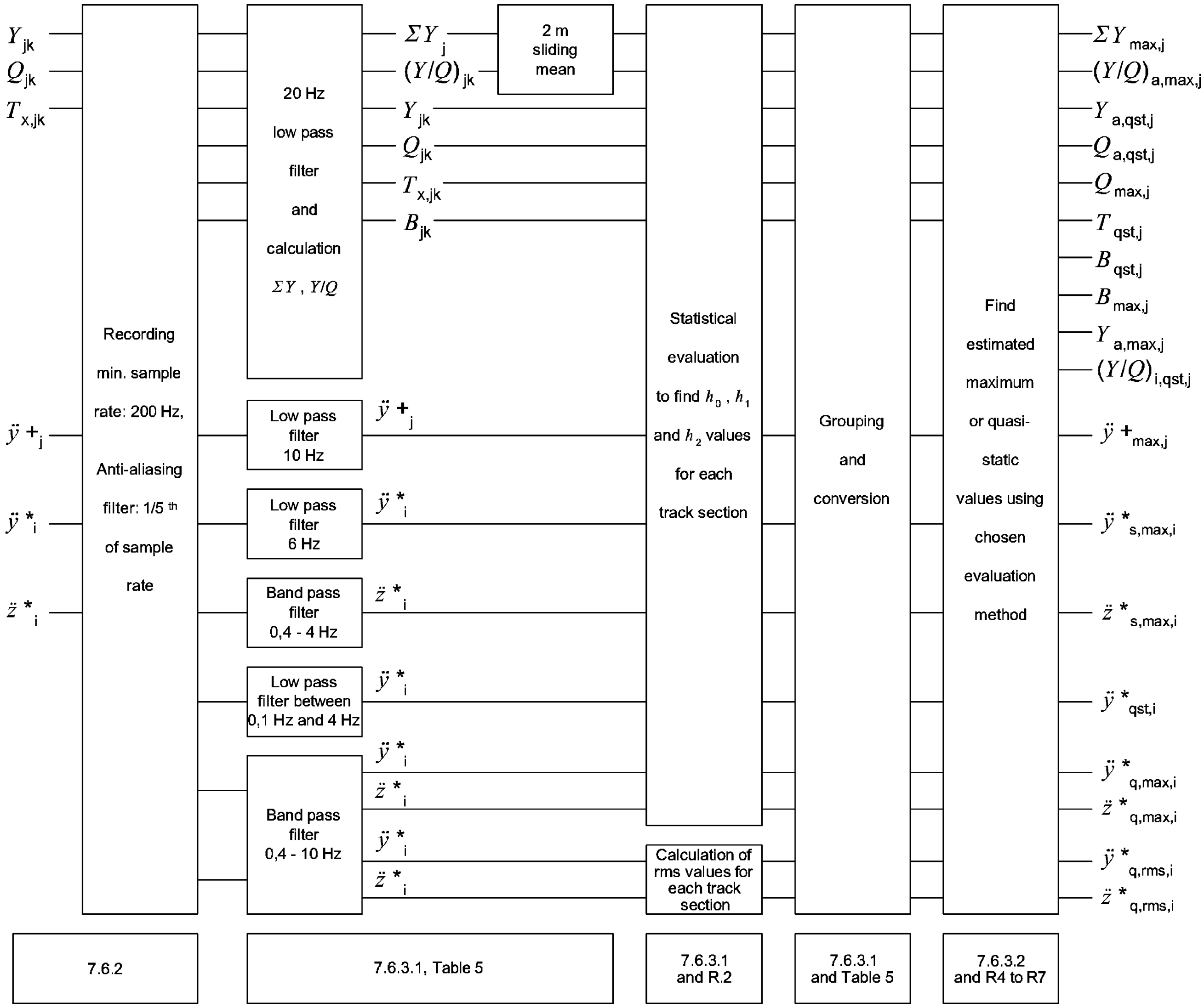


Figure 10 — Principle of evaluation process

7.6.2 Recording the measuring signals

In principle, the measuring signals of all measured parameters and influencing parameters intended for subsequent evaluation shall be recorded using machine-readable data carriers. For the recording of the measuring signals, a low-pass anti-aliasing filter shall be used. The cut-off frequency of the filter depends on the type of recording and of the type of parameter:

a) minimum sample frequency of 200 Hz with anti-aliasing filter less than or equal to 1/5 of the sample frequency;

b) for graphical representation consistent with the filtering given in Table 5.

The applied sample rate and anti-aliasing filter shall not influence the percentiles of the signals filtered according to the conditions given in Table 5.

7.6.3 Statistical evaluation in test zones

7.6.3.1 Processing the measuring signals

As a prerequisite for the statistical evaluation, the measured data shall be filtered as specified in Table 5. In some cases this includes the application of the sliding mean method or the sliding rms method, where arithmetic mean values or rms-values are calculated for windows of a specified length (number of instantaneous values), which are shifted by a specified step length.

NOTE The number of values included in the calculations per window depends on the speed and the sampling rate as the window length is specified as a track length here. The number of the filtered data are determined by the step length.

The percentiles specified in Table 5 shall be determined from the filtered signals.

Table 5 — Conditions for the processing of the measuring signals

Assessment quantity	**Symbol**	**Unit**	**Evaluation filter**	**Percen-tiles** [d]	**Grouping and Conversion**	
					Test zone 1	Test zones 2, 3 and 4
Running safety						
Sum of guiding forces	ΣY_{max}	kN	Low-pass filter 20 Hz [a] and Sliding mean method with - window length 2,0 m - step length ≤ 0,5 m	h_1 = 0,15 % h_2 = 99,85 %	Per wheelset, group $y_j\,(h_1)\cdot(-1)$ and $y_j\,(h_2)$	Per wheelset, group $y_j\,(h_2)$ (left-hc [e]) and $y_j\,(h_1)\cdot(-1)$ (right-hc)
Ratio of guiding force and vertical wheel force leading wheelset	$(Y/Q)_{\text{a,max}}$	—			—	For leading wheelset, group (external) wheels $y_{11}(h_2)$ (left-hc) and $y_{12}(h_1)\cdot(-1)$ (right-hc)
Ratio of guiding force and vertical wheel force, recalculated, leading wheelset [b]	$(Y/Q)_{\text{a,max, rec}}$			h_1 = 2,5 % h_2 = 97,5 %		
Sum of lateral axle box forces	H_{max}	kN		h_1 = 0,15 % h_2 = 99,85 %	Per wheelset, group $y_j\,(h_1)\cdot(-1)$ and $y_j\,(h_2)$	Per wheelset, group $y_j\,(h_2)$ (left-hc) and $y_j\,(h_1)\cdot(-1)$ (right-hc)
Acceleration of bogie frame	$\ddot{y}^{+}_{\text{max}}$	m/s²	Low-pass filter 10 Hz [a]			
Acceleration in vehicle body	$\ddot{y}^{*}_{\text{S,max}}$		Low-pass filter 6 Hz [a]		Per end, group $y_j\,(h_1)\cdot(-1)$ and $y_j\,(h_2)$	Per end, group $y_j\,(h_2)$ (left-hc) and $y_j\,(h_1)\cdot(-1)$ (right-hc)
	$\ddot{z}^{*}_{\text{S,max}}$		Band-pass filter 0,4 Hz to 4 Hz [a]		—	Per end, group $y_j\,(h_1)\cdot(-1)$ and $y_j\,(h_2)$
Overturning parameter [g]	κ	—	Low-pass filter 1,5 Hz [a]		Per bogie, group $y_j\,(h_1)$ and $y_j\,(h_2)$ [f]	Per bogie, group $y_j\,(h_1)$ for $I < 0$ $y_j\,(h_2)$ for $I > 0$ [f]
Instability criterion	ΣY_{rms}	kN	Band-pass filter [a] f_0 [c] ± 2 Hz and Sliding rms method with - window length 100 m - step length ≤ 10 m	max-values	Per wheelset along the whole test route	—
	H_{rms}					
	$\ddot{y}^{+}_{\text{rms}}$	m/s²				
	$\ddot{y}_{\text{rms}}$					

Assessment quantity	**Symbol**	**Unit**	**Evaluation filter**	**Percentiles** [d]	**Grouping and Conversion**	
					Test zone 1	Test zones 2, 3 and 4
Track loading						
Guiding force	$Y_{a,qst}$	kN	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	—	Per wheelset, group external wheels y_{j1} (h_0) (left-hc) and y_{j2} (h_0) · (−1) (right-hc)
Vertical wheel force	$Q_{a,qst}$					Per wheelset, group external wheels y_{j1} (h_0) (left-hc) and y_{j2} (h_0) (right-hc)
	Q_{max}			h_2 = 99,85 %	Per wheelset, group all wheels y_{jk} (h_2)	Per wheelset, group external wheels y_{j1} (h_2) (left-hc) and y_{j2} (h_2) (right-hc)
Ride characteristics						
Acceleration in vehicle body	$\ddot{y}^*_{q,max}$ $\ddot{z}^*_{q,max}$	m/s²	Band-pass filter 0,4 Hz to 10 Hz [a]	h_1 = 0,15 % h_2 = 99,85 %	Per end group $y_j(h_2)$ and $y_j(h_1)$ · (−1)	
Displacement characteristics						
Roll angle difference between vehicle body and bogie frame for bogie vehicles or between vehicle body and wheelset for non-bogie vehicles	$\Delta\eta^*$	mrad	Low-pass filter between 0,1 Hz and 4 Hz without phase shift [a, h]	h_0 = 50,0 %	—	Per end, group y_j (h_2) (left-hc) and y_j (h_1) · (−1) (right-hc)
Roll angle between bogie frame and wheelset for bogie vehicles	$\Delta\eta^+$		Low-pass filter between 0,1 Hz and 4 Hz without phase shift [a, h]		—	Per end, group y_j (h_2) (left-hc) and y_j (h_1) · (−1) (right-hc)
Lateral Acceleration in vehicle body	$\ddot{y}^*_{qst}$	m/s²	Low-pass filter between 0,1 Hz and 4 Hz without phase shift [a, h]		—	Per end, group y_j (h_2) (left-hc) and y_j (h_1) · (−1) (right-hc)
Influencing parameters						
Speed	V	km/h	Low-pass filter between 0,1 Hz and 4 Hz without phase shift [a, h]	h_0 = 50,0 %	—	
Cant deficiency	I	mm				
Unbalanced lateral acceleration	$\ddot{y}$	m/s²				
Ratio leading wheelset, curve-inner rail	$(Y/Q)_i$	—	Low-pass filter 20 Hz [a]		—	Per leading wheelset, internal wheels $y_{j2}(h_0)$ (left-hc) and $y_{j1}(h_0)$ · (−1) (right-hc)

Assessment quantity	**Symbol**	**Unit**	**Evaluation filter**	**Percentiles** [d]	**Grouping and Conversion**	
					Test zone 1	Test zones 2, 3 and 4
Additional track loading parameters without limit values to gather experience for future revisions of the standard (Informative)						
Rail surface damage parameter, See informative Annex K	T_{qst}	kN	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	—	Per wheelset, group wheels y_{j1} (h_0) (left-hc) and y_{j2} (h_0) · (−1) (right-hc)
Quasi-static rail load parameter	B_{qst}	kN	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	—	Per wheelset, group external wheels y_{j1} (h_0) (left-hc) and y_{j2} (h_0) (right-hc)
Maximum rail load parameter	B_{max}	kN	Low-pass filter 20 Hz [a]	h_2 = 99,85 %	—	Per wheelset, group external wheels y_{j1} (h_2) (left-hc) and y_{j2} (h_2) (right-hc)
Maximum guiding force	$Y_{\mathrm{a,max}}$	kN	Low-pass filter 20 Hz [a]	h_1 = 0,15 % h_2 = 99,85 %	—	Per wheelset, group external wheels y_{j1} (h_2) (left-hc) and y_{j2} (h_1) · (−1) (right-hc)
Additional parameters for plausibility investigations and model validation (Informative)						
Sum of quasi-static guiding forces of wheelset	ΣY_{qst}	kN	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	Per wheelset y_j (h_0)	Per wheelset y_j (h_0) (left-hc) and y_j (h_0) · (−1) (right-hc)
Sum of quasi-static guiding forces of bogie	$\Sigma\Sigma Y_{\mathrm{qst}}$	kN	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	Per bogie y (h_0)	Per bogie y (h_0) (left-hc) and y (h_0) · (−1) (right-hc)
Ratio of quasi-static guiding force and quasi-static vertical wheel force leading wheelset	$(Y/Q)_{\mathrm{qst}}$	—	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	—	Per wheelset, group (external) wheels y_{j1} (h_0) (left-hc) and y_{j2} (h_0) · (−1) (right-hc)
Sum of quasi-static lateral axle box forces per wheelset	H_{qst}	kN	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	Per wheelset y_j (h_0)	Per wheelset y_j (h_0) (left-hc) and y_j (h_0) · (−1) (right-hc)
Sum of quasi-static vertical wheel forces per wheelset	ΣQ_{qst}	kN	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	Per wheelset y_j (h_0)	Per wheelset y_j (h_0)
Sum of quasi-static vertical wheel forces per bogie	$\Sigma\Sigma Q_{\mathrm{qst}}$	kN	Low-pass filter 20 Hz [a]	h_0 = 50,0 %	Per bogie y (h_0)	Per bogie y (h_0)

[a] Filter with cut-off frequency at −3 dB, gradient ≥ 24 dB/octave, tolerance ± 0,5 dB up to the cut-off frequency, ± 1 dB beyond that value.
[b] See 7.6.3.2.5.
[c] f_0 is the instability frequency. It is defined as the dominant frequency in the case of unstable behaviour. It has to be determined before evaluation of test results (see 7.6.5 for details).
[d] For determination of percentiles, see R.2.
[e] Means "left hand curve".
[f] Bi-dimensional analysis (see R.6).
[g] To be evaluated only for test conditions with I_{adm} > 165 mm.
[h] Low values to be used for evaluation of maximum speed variation within each track section as required by Table 2.

7.6.3.2 Calculation of results

7.6.3.2.1 General

The estimated values shall be evaluated by one of the statistical methods according to normative Annex R for each assessment quantity and for each test zone separately. Only results from track sections compliant with the test parameters given in Table 2 shall be used for the statistical evaluation. This evaluation is performed for the percentiles of each assessment quantity after grouping and conversion as specified in Table 5. Transition curves are not subject of this statistical evaluation.

The evaluation parameters y for statistical analysis are the assessment quantities Y, Q, ΣY, Y/Q, B, T, T_x, H, $\ddot{y}^+$, $\ddot{y}^*$ and $\ddot{z}^*$.

In general the following two assessment types are used:

— maximum values y_{max};

— median values y_{med}.

Maximum values y_{max} and median values y_{med} are calculated from the percentiles of the filtered signals in each test zone. For each assessment quantity and test zone the estimated maximum value of the sample $Y(PA)_{max}$ is calculated applying a statistical method which is either:

— one-dimensional; or

— two-dimensional (only applicable for test zones 2, 3 and 4); or

— a multiple regression method.

The statistical methods and the necessary mathematics are given in normative Annex R. Estimated quasi-static values shall be calculated only by the two-dimensional method or by multiple regression.

NOTE 1 Many assessment quantities depend more on other quantities than the cant deficiency. The multiple regression gives a much better determination of the estimated value for a set of target test conditions taking into account all relevant test parameters. The development of this method has reached a state that allows the use as alternative to the established evaluation methods.

Depending on the type of the assessment quantity the following confidence levels shall be used:

— PA = 99,0 % for assessment values of running safety;

— PA = 95,0 % for assessment of track loading and ride characteristics.

Assessment of quasi-static values is done with the regression without a confidence interval. The one-dimensional analysis is not allowed for quasi-static values.

If the two-dimensional method is used, the following target values are used for calculating estimated maximum values:

— $I_{target} = 1,1 \cdot I_{adm}$ for maximum values;

— $I_{target} = 1,0 \cdot I_{adm}$ for quasi-static values.

If multiple regression is used, it is necessary to determine the target values of geometric track quality TQ_σ the following standard deviations shall be used depending on the assessment quantity:

Δy_σ^0 for Y, ΣY, Y/Q, T, T_x, H, $\ddot{y}$, $\ddot{y}^+$, $\ddot{y}^*$

Δz_σ^0 for Q, $\ddot{z}^*$, B

The following list gives all the target values to be used for calculating estimated maximum values:

Test zone “Straight track”:

— $V_{target} = 1{,}1 \cdot V_{adm}$; and

— $TQ_{\sigma} = TL50$ (V_{adm});

Test zone "curves":

— large radius curves (analogous to test zone 2), not for quasi-static quantities:

  — $V_{target} = 1{,}0 \cdot V_{adm}$; and

  — $I_{target} = 1{,}1 \cdot I_{adm}$;

  — $TQ_{\sigma} = TL50$ (V_{adm});

— small radius curves (analogous to test zone 3):

  — $R_{target} = 500$ m;

  — $I_{target} = 1{,}1 \cdot I_{adm}$;

  — $I_{target} = 1{,}0 \cdot I_{adm}$ for quasi-static quantities;

  — $TQ_{\sigma} = TL50$ (120 km/h);

— very small radius curves (analogous to test zone 4):

  — $R_{target} = 350$ m;

  — $I_{target} = 1{,}1 \cdot I_{adm}$;

  — $I_{target} = 1{,}0 \cdot I_{adm}$ for quasi-static quantities;

  — $TQ_{\sigma} = TL50$ (120 km/h).

In cases where the vehicle needs testing for more than one combination of V_{adm} and I_{adm} as described in 7.1, the target values for test zone 1 and test zone 2 shall be determined by analogy.

7.6.3.2.2 Details for two-dimensional evaluation

If the shape of the regression line or confidence interval leads to higher values at $0{,}75 \cdot I_{adm}$ than at the target value of cant deficiency, it shall be reported and assessed.

NOTE 1 Reasons for such a case could be physical behaviour of the vehicle or violations of the underlying regression assumptions. Examples are collinearity, non-normality of the residuals or a non-uniform influence of other relevant parameters on the percentiles. Additional investigations like:

— regarding results of one-dimensional evaluation;

— extension of the evaluation interval;

— separate evaluation of track sections with more similar test conditions;

— multiple regression as proposed in normative Annex R;

can help to assess if the reason is related to the physical behaviour of the vehicle or not.

The narrow range of cant deficiency as specified in Table 2 is appropriate when using the one-dimensional method but may lead to low significance of the regression line when using the two-dimensional method.

Therefore, in order to increase the range and size of the sample when using the two-dimensional method:

— the multiple use of the same track section within the same test zone;

— and/or the use of additional track sections;

is recommended.

The following conditions apply:

— $n_{ts,min}$ and $\Sigma L_{ts,min}$ specified in Table 2 shall be reached and the given cant deficiency distribution shall be achieved taking into account the number of unique track sections (n_{ts}) within the cant deficiency range defined for the test zone;

— for multiple use of the same section the cant deficiency shall differ by at least $0{,}05 \cdot I_{adm}$;

— the mean radius R_m (for zones 3 and 4) specified in Table 2 shall be evaluated taking into account all the occurrences of every track section;

— all data added by multiple use or additional sections shall be such that $I > 40$ mm;

— the number of sections below $0{,}7 \cdot I_{adm}$ shall be less than 50 % of the total number of sections;

— the speed requirements for test zone 2 stated in Table 2 are applicable for all track sections used.

NOTE 2 The aim to improve the width of the confidence interval is missed, if the distribution of the data along the regression line is uneven or has a concentration at the lower end of the regression line.

7.6.3.2.3 Multiple regression

Multiple regression can also be used for the assessment of a vehicle. Normative Annex R gives more information. If dependent parameters are chosen carefully, a sufficient confidence in calculated estimated values is achievable. This method in its full extension can replace the two-dimensional evaluation as in many cases the assessment quantities depend more on other input quantities than the cant deficiency. On the other hand, the one-dimensional and the two-dimensional evaluations are special cases of the full multiple regression with no (one-dimensional) or only one input parameter (cant deficiency).

7.6.3.2.4 Determination of permissible cant deficiency

When the vehicle does not comply with the limit values in one or more test zones, supplementary analysis shall be made to determine the necessary reduction(s) of admissible operating condition(s), for example:

— a reduced cant deficiency I_{red} that is admissible for that test zone(s);

— the test zone(s) in which the cant deficiency I_{adm} is admissible;

— combinations of cant deficiency, speed and curve radius which are admissible;

— a reduced admissible speed.

This can be applied if two dimensional analysis or multiple regression is used. In both, the regression coefficient for cant deficiency or speed can be used to calculate the necessary reduction and the assessment will be done with this new target value.

If the operating envelope of the vehicle requires testing with more than one combination of cant deficiency and speed then these combinations shall be handled in different test zones 2, possibly leading to different reduced cant deficiencies I_{red}.

7.6.3.2.5 Recalculated quotient of lateral and vertical wheel force coefficient $(Y/Q)_{a,max,rec}$

In the event that the limit value for $(Y/Q)_{a,max}$ given in Table 4 is exceeded or if $\lambda < 1{,}1$, it is permissible to recalculate the test results. The recalculation shall be carried out according to the following process.

— create an alternative test zone made up of all track sections with 300 m ≤ R ≤ 500 m;

— for the statistical processing per section (see R.2), use $h_1 = 2{,}5$ % instead of $h_1 = 0{,}15$ % and $h_2 = 97{,}5$ % instead of $h_2 = 99{,}85$ %;

— for the statistical processing per zone replace confidence level $PA = 99{,}0$ % by $PA = 95{,}0$ %;

— the mean curve radius shall be in the range 350 m to 400 m;

— all requirements related to the number of sections and distribution of the sample shall be the same as for test zone 4.

If the vehicle respects the criterion after recalculation, this replaces the assessment of $(Y/Q)_{a,max}$ in test zones 3 and 4.

NOTE 1 The recalculation process is consistent with the method used in ORE C138, when the limit value of 0,8 was defined and validated for existing vehicles. In ORE C138 Rp 9 [9] it is stated: “Long service experience with values approaching 1 never resulted in derailments. Adhering to a limit value $(Y/Q)_{a,max,lim} = 0,8$ in any case provides a high degree of safety against derailment” and ”To determine how far this [limit value for $(Y/Q)_{a,max}$ evaluated as above] could be increased would require additional studies concerning the probability of the simultaneous occurrence of influences favouring derailment under normal operating conditions”. The use of recalculation process in this standard is justified by the UIC study B12 RP 76 [13] based on tests performed with empty freight wagons equipped with Y25 bogies that operate safely. Information available from this project and other projects indicates that an increase of the limit value of approximately 25 % applied with the standard evaluation method would maintain the existing safety level for the railway system. Further work is required to find an appropriate limit value which properly takes into account the behaviour of existing vehicles with long satisfactory service experience. The above study indicates also that some existing freight vehicles which have dispensation from on-track testing according to EN 16235 or TSI WAG do not respect the limit value $(Y/Q)_{a,max,lim}$ even if the recalculation method is used.

NOTE 2 If the recalculation is made for vehicles with a nominal static vertical wheelset force $P_{F0} > 150$ kN there may be a track loading problem related to an unfavourable angle of the resulting force leading to failure of fastenings on sharp curves. In this case operation may not be accepted on some networks.

7.6.3.2.6 Quasi-static guiding force

The evaluation of the estimated value for the guiding force is performed in two steps:

1) If during the test some individual 50 %-$(Y/Q)_i$ values exceeded 0,40, the estimated value shall be normalized:

   In track sections where $(Y/Q)_{i,50\,\%}$ exceeds the value of 0,40 replace the percentiles $Y_{a,50\,\%}$ on the outer rail of the track sections by:

   $Y_{a,f,50\,\%} = Y_{a,50\,\%} - 50[(Y/Q)_{i,50\,\%} - 0,4]$ kN

   Afterwards calculate the estimated value normalized by friction $Y_{a,f,qst}$

   NOTE 1 The normalization takes into account roughly 50 % of the physical influence of values of Y/Q_i above 0,4 on the increase of the guiding force.

   NOTE 2 The normalization is only performed for $(Y/Q)_i$ values above 0,4 as $(Y/Q)_i$ represents friction only in case of saturation of the creep force law.

   If multiple regression is used, it is allowed to apply a multiple regression for curves below 400 m including $(Y/Q)_i$ as input variable and use 50 % of the influence given by the regression coefficient for normalization. The reduced regression coefficient then replaces “50” in the formula.

2) If one dimensional or two dimensional evaluation is applied, for test zone 4, the test results $Y_{a,f,qst}$ with a given mean curve radius R_m shall be normalized to the radius $R = 350$ m by the following formulae:

   $Y_{a,nf,qst} = Y_{a,f,qst} - (10\,500 \text{ m} / R_m - 30)$ kN

   R_m indicating the mean radius of all track sections in the test zone.

In the case that multiple regression is used with the input parameter 1/R, the radius normalization shall be realized by using the target radius of 350 m directly instead of application of the above formula.

7.6.3.2.7 Overturning parameter κ

For test conditions with $I_{adm} > 165$ mm a special analysis shall be performed in order to take into account a possible asymmetry. Therefore the overturning parameter κ defined in 7.5.2 shall be evaluated. After calculation of the percentiles $y(h_j)$, a special bi-dimensional analysis of the maximum $\boldsymbol{y}_{max,i}$ values versus cant deficiency shall be performed with the regulations defined in R.6 in order to treat the effect of quasi-static accelerations on each side of the vehicle separately.

In this special case, the estimated maximum value is given by the maximum of the absolute values of the linear functions Y_P at 1,5 I_{adm} and Y_N at −1,5 I_{adm}.

7.6.3.3 Calculation of safety factors

For the complete on-track test the safety factor λ and the track loading factor λ' (only for vehicles with $P_{F0} > 225$ kN) shall be determined as described in U.2.

7.6.4 Evaluation of test results in transition curves

Maximum values $\boldsymbol{y}_{max,i}$ shall be calculated from the percentiles $y(h_j)$ for each track section depending on the track layout. For each parameter (test zone, vehicle test condition, etc.) the maximum values shall be compared to the limit values. The evaluation is restricted to parameters of running safety.

7.6.5 Verification of stability

Verification of stability is done using the assessment quantity for the instability criterion. Depending on the applied measuring method the appropriate assessment quantity ΣY_{rms}, H_{rms}, $\ddot{y}^{+}_{rms}$ or $\ddot{y}_{rms}$ is used. The signal shall be filtered with a band-pass filter having a minimum width of 4 Hz covering the dominant frequency in the case of unstable behaviour without damping. To exclude quasi-static and high frequency effects the lower cut-off frequency shall not be below 0,4 Hz and the upper cut-off frequency shall not be above 12 Hz.

NOTE 1 The main aim of the 4 Hz band-pass is to ensure that the amplitude at the dominant frequency is not significantly affected by the filter characteristic.

A sliding rms with a window length of 100 m and a step length up to 10 m shall be evaluated along the whole test run performed for testing stability. Stability is verified if all rms values of tangent track are lower than the limit value.

If unstable behaviour is observed in other test runs it shall be also evaluated and reported according to the above procedure.

NOTE 2 Periodic track effects may be capable of giving a false indication of instability.

NOTE 3 For certain types of vehicles bad Running Behaviour can occur (low frequency body motions) in large radius curves or straight track with a high wheel/rail clearance (large track gauge and/or thin flanges). If such behaviour is observed during the test runs, additional tests to investigate this behaviour may be required.

7.7 Documentation

7.7.1 General

All necessary information as specified in 5.5 shall be documented. The following sub clauses detail some of these requirements for on-track testing.

7.7.2 Description of the vehicle design and status of the tested vehicle

The tested vehicle shall be described. This description shall include as a minimum the following:

— schemes of vehicle and running gear;

— wheel- and wheelset force distribution for each tested load case;

— scheme of payload distribution of applied load for each load case (see 5.3.2);

— all deviations from the nominal design of the vehicle (e.g. masses replacing missing parts);

— position and coupling status of the vehicle within the test train;

— status of the traction and braking system (active/passive);

— theoretical and measured wheel profiles;

— equivalent conicities of measured wheel profiles combined with theoretical rail profiles;

— status of flange lubrication;

— investigated fault modes and reasons (see 5.2.2).

7.7.3 Additional information for future extension of acceptance

For future extension of acceptance the knowledge of the relevant parameters influencing the dynamic behaviour of the tested vehicle is fundamental. If the intention is to allow for a future acceptance (after design modification, etc.) then additional information including descriptions, drawings, component test results, etc., including all design parameters given in Table U.1 and any other relevant elements which are not in this list such as characteristics of yaw dampers and inter-car dampers shall be documented.

NOTE For reasons of confidentiality this information may be given in a separate document.

7.7.4 Description of the test routes

— Location of the test routes;

— track layout (curvature and cant);

— geometric track quality for each track section;

— if available: equivalent conicity for each track section of test zone 1 evaluated with measured rail profiles and representative wheel profiles for the tested vehicle;

— if available: radial steering index (see informative Annex Q) for each track section of test zone 4 evaluated with measured rail profiles and representative wheel profiles for the tested vehicle;

— if available: measured rail profiles for validation of simulation models;

— if available: distance history data of geometric track deviations for validation of simulation models.

7.7.5 Description of data capture

— Instrumentation plan (including additional measurements for model validation);

— definition of positive measuring direction (see normative Annex G);

— list of elements in the measuring and recording chain (transducers, cables, recording devices, …);

— sampling frequency and anti-aliasing filter frequency;

7.7.6 Description of evaluation

— Assessed operating conditions (combination(s) of speed and cant deficiency);

— calculation of combined measuring quantities;

— list of excluded track sections due to amplitudes higher than the stated *QN3* values (see M.4);

— list of excluded track sections due to exceptional high equivalent conicities (see Table 2);

— for each test zone and test condition the number of track sections used for the evaluation:

  — complying with the conditions in Table 2;

  — additionally used for two-dimensional evaluation;

— limit values used;

— results of plausibility checks if performed;

— results of checks of the statistical assumptions if performed

7.7.7 Test results (including additional information for model validation)

7.7.7.1 General

For all assessment quantities according to Table 4, the results of the statistical evaluation shall be shown. For this purpose, the estimated values $Y(PA)$ of all evaluation variables shall be presented for the evaluated random sample distributions in graphical form (e.g. a scatter diagram and/or bar chart) and in a table (e.g. as a ratio of the limit value). It shall be stated whether all estimated values from the statistical evaluation in the test zones 1 to 4 respect the corresponding limit values for all test conditions.

For track sections in transition curves the maximum percentiles of $y(h_2)_{\max}$ and $|y(h_1)|_{\max}$ shall be compared with the limit values.

For the complete on-track test the documentation of results shall be completed with the calculated safety factor λ of the assessment quantities for running safety. For vehicles with P_{F0} > 225 kN also the track loading factor λ' shall be reported. All calculated ratios used for the determination of λ (and λ') shall be reported (see U.2).

A summary of the percentiles as well as the influencing parameters (speed, radius, cant deficiency, track geometry quality) shall be enclosed in tabular or graphical form at least for cases in which estimated values exceed the limit values.

For further investigation like multiple regression a list of track sections used for statistical evaluation shall be provided in a digital form for each test zone and test condition containing the following information:

— curvature, cant, section length, location (test route, track ID, track kilometre);

— speed, cant deficiency;

— equivalent conicity (for stability testing), radial steering index (zone 4, if available), $(Y/Q)_i$ if available;

— track geometric quality: standard deviation of alignment and longitudinal level;

— percentiles for each assessment quantity.

NOTE 1 Depending on the purpose it might be useful to include also track sections that were excluded from the statistical evaluation in this list.

If individual percentiles of assessment quantities for running safety exceed the limit value, this shall be documented. A summary of the values shall be given.

NOTE 2 The estimated maximum value $Y(PA)_{\max}$ is calculated with the confidence limit PA. Therefore a number of individual values y_i could be located above the estimated maximum value.

A typical graphical representation in the time domain of each assessment quantity and on each test zone shall be provided.

7.7.7.2 Details for maximum quotient of lateral and vertical wheel force

If the quotient $(Y/Q)_{\mathrm{a,max}}$ was recalculated according to 7.6.3.2.5, both results (before and after recalculation) shall be reported.

7.7.7.3 Details for quasi-static guiding force

If $Y_{\mathrm{a,qst}}$ was normalized according to 7.6.3.2.6 the results of each step of the normalization shall be reported separately.

7.7.7.4 Details for Stability

The results of stability testing (rms-values) shall be presented together with:

- the centre frequency of the used band pass filter;
- the speed profile; and
- the available equivalent conicity data (at minimum in the high equivalent conicity sections) evaluated with measured rail profiles and measured representative wheel profile(s) of the tested vehicle.

7.7.8 Deficiencies in reaching the target test conditions

All reached test conditions that are not in line with the target test conditions shall be documented to give an overview of the deficiencies. If adjustments to the test results are made, the results before and after adjustment shall be documented.

7.7.9 Infrastructure conditions more severe than the target test conditions

Where testing the vehicle demonstrates that the performance of a vehicle complies with the requirements of this standard when operating at maximum speed and maximum cant deficiency under infrastructure conditions that are more severe than the target test conditions, it is recommended that the results of such investigations (test and proven operating conditions) are documented to avoid unnecessary testing in several countries.

Annex A
(informative)

Information on safety against derailment

A.1 Factors influencing the safety against derailment of vehicles running on twisted track

A.1.1 General

The existence of track twist in railway tracks is fundamental. It is a result of transition layout between levelled track and canted track as well as cross level deviations.

The coincident appearance of a horizontal force with a wheel unloading at the leading wheel in a curve may result in a derailment, if both effects are present over a sufficient distance.

The test of safety against derailment according to methods 1 and 2 is carried out under the influence of a vehicle test twist and of a curve of a radius of R = 150 m.

A.1.2 Wheel unloading influences

Vehicle based influences are:

— torsional stiffness of the vehicle-body combined with the vertical stiffness of the suspension system;

— torsional stiffness of the bogie frame combined with the vertical stiffness of the primary suspension;

— eccentricity of the vehicle centre of gravity;

— torsional hysteresis during twisting;

— longitudinal eccentricity of anti-roll bars inside a bogie in the case of flexible bogie frames.

Track based influences are:

— track twist due to cant transition;

— additional track twist due to cross level deviations;

— cant excess or deficiency.

A.1.3 Guiding force influences

Vehicle based influences are:

— bogie wheel base for bogie vehicles or wheelset distance in the vehicle for non-bogie vehicles;

— yaw resistance of the bogie;

— longitudinal stiffness of the primary suspension.

Track based influences are:

— curve radii as a result of the track layout;

— track alignment deviations.

Friction condition of wheel/rail contact surfaces are influenced by:

— weather conditions;

— lubrication and contamination in the wheel/rail contact patch.

Guiding forces are also influenced by wheel/rail contact geometry which depends on:

— wheel profiles;

— rail profiles;

— rail inclination;

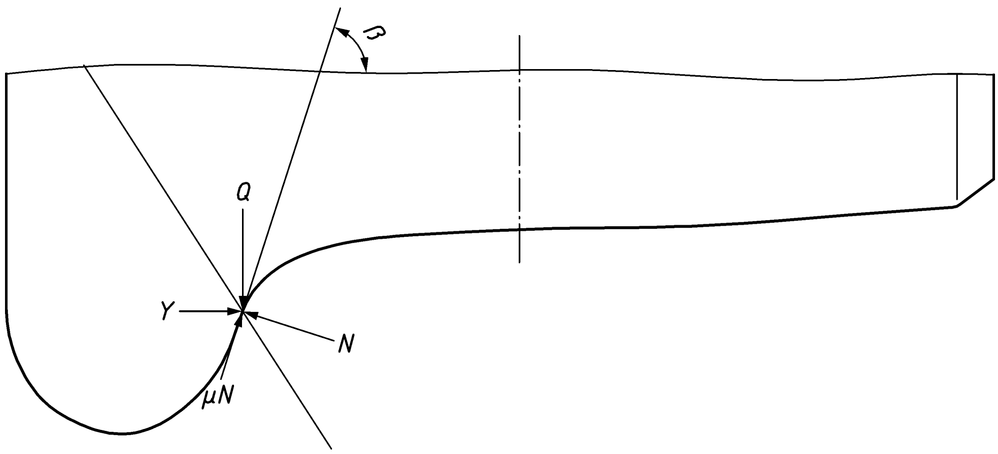
— track-wheelset gauge clearance.

A.2 Evaluation and limit value for safety against derailment

The maximum single wheel lateral to vertical force ratio $(Y/Q)_a$ is used as a measure of proximity to a flange climb derailment situation. The ratio of lateral to vertical force $(Y/Q)_a$ was first suggested by Nadal in 1908 and has been used extensively ever since by many railways throughout the world.

The criterion is based on the equilibrium of forces on the inclined plane of contact between wheel and rail. Derailment occurs if the sum of the vertical components of the normal and tangential forces is sufficient to support the vertical force on the wheel. It assumes that there is downward sliding on a flange contact point. Furthermore it is assumed that the tangential (friction) force across the flange is equal to the coefficient of friction on the flange μ multiplied by the normal force on the flange N.

Figure A.1 shows the system of forces acting on the flange contact point.



Key

β flange angle

Figure A.1 — Flange forces at incipient derailment

A lateral force Y and a vertical force Q are exerted on the wheel. Forces in the contact zone are the normal force N and the friction force μN. Equating forces in the lateral and vertical directions give the following formulae:

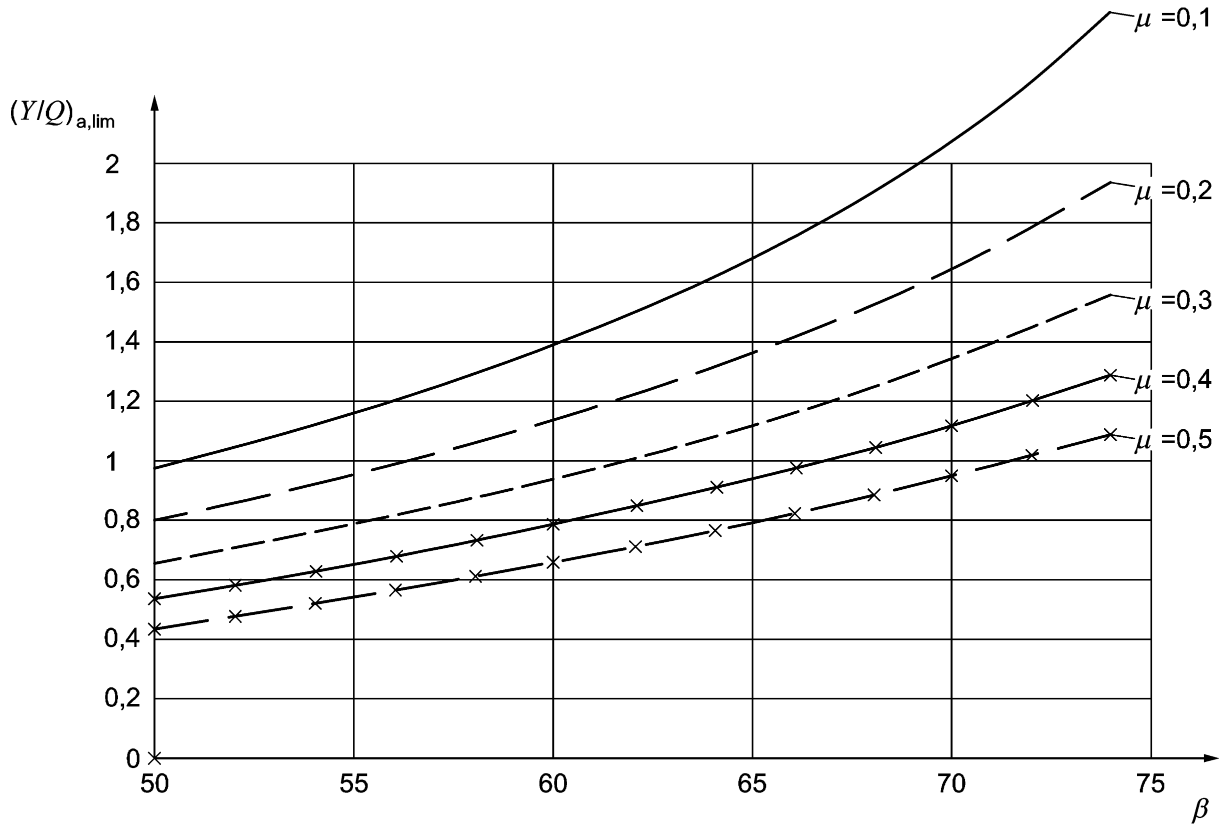
$$Y = N\sin\beta - \mu N\cos\beta$$

$$Q = N\cos\beta + \mu N\sin\beta$$

Nadal's formula for limiting $(Y/Q)_a$ is then obtained:

$$\frac{Y}{Q} = \frac{\tan\beta - \mu}{1 + \mu\tan\beta} = \tan(\beta - \arctan\mu)$$

The limiting *(Y/Q)*a is a function of the flange angle and the flange coefficient of friction μ. Values for practical ranges of flange angles and friction coefficients are shown in Figure A.2.



Key

$(Y/Q)_{a,lim}$ limiting value of $(Y/Q)_a$

β flange angle [degrees]

Figure A.2 — Limiting *(Y/Q)*a for variations in flange angle and friction coefficient

Nadal's formula determines the minimum $(Y/Q)_a$ ratio at which flange climb can occur. Particularly for small and negative angles of attack it is very conservative. The reason is that Nadal's formula is only valid for pure downward sliding of the flange. If there is longitudinal creep at flange contact, longitudinal creep forces exist and the wheel lifting component of the creep force will be less than μN. This permits higher values of $(Y/Q)_a$ than those obtained by Nadal's formula.

A.3 Friction conditions during testing on special track

Tests shall be done under dry conditions in order to consider high friction forces between wheel and rail. To describe these "dry conditions" the following background information is used.

A simplifying assumption is made that only lateral slip is considered. Then Figure A.3 shows the forces present on the inner wheel when negotiating a curve.

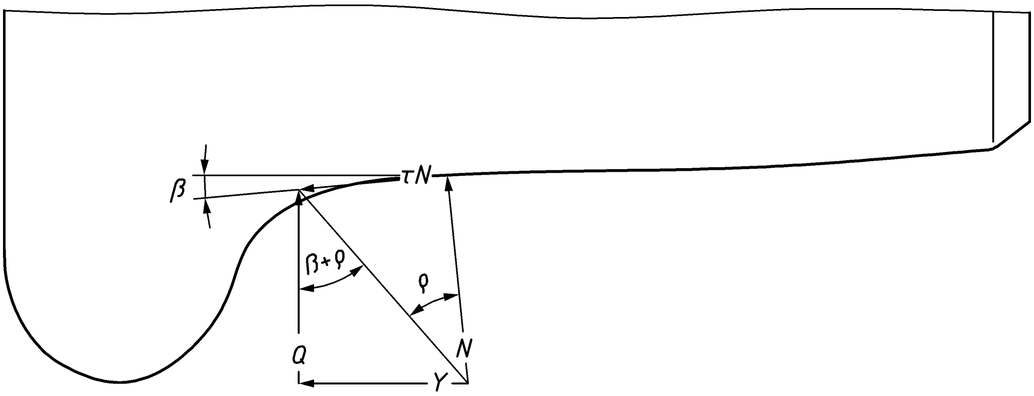


Figure A.3 — Forces on the inner wheel

By the equilibrium of forces in the contact point $(Y/Q)_i$ can be written as:

$$(Y/Q)_\mathrm{i} = \tan(\beta + \rho)$$

and transformed to:

$$(Y/Q)_\mathrm{i} = \frac{\tan\beta + \tan\rho}{1 - \tan\beta \cdot \tan\rho}$$

with β: Contact angle of the tread at the contact point on the inner rail

Since tanβ is small, $(Y/Q)_i$ can be approximated to:

$$(Y/Q)_i \approx \tan\beta + \tan\rho$$

NOTE For example for a S1002 profile according to EN 13715 the angle of contact zone tan β can be assumed to be 0,025.

tan ρ represents the relationship between lateral creep force and normal force which is termed friction coefficient τ and depends on the angle of attack (lateral creepage) and vertical wheel force. It is not to be confused with Coulomb's friction value μ, which is the maximum value of τ. Using:

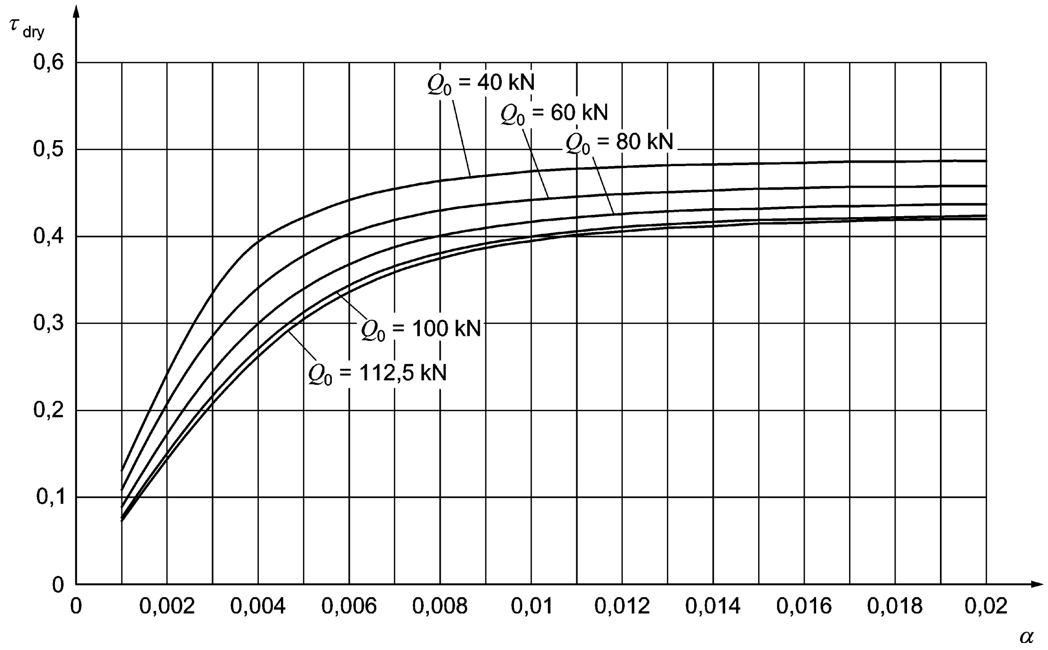
$$\tau = \tan\rho$$

leads to:

$$(Y/Q)_\mathrm{i} = \tau + \beta$$

In the above formula the contact angle of the tread β at the contact point on the inner rail shall be inserted.

The friction coefficient τ_{dry} for dry rail conditions has been determined by ERRI C9 [7]. Results are documented in UIC 510-2 [10]. The formulae are given in 6.1.3; the graphical representation is given in the Figure A.4 below.



Key

τ_{dry} ratio lateral friction force – vertical force

α angle of attack in rad

Q_0 mean static vertical wheel force of the investigated wheeset [kN]

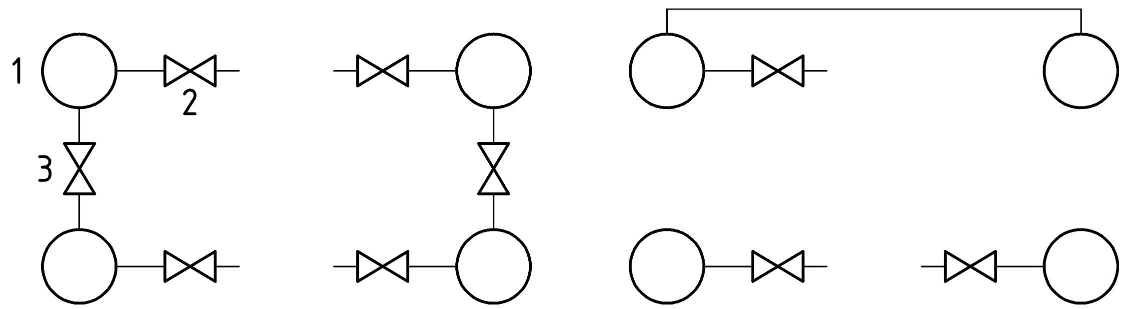
Figure A.4 — Ratio of lateral friction force to vertical force for dry friction conditions

NOTE If the actual mean vertical wheel force on the inner rail during the test differs from Q_0 it is permitted to use this value in the above diagram.

A.4 Special conditions for vehicles with air springs

A.4.1 General

There are many different types of levelling systems, therefore the examples given are not a complete list, but the factors discussed below may be relevant to other configurations. Figure A.5 and Figure A.6 show some examples.



Key

1 air spring

2 levelling valve

3 pressure difference regulator

Figure A.5 — Example of 4-point (left) and 3-point levelling system (right)

Tests on the test rig shall be done as quickly as practical to reflect the dynamic behaviour of the levelling system. Breaks at maximum twist shall be included into the test procedure to enable the system to stabilize.

A.4.2 4-point levelling systems

For limitation of vertical wheel force changes caused by twisted track, pressure difference regulators between both air springs of one bogie are used. Normally, displacements from twist may be high enough to cause the pressure difference regulators to work.

A.4.3 3-point levelling system with longitudinal connection

In case of 3-point levelling systems with longitudinal connection a connection between the two air springs on one side of the vehicle is used. The two other air springs are not connected. If the load from vehicle body on the bogie differs it may be necessary to include a pressure intensifier valve in the connection.

This levelling system uses only three levelling valves, at their position the distance between bogie and vehicle body will be nearly constant if there is enough time for stabilization of the system. After sufficient time therefore the whole displacement caused by the twist will occur on the air spring without a local levelling valve. In the event of contact with the emergency spring the vertical wheel forces may be affected.

A.4.4 2-point levelling systems

2-point levelling systems use one levelling valve per bogie which is situated near the centre of the bogie. Roll stabilization is done by anti-roll bars.

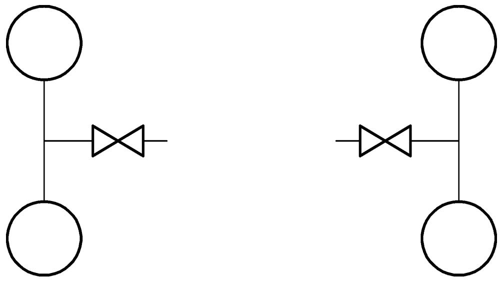


Figure A.6 — Example of 2-point levelling system

A.5 Test twist conditions for articulated vehicles

In the case of articulated vehicles where adjacent vehicle bodies are supported by a common bogie and/or a joint articulation, the connection of the vehicle bodies has a decisive influence on the safety against derailment.

If there are no significant inter-vehicle constraints, especially torsional moments around the longitudinal axis, the articulated vehicles act as individual vehicles.

The following cases shall be considered:

— Testing of an end bogie: Test twist due to the bogie wheel base $2a^{+}$ combined with a test twist due to the bogie centre distance $2a_{12}$ to $2a_{1n}$ (case b in Figure A.7).

— Testing of intermediate bogies: Test twist due to the bogie wheelbase $2a^{+}$ combined with a test twist due to the bogie centre distance $2a_{j(j+1)}$ to $2a_{jn}$ (case c in Figure A.7).

The whole train-set will have to be placed according to the test twist conditions described in 6.1.5.1.2 and 6.1.5.2.2. The calculation of the twist condition is to be based on the distances $2a_{i}$ between the respective running gear and the running gear to be tested. The corresponding twist heights are demonstrated in Figure A.7b and Figure A.7c with the running gear to be tested being positioned at 0.

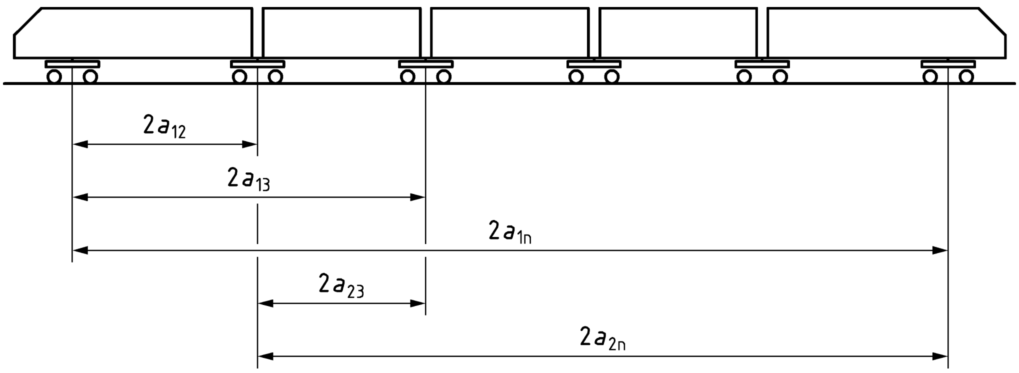
For bogie vehicles, the bogie twist (base of length $2a^{+}$) shall be superimposed on the twist of the train-set analogous to Figure 1.

If method 2 is used, the admissible wheel climb of 5 mm shall be considered for the wheelset to be tested.

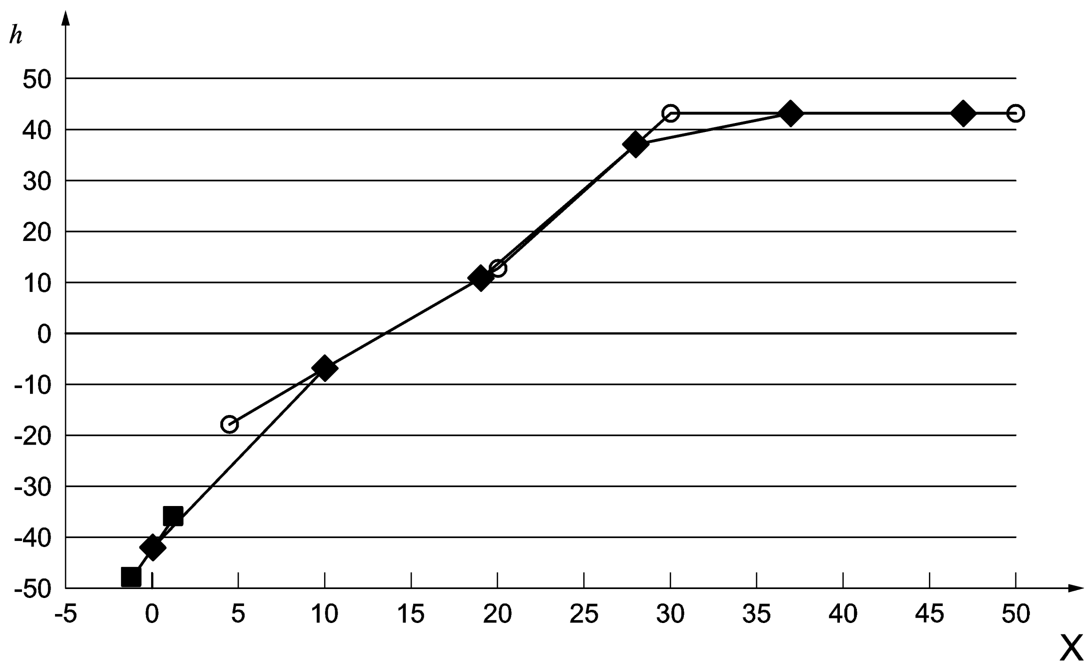
Using method 1 the effect from vehicle roll is roughly eliminated by the given track layout. Using method 2 the roll moment compensation shall be achieved by applying the twist heights such that the sum of the real cant of all running gears including the running gear tested amounts to zero within the distance of 30 m (tilting of the whole arrangement around the longitudinal axis).

The tests are to be carried out for at least one end running gear and one intermediate running gear that are likely to lead to the most unfavourable conditions. If it is not possible to determine the running gear of the most unfavourable conditions by means of its design features, more than one running gear shall be tested.

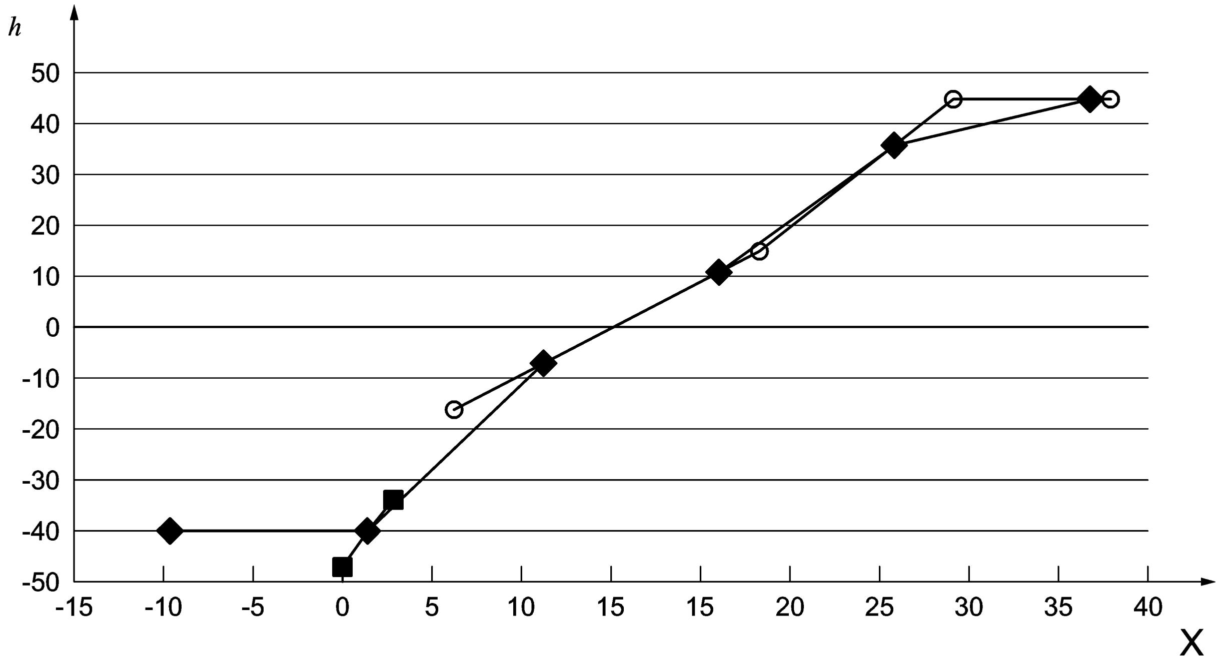
EXAMPLE Figure A.7 demonstrates the test of running gear 1 and running gear 2 of a five-unit articulated train.



a) — Configuration of five-unit articulated train



b) — Test twist for an end running gear of a coupled articulated train on the twist test rig



c) — Test twist for a centre running gear of a coupled articulated train on the twist test rig

Key

h twist height [mm]

X distance from the tested running gear [m]

—◆— test twist of the train

—■— test twist of the bogie

—○— course according to 6.1.5.2.2

Figure A.7 — Testing of an articulated vehicle

Testing of the end running gear 1:

The twist heights for the test rig twist (method 2) as well as the shims for the testing in the twisted measurement curve (method 1) are calculated first as shown in Table A.1. The required twist heights are calculated on the basis of the wheelbases, on the longitudinal distances of the bogies from the respective running gear tested and on the test twist, with the admissible wheel climb of 5 mm being considered for the twist test rig. In addition, the influence of the roll moment on the wheel unloading will be compensated in this method.

The difference between the calculated twist height and the twist height given by the geometry of the test track twisted by 3 ‰ requires the installation of shims in the suspension system in method 1. For the bogie tested, the difference between the bogie twist and the measurement track twist shall additionally be generated by shims in the primary suspension system. The thickness of the shims results from a calculation transferring twist heights to the spring base and taking the requested distribution into consideration (here bogie twist by a diagonal packing of the springs with shims in the primary suspension system and vehicle body twist by a one-sided packing of the springs with shims in the intermediate vehicle and in the end vehicle in the secondary suspension system).

Using method 2 the running gear 1 to be tested will be positioned at the continuously height-adjustable force measuring points. After the calculation of the twist condition according to Table A.1, the whole vehicle will first be lifted such that the required lowering at wheelset 1 can be realized. Force measuring devices may also be positioned under the other wheelsets. In the level condition, the first measurement of the vertical wheel forces will be carried out. Subsequently, the wheels of one vehicle side of the wheelsets 3 to n are lifted up to the calculated level. In that condition, the vertical wheel forces are again measured. When the wheels of the wheelsets 1 and 2, which are located on the height-adjustable rails, are lowered down to the calculated level of the twist of the train, the wheel force alteration is continuously measured and recorded against the height of the rails. Finally, the bogie test twist is applied by means of an additional lowering process at wheelset 1 and a lifting process at wheelset 2. Subsequently, the process is reversed using the same steps until the train is again levelled. Finally, the process described is repeated on the opposite side of the vehicle.

Testing of the intermediate running gear 2

The twist heights for the test rig twist (method 2) as well as the shims for the testing in the twisted measurement curve (method 1) are calculated first as shown in Table A.2.

Using Method 2 the running gear 2 to be tested will be positioned at the continuously height-adjustable force measuring points. After the calculation of the twist condition according to Figure A.7c, the whole vehicle will first be lifted such that the required lowering at wheelset 3 can be realized. Force measuring devices may also be positioned under the other wheelsets. In the level condition, the first measurement of the vertical wheel forces will be carried out. Subsequently, the wheels of one vehicle side of the wheelsets 1 and 2 as well as 5 to *n* are lifted up to the calculated level. In that condition, the vertical wheel forces are again measured (alternatively the level of the wheelsets 5 and 6 may also be applied to the wheelsets 3 and 4). When the wheels of the wheelsets 3 and 4, which are located on the height-adjustable rails, are lowered down to the calculated level of the twist of the train, the vertical wheel force alteration is continuously measured and recorded against the height of the rails. Finally, the bogie test twist is applied by means of an additional lowering process at wheelset 3 and a lifting process at wheelset 4. Subsequently, the process is reversed using the same steps until the train is again levelled. Finally, the process described is repeated on the opposite side of the vehicle.

Table A.1 — Example of twist height and shim height calculation for testing the end bogie of an articulated train

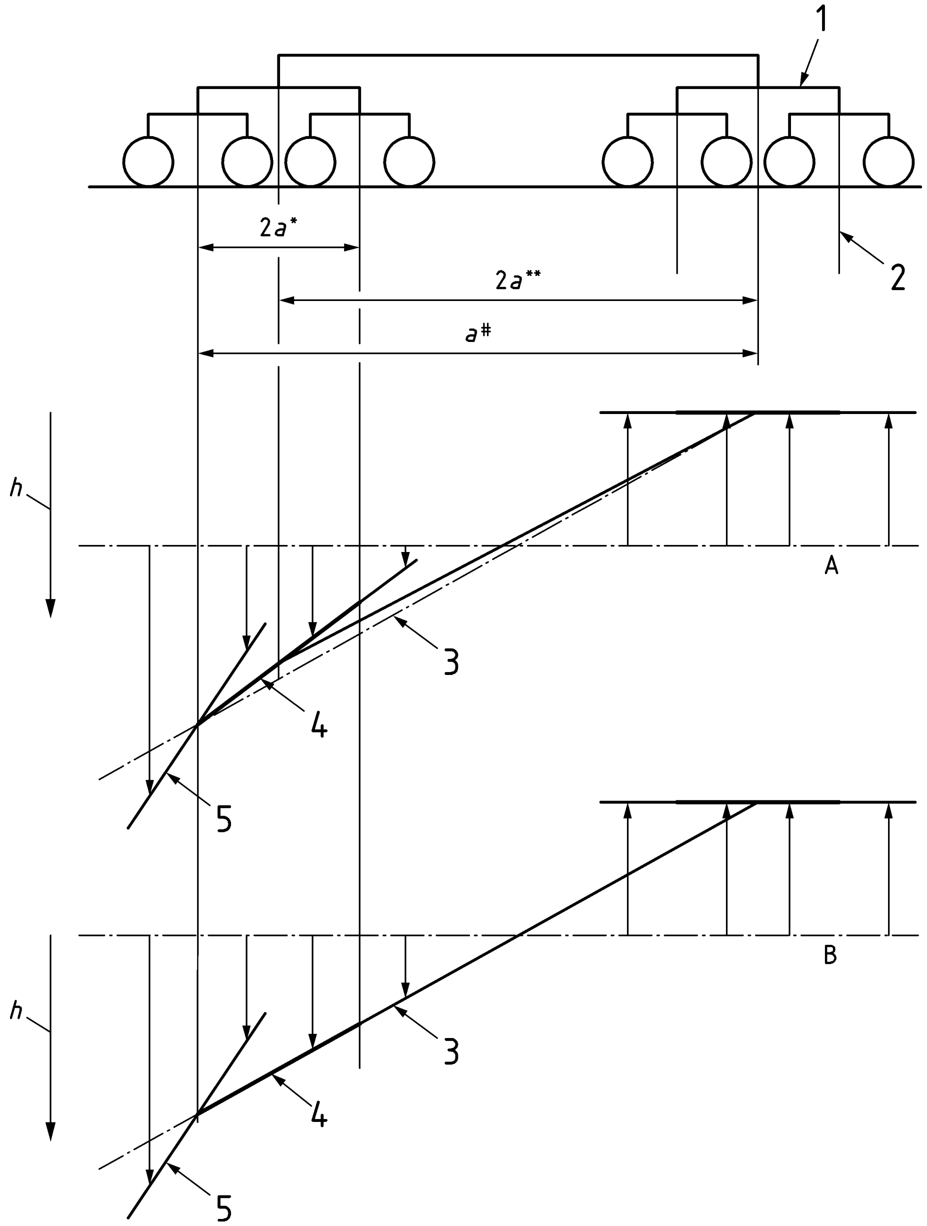
Bogie		**I**		**II**		**III**		**IV**		**V**		**VI**	
Wheelset		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
$2a^+$	m	2,400		2,600		2,600		2,600		2,600		2,400	
$2a_{1j}$	m	0,000		10,000		19,000		28,000		37,000		47,000	
Method 2													
Test twist on twist test rig													
g^+	$^0/_{00}$	$7–5/2a^+ = 4{,}92$											
g^*	$^0/_{00}$	reference		$2 + 15/2a_{1j}$ = 3,50		$2 + 15/2a_{1j}$ = 2,79		$3–5/2a_{1j}$ = 2,82		$85/2a_{1j}$ = 2,30		$85/2a_{1j}$ = 1,81	
Calculation of twist heights used on test rig													
$h^+ = g^+ \cdot 2a^+$	mm	11,8											
$h^* = g^* \cdot 2a_{1j}$	mm	0		35		53		79		85		85	
$h^*_{mean}(30\ m)$	mm	41,8											
$h^*_{corr} = h^* - h^*_{mean}(30\ m)$	mm	−41,8		−6,8		11,3		37,3		43,3		43,3	
$h\ (h^+, h^*)$	mm	−47,7	−35,9	−6,8	−6,8	11,3	11,3	37,3	37,3	43,3	43,3	43,3	43,3
Method 1													
Test twist used on test track													
g^+	$^0/_{00}$	7 = 7,00											
g^*	$^0/_{00}$			$2 + 20/2a_{1j}$ = 4,00		$2 + 20/2a_{1j}$ = 3,05		3 = 3,00		$90/2a_{1j}$ = 2,43		$90/2a_{1j}$ = 1,91	
Calculation of twist heights used on test track													
$h^+ = g^+ \cdot 2a^+$	mm	16,8											
$h^* = h_{ref} + g^* \cdot 2a_{1j}$	mm	$h_{ref} = −45$		−5		13		39		45		45	
Calculation of shim heights													
$2b^+$	m	2,1		1,8		1,8		1,8		1,8		2,1	
$2b^*$	m	1,9		2,0		2,0		2,0		2,0		1,9	
$2b_A$	m	1,5											
g^0	$^0/_{00}$	3											
$h_0 = h_{ref} + g^0 \cdot 2a_{1j}$ for $2a_{1j} \le 30$ $h_0 = h_{ref} + 90$ for $2a_{1j} > 30$	mm	−45		−15		12		39		45		45	
$d_a^+ = (g^+ - g^0) \cdot 2a^+/2 \cdot 2b^+/2b_A$	mm	0,0	6,7										
$d_i^+ = (g^+ - g^0) \cdot 2a^+/2 \cdot 2b^+/2b_A$	mm	6,7	0,0										
d_a^*	mm	0,0		$(h^* - h_0) \cdot 2b^*/2b_A$ = 13,3		$(h^* - h_0) \cdot 2b^*/2b_A$ = 1,3		0,0		0,0		0,0	
d_i^*	mm	0,0		0,0		0,0		0,0		0,0		0,0	

Table A.2 — Example of twist height and shim height calculation for testing of intermediate bogie of an articulated train

Bogie		**I**		**II**		**III**		**IV**		**V**		**VI**	
Wheelset		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
$2a^+$	m	2,400		2,600		2,600		2,600		2,600		2,400	
$2a_{2j}$	m	−10,000		0,000		9,000		18,000		27,000		37,000	
Method 2													
Test twist on twist test rig													
g^+	$^0/_{00}$			7 - $5/2a^+$ = 5,08									
g^*	$^0/_{00}$	0		reference		2 + $15/2a_{2j}$ = 3,67		2 + $15/2a_{2j}$ = 2,83		3 - $5/2a_{2j}$ = 2,81		$85/2a_{2j}$ = 2,30	
Calculation of twist heights used on test rig													
$h^+ = g^+ \cdot 2a^+$	mm			13,2									
$h^* = g^* \cdot 2a_{2j}$	mm	0		0		33		51		76		85	
$h^*_{mean}(30\ m)$	mm	40,0											
$h^*_{corr} = h^* - h^*_{mean}(30\ m)$	mm	−40,0		−40,0		−7,0		11,0		36,0		45,0	
$h\ (h^+, h^*) = h^*_{corr} \pm h^+/2$	mm	−40,0	−40,0	−46,6	−33,4	−7,0	−7,0	11,0	11,0	36,0	36,0	45,0	45,0
Method 1													
Test twist used on test track													
g^+	$^0/_{00}$			7 = 7,00									
g^*	$^0/_{00}$					2 + $20/2a_{2j}$ = 4,22		2 + $20/2a_{2j}$ = 3,11		3 = 3,00		$90/2a_{2j}$ = 2,43	
Calculation of twist heights used on test track													
$h^+ = g^+ \cdot 2a^+$	mm			18,2									
$h^* = h_{ref} + g^* \cdot 2a_{2j}$	mm	−45		h_{ref} = −45		−7		11		36		45	
Calculation of shim heights													
$2b^+$	m	2,1		1,8		1,8		1,8		1,8		2,1	
$2b^*$	m	1,9		2,0		2,0		2,0		2,0		1,9	
$2b_A$	m	1,5											
g^0	$^0/_{00}$	3											
$h_0 = h_{ref} + g^0 \cdot 2a_{2j}$ for $2a_{2j} \leq 30$ $h_0 = h_{ref} + 90$ for $2a_{2j} > 30$	mm	−45		−45		−18		9		36		45	
$d_a^+ = (g^+ - g^0) \cdot 2a^+/2 \cdot 2b^+/2b_A$	mm			0,0	6,2								
$d_i^+ = (g^+ - g^0) \cdot 2a^+/2 \cdot 2b^+/2b_A$	mm			6,2	0,0								
d_a^*	mm	0,0		0,0		$(h^* - h_0) \cdot 2b^*/2b_A$ = 14,7		$(h^* - h_0) \cdot 2b^*/2b_A$ = 2,7		0,0		0,0	
d_i^*	mm	0,0		0,0		0,0		0,0		0,0		0,0	

A.6 Test twist conditions for vehicles with more than two suspension levels

The vehicle test twist conditions in 6.1.5.1.2 and 6.1.5.2.2.3 are used as a basis for the tests. The synchronous twist of bogie wheel base and twist of the different suspension levels shall be applied.



Key

A	case 1	2	bogie	4	inter-level test twist (according to $2a^{*}$)
B	case 2	1	suspension inter-level	5	bogie test twist
h	vertical displacement	3	vehicle body test twist (according to $a^{\#}$)		

Figure A.8 — Testing of vehicles with more than two suspension levels

Test twist shall be calculated according to 6.1.5.1.2 and 6.1.5.2.2.3 with

$g_{\lim}^{+}(2a^{+})$ for bogie twist with $2a^{+}$ as the bogie wheel base

$g_{\lim}^{n^*}(2a^{n^*})$ for inter-level twist of the n^{th} level with $2a^{n*}$ as the longitudinal distance between suspension centres

$g_{\lim}^{\#}(a^{\#})$ for body twist with $a^{\#}$ as distance between one body pivot centre and the opposite centre of the first suspension level. See Figure A.8.

Tests shall be done to examine two cases:

— test twist of the different suspension levels is calculated starting with the level after the primary suspension. Test twist on vehicle body level is calculated so that $g_{\lim}^{\#}(a^{\#})$ is respected (case 1 in Figure A.8). This is combined with bogie test twist. This case leads to extreme unloading if the inter-level suspensions are rather stiff against twist;

— body twist $g_{\lim}^{\#}(a^{\#})$ is used for all suspension levels and is combined with bogie test twist (case 2 in Figure A.8).This case leads to extreme unloading if the body has an high twist stiffness.

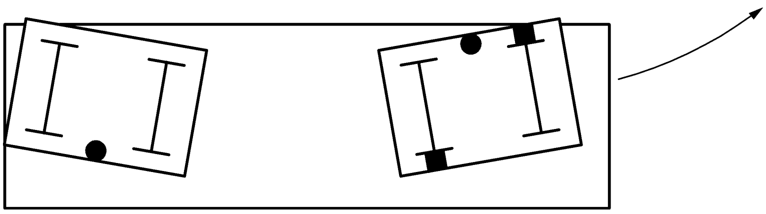
A.7 Calculation of the shim sizes (test method 1)

Test method 1 (twisted test track) uses an installed track twist. The vehicle test twist condition which is greater than the installed twist shall be installed within the vehicle by packing with shims. In general this is achieved by shims under the springs and anti-roll bar seats where applicable.

Additional vertical heights required to simulate the additional twist in the vehicle are calculated as:

$h^+ = (g^+ - g^0)\ 2a^+$ for bogie test twist

$h^* = (g^* - g^0)\ 2a^*$ for body test twist



Key

■ shims for bogie twist
● shims for body twist

Figure A.9 — Positioning of shims

These additional vertical heights are achieved by installing shims under the springs, generally in diagonally opposite corners (see Figure A.9). For calculation of shim sizes the lateral spacing of springs and wheel/rail contact points shall be considered. Shim size calculates as:

$d^+ = \frac{h^+}{2}\ \frac{2b^+}{2b_A}$ for bogie test twist

$d^* = \frac{h^*}{2}\ \frac{2b^*}{2b_A}$ for vehicle test twist

where

g^+ is the bogie test twist;
g^* is the vehicle test twist;

g^0 is the installed track twist (normally 3 ‰);
$2b^+$ is the lateral spacing of primary suspension;
$2b^*$ is the lateral spacing of secondary suspension;
$2b_A$ is the lateral spacing of rail-wheel contact points.

NOTE If packing of secondary springs with shims is complicated or not possible (e.g. freight bogies) the vertical heights for vehicle test twist can also be included into the calculation of shim sizes for primary springs.

A.8 Performing and evaluating a twist test for a two-axle vehicle (test method 2)

A.8.1 General

To evaluate safety against derailment, it is necessary to know the minimal vertical wheel force during negotiation of twisted track. This may be determined on an appropriate test rig which is able to simulate the track twist.

For evaluation of safety against derailment knowledge of minimal vertical wheel force $Q_{\min}$ is required.

If a more detailed analysis of results is required it is necessary to determine the different factors affecting wheel unloading. By evaluating the twist diagrams the different factors affecting wheel unloading arising from:

— torsional stiffness of the vehicle;

— torsional hysteresis;

— vehicle own twist; and

— eccentricity of vehicle centre of gravity

can be determined.

A.8.2 Required test rig

For evaluating the vehicle specific data a test rig should be used on which at least the supports of one wheelset are lifted and lowered. With this the twist of the track can be simulated.

To simplify the description it is assumed, that the wheels 11 and 12 of wheelset 1 are situated on such a twist device and wheelset 2 remains on horizontal track.

The displacements Δz_{jk} of the wheels 11 and 12 shall be measured continuously during the twist test. Additionally the vertical wheel forces Q_{jk} of all wheels 11, 12, 21 and 22 shall be measured by suitable devices.

All measurements shall reflect the contact points of wheel and rail. If it is not possible to measure directly at the contact points it is necessary to convert the measured values (displacements and forces) to equivalent values in the contact zone.

A similar process is to be followed if simplified measurements are carried out by lifting and lowering one wheelset using lifting devices under axle boxes.

A.8.3 Performing the twist test

Initially all four wheels shall be on a horizontal plane.

By lifting and lowering of one or more support points a closed hysteresis loop (displacement force) is created. At the beginning of the test the position of the starting point within the hysteresis loop is not known. Therefore the hysteresis loop shall be closed to enable evaluation for positive and negative twists.

To enable unambiguous evaluation of the gradient of force-displacement lines in the range of the maximum twist, test twist shall be 10 % to 20 % higher than specified vehicle test twist.

Actual twist is calculated as:

$$g^* = \frac{\Delta z_{11} - \Delta z_{12} - \Delta z_{21} + \Delta z_{22}}{2a^*}$$

where

Δz_{jk} are the displacements at the contact points *jk* in mm

$2a^*$ is the vehicle wheel base in m

g^* is the vehicle twist in ‰

If only one wheelset is moved the inclination of the vehicle body causes additional vertical wheel force changes. The effect of this additional roll moment shall be compensated (see A.8.4).

A.8.4 Evaluation of twist diagrams

Figure A.10 shows twist diagrams of a 2-axle vehicle.

Vertical wheel forces on level track are calculated as:

$$Q_{0,jk} = \frac{Q_{0,jk,\min} + Q_{0,jk,\max}}{2}$$

where

$Q_{0,jk,\text{ min}}$ is the minimum vertical wheel force at $g^* = 0$ within hysteresis loop;

$Q_{0,jk,\text{ max}}$ is the maximum vertical wheel force at $g^* = 0$ within hysteresis loop.

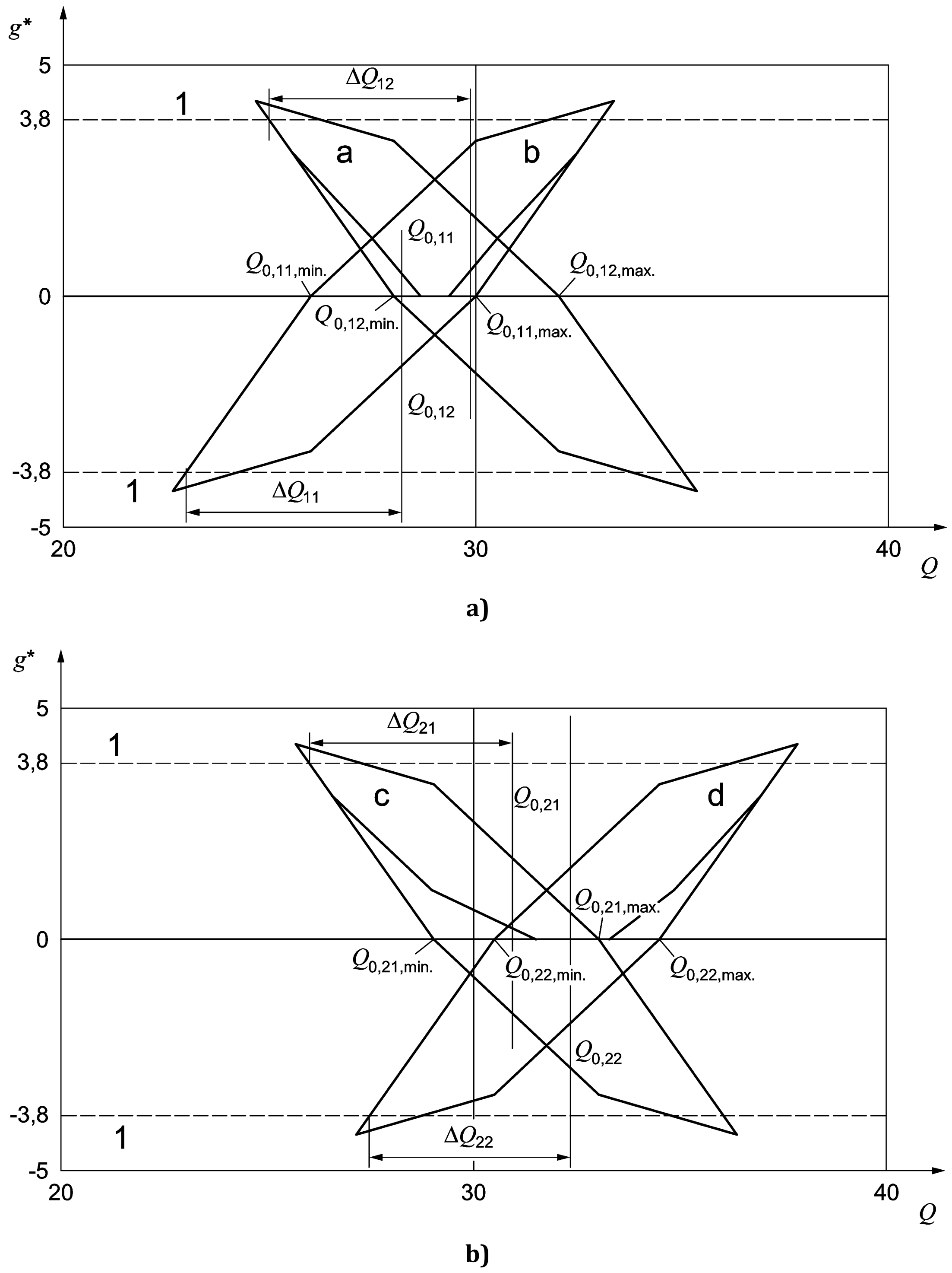
Vertical wheel force change ΔQ_{jk} is evaluated from the diagram at twist g^* (see Figure A.10).

Minimum vertical wheel forces are calculated by:

$$Q_{jk,\min} = Q_{0,jk} - \Delta Q_{jk}$$

$$c_{\text{tA}(2\text{a}^*)} = \frac{\Delta Q_{11} - \Delta Q_{12} - \Delta Q_{21} + \Delta Q_{22}}{4g^*}$$

NOTE If only one wheelset was moved and the vehicle is symmetric, the wheel-unloading due to twist is the mean wheel-unloading determined from the diagrams for wheelset 1 and wheelset 2.



Key

Q	vertical wheel force	a	wheel 12
g^*	vehicle twist	b	wheel 11
1	test twist	c	wheel 21
		d	wheel 22

Figure A.10 — Twist diagram for two-axle vehicle

A.9 Performing and evaluation of a twist test for a vehicle with two bogies with two axles (test method 2)

A.9.1 General

To evaluate safety against derailment, it is necessary to know the minimum vertical wheel force during negotiation of twisted track. This may be determined on an appropriate test rig which is able to simulate the track twist. It is necessary that the simultaneous occurrence of twist on bogie wheel base as well as twist on bogie centre distance can be simulated.

For evaluation of safety against derailment knowledge of minimal vertical wheel force $Q_{\min}$ is required.

If a more detailed analysis of results is required it is necessary to determine the different factors affecting wheel unloading. By evaluating the twist diagrams the different factors of wheel unloading arising from:

— torsional stiffness of vehicle body and vertical stiffness of suspension;

— torsional stiffness of bogie frame and vertical stiffness of primary suspension;

— torsional hysteresis;

— twist of the body and the bogie frame as a result of construction tolerances;

— eccentricity of vehicle centre of gravity

can be determined.

A.9.2 Required test rig

For evaluating the vehicle specific data a test rig should be used on which at least the supports of the two wheelsets of one bogie may be lifted and lowered. With this the twist of the track on bogie wheel base as well as on bogie centre distance can be simulated.

To simplify the description it is assumed, that the wheelsets 1 and 2 of bogie I are situated on such a twist device and wheelsets 3 and 4 of bogie II remain on horizontal track.

NOTE The influence of the inclination (see Figure A.11) of the vehicle can be excluded by moving the wheelsets of both bogies to perform the vehicle test twist.

The displacements Δz_{jk} of the wheels 11, 12, 21 and 22 shall be measured continuously during the twist test. Additionally the vertical wheel forces Q_{jk} of all wheels (11, 12, 21 22, 31, 32, 41 and 42) shall be measured by suitable devices.

All measurements shall reflect the contact points of wheel and rail. If it is not possible to measure directly at the contact points it is necessary to convert the measured values (displacements and forces) to equivalent values in the contact zone.

A similar process is to be followed if simplified measurements are carried out by lifting and lowering the wheelsets using lifting devices under axle boxes and measuring forces in the lifting devices.

A.9.3 Performing and evaluating a combined body and bogie twist test (test method 2.1)

A combined body and bogie twist test consists of twist on bogie distance base $2a^*$ combined with twist on bogie wheel base $2a^+$.

NOTE 1 This test allows a direct determination of the relevant minimal vertical wheel force $Q_{\min}$ if both bogies are moved to perform vehicle test twist. If only the wheelsets of one bogie are moved the influence of vehicle inclination (see Figure A.11) has to be considered.

In the following example in Figure A.11 it is assumed that at the wheelsets of bogie II half of the body twist is applied and the wheelsets of bogie I are moved in steps to apply the full body twist and the bogie twist: Initially all eight wheels of the vehicle shall be on a horizontal plane. First the wheelsets 3 and 4 are moved in a position, where half of the intended vehicle twist is applied to the vehicle. The measurements are taken afterwards while the twist on bogie distance base $2a^*$ is applied by synchronous lifting of wheels 11 and 21 and simultaneous lowering of wheels 12 and 22 up to the vehicle test twist g^*. Then a bogie wheel base twist is applied on bogie I by simultaneously lifting wheels 11 and 22 and lowering wheels 12 and 21 up to the bogie test twist g^+ with an extra of 10 % to 20 %. Using this sequence the minimal vertical wheel force $Q_{\min}$ occurs on wheel 12.

To get a closed hysteresis loop, bogie wheel base twist is reduced to 0, then bogie distance twist is reduced to 0.

NOTE 2 Using the sequence as described in this example the results obtained for wheelset 2 will not be valid because of reversal of forces.

NOTE 3 The example describes how to apply the twist angle to bogie II (wheelsets 3 and 4) before starting the measurement of forces and deflections.

Determination of minimal vertical wheel force on wheel 11 is done by analogy, changing also the direction of the twist by moving wheelsets 3 and 4.

Vertical wheel forces on level track for the tested wheels are calculated as:

$$Q_{0,jk} = \frac{Q_{0,jk,\min} + Q_{0,jk,\max}}{2}$$

where

$Q_{0,jk,\min}$ is the minimum vertical wheel force at $g^* = 0$ and $g^+ = 0$ within hysteresis loop

$Q_{0,jk,\max}$ is the maximum vertical wheel force at $g^* = 0$ and $g^+ = 0$ within hysteresis loop

Mean vertical wheel force for the tested wheelset is calculated as:

$$Q_{0,j} = \frac{Q_{0,j1} + Q_{0,j2}}{2}$$

Vertical Wheel force change ΔQ_{jk} due to tested effects is evaluated from the diagram at twist (g^* and g^+).

Minimum vertical wheel forces are calculated by:

$$Q_{jk,\min} = Q_{0,jk} - \Delta Q_{jk}$$

Using the combined twist the minimal vertical wheel force results from overlaying twist on base $2a^*$ and base $2a^+$. This shall be done in such a way that the wheel unloading effects of both twists are additive.

In the case of vehicles with hysteresis (e.g. leaf springs, friction dampers, spherical centre pivots) the sequence of test steps shall be carried out in such a way that there is no reversal of forces in the hysteresis.

NOTE 4 See last paragraph in A.8.3 (effect of lateral shift of centre of gravity).

If it is necessary to apply the full vehicle test twist on one bogie (deviating from Figure A.11) the wheel loading of the unloaded wheel by the induced roll moment should be quantified by calculation. The evaluated minimum vertical wheel force should be reduced by this calculated value.

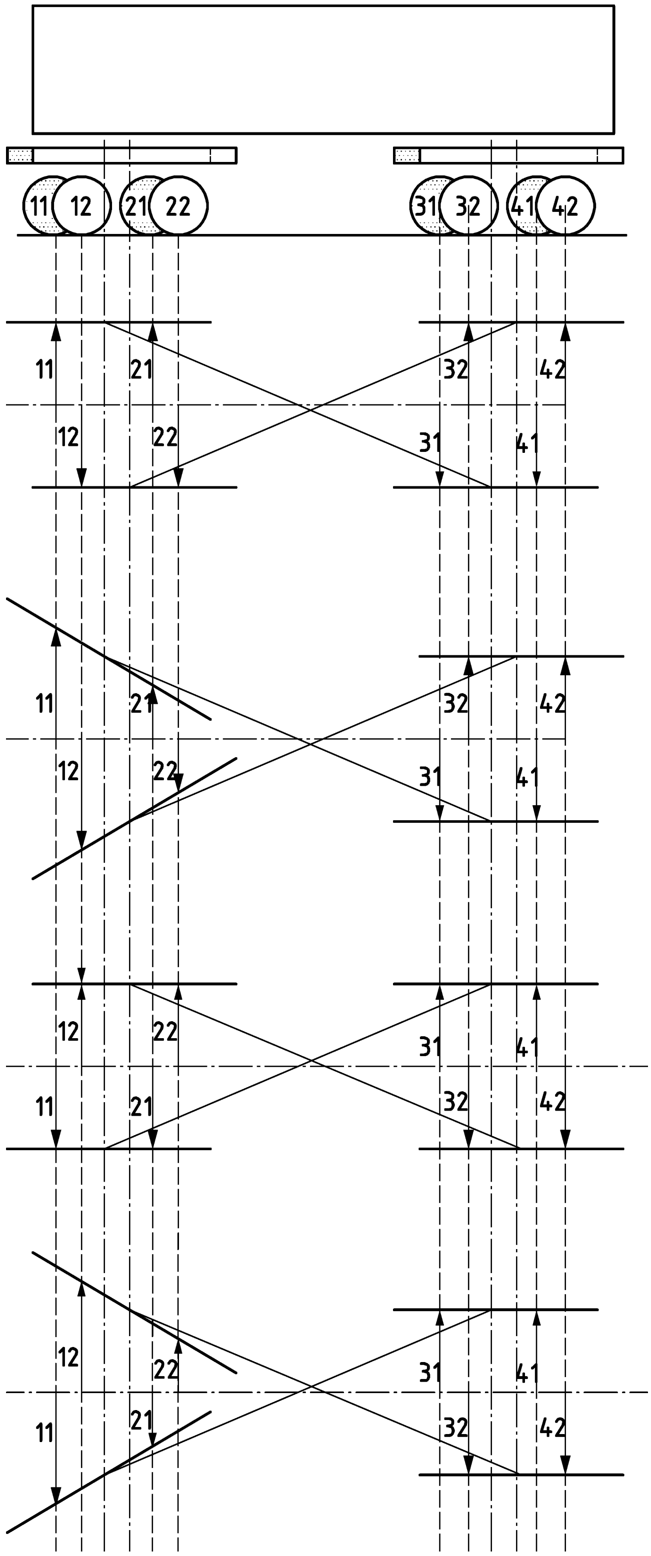


Figure A.11 — Example for sequence of the combined bogie and body twist test

A.9.4 Performing separate twist tests on bogie centre distance and bogie wheel base (test method 2.2)

A.9.4.1 General

An alternative approach to the evaluation of the vehicle is to carry out separate tests considering the effect of body twist and bogie twist. The results of these tests can then be combined to produce an overall result.

A.9.4.2 Performing and evaluating a body twist test

Initially all eight wheels of the vehicle have to be on a horizontal plane. The four wheels of bogie I are situated on the moveable supports incorporating vertical wheel force measuring devices. In this example it is assumed that the four wheels of bogie II remain level on vertical wheel force measuring devices.

By synchronous lifting and lowering of wheels 11/21 and wheels 12/22 of bogie I according to Figure A.12 closed hysteresis loops (displacement-force) are created.

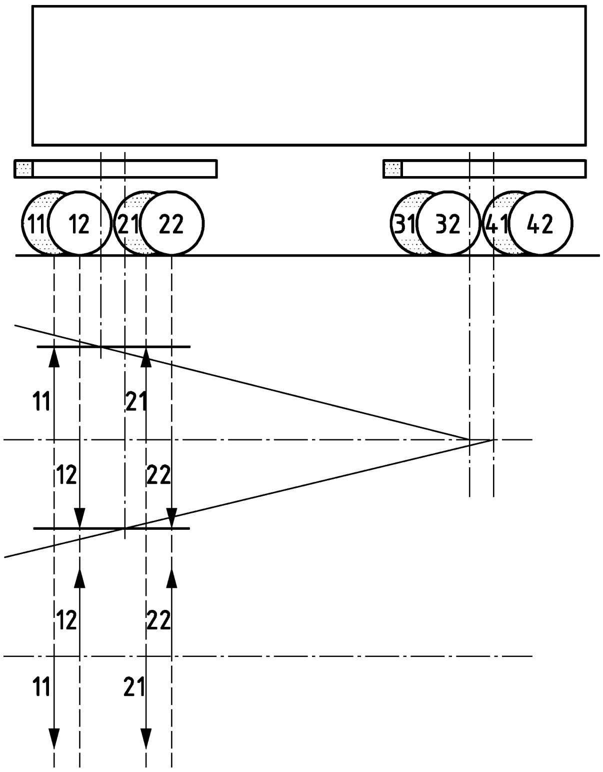


Figure A.12 — Example for sequence of twist test (bogie centre distance 2*a)**

The hysteresis loops shall have an evaluable branch for both – positive and negative – twists. At the beginning of the test the position of the starting point within the hysteresis loop is not known, therefore the first part of the twist test shall be repeated at the end of the test.

To enable unambiguous evaluation of the gradient of force-displacement lines in the range of the maximum twist, test twist shall be 10 % to 20 % higher than the specified vehicle test twist.

Actual twist is calculated as:

$$g^* = \frac{\frac{\Delta z_{11} + \Delta z_{21}}{2} - \frac{\Delta z_{12} + \Delta z_{22}}{2}}{2a^*}$$

where

$\Delta z_{12} = -\Delta z_{11}$

$\Delta z_{21} = \Delta z_{11}$

$\Delta z_{22} = -\Delta z_{11}$

$\Delta z_{31} = 0$

$\Delta z_{32} = 0$

$\Delta z_{41} = 0$

$\Delta z_{42} = 0$

Vertical wheel force change due to torsional hysteresis is equal to the half width of the hysteresis loop at twist $g^* = 0$.

Force displacement lines are analysed to determine the torsional stiffness $c^*_{\text{tA}ij}$ for each wheel. This is done by linearization between the zero twist value and test twist value using the section of hysteresis loop leading from zero twist to the extreme values of twist.

Torsional stiffness is calculated for the moved and the remote bogie:

$$c^*_{\text{tA,r}} = \frac{\sum_{j=3}^{4} \sum_{k=1}^{2} c^*_{\text{tA},jk}}{4}, c^*_{\text{tA,m}} = \frac{\sum_{j=1}^{2} \sum_{k=1}^{2} c^*_{\text{tA},jk}}{4}$$

Torsional stiffness of vehicle body calculates as mean:

$$c^*_{\text{tA}} = \frac{c^*_{\text{tA,r}} + c^*_{\text{tA,m}}}{2}$$

NOTE 1 The use of the mean stiffness takes into account that only one bogie is moved. The influence of the inclination of the vehicle body is removed from the result by this approach.

Vertical wheel force change due to inclination of vehicle body during twist test:

$$\frac{\Delta Q^*_{\text{üg}}}{g^*} = \frac{c^*_{\text{tA,r}} - c^*_{\text{tA,m}}}{2}$$

Vertical wheel force change due to lateral eccentricity of centre of gravity and from construction tolerances of the vehicle body are calculated as:

$$(\Delta Q^*_{\text{t0}} + \Delta Q_{\text{eb0}})_{\text{I}} = \frac{Q_{0,11} - Q_{0,12} + Q_{0,21} - Q_{0,22}}{4} \quad \text{for bogie I}$$

$$(\Delta Q_{t0} + \Delta Q_{\text{eb0}})_{\text{II}} = \frac{Q_{0,31} - Q_{0,32} + Q_{0,41} - Q_{0,42}}{4} \quad \text{for bogie II}$$

Twist g_{G} is defined as average twist g^* which is possible within the sidebearer clearances. It exists in general only in freight wagons with a spherical centre pivot.

NOTE 2 In this case the position within the sidebearer clearance is not defined within the width of the hysteresis loop. Therefore a secure result from a twist diagram of a twist on bogie distance base $2a^*$ is not possible (within the width of hysteresis loop). In such cases results about the maximum torsional hysteresis can be found only by a twist test on bogie wheel base $2a^+$.

A.9.4.3 Performing and evaluating the twist test on bogie wheel base

Starting from a horizontal position of all four wheels of bogie I twist on bogie wheel base $2a^+$ is applied by synchronous lifting of wheels 11 and 22 and lowering of wheels 12 and 21. Figure A.13 shows the test sequence.

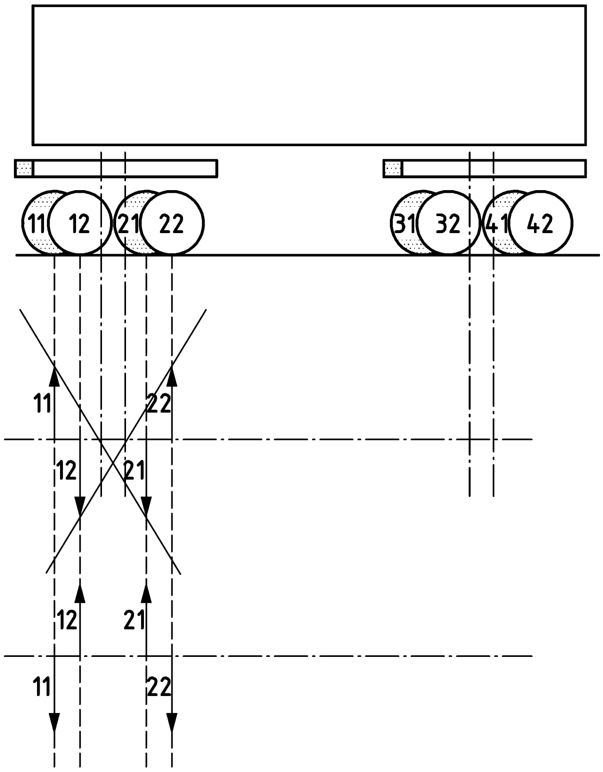


Figure A.13 — Example for sequence of bogie twist test (bogie wheel base $2a^+$)

Actual twist is calculated as:

$$g^+ = \frac{\Delta z_{11} - \Delta z_{12} - \Delta z_{21} + \Delta z_{22}}{2a^+}$$

where

$\Delta z_{12} = -\Delta z_{11}$

$\Delta z_{21} = -\Delta z_{11}$

$\Delta z_{22} = \Delta z_{11}$

NOTE 1 If twist on bogie wheel base $2a^+$ is simulated by lifting and lowering of only one wheelset (wheels 11 and 12 or wheels 21 and 22) the result is falsified by a resulting additional twist of the vehicle body.

If twist on bogie wheel base $2a^+$ is simulated by lifting and lowering of only one bogie side (wheels 11 and 21 or wheels 12 and 22) the result may be falsified by forces in the body-bogie connections (e.g. friction in a spherical pivot, anti-roll bar).

NOTE 2 If anti roll bars are arranged unsymmetrically, their influence on vertical wheel force distribution will be taken into account.

Vertical wheel force on level track is calculated as:

$$Q_{0,jk} = \frac{Q_{0,jk,\min} + Q_{0,jk,\max}}{2}$$

where

$Q_{0,jk,\min}$ is the minimum vertical wheel force at $g^+ = 0$ within hysteresis loop;

$Q_{0,jk,\max}$ is the maximum vertical wheel force at $g^+ = 0$ within hysteresis loop.

Mean vertical wheel force for the tested wheelset is calculated as:

$$Q_{0,j} = \frac{Q_{0,j1} + Q_{0,j2}}{2}$$

Vertical wheel force change due to torsional hysteresis ΔQ is equal to the half width of the hysteresis loop at twist $g^+ = 0$ and calculated as:

$$\Delta Q_{\mu,jk} = \frac{Q_{0,jk,\max} - Q_{0,jk,\min}}{2}$$

$$\Delta Q_{\mu,j} = \frac{Q_{\mu,j1} + Q_{\mu,j2}}{2}$$

Torsional stiffness $c^+_{\mathrm{tA},j}$ for each wheelset is determined from the gradient of the hysteresis loops of both wheels. Linearization is done between the zero twist value and test twist value using the section of hysteresis loop leading from zero twist to the extreme values of twist.

$$c^+_{\mathrm{tA},j} = \frac{\sum_{k=1}^{2} c^+_{\mathrm{tA},jk}}{2}$$

Vertical wheel force change due to twist arising from construction tolerances of the bogies is given by:

$$\Delta Q^+_{\mathrm{t0,I}} = \frac{-Q_{0,11} + Q_{0,12} + Q_{0,21} - Q_{0,22}}{4} \quad \text{for bogie I}$$

$$\Delta Q^+_{\mathrm{t0,II}} = \frac{-Q_{0,31} + Q_{0,32} + Q_{0,41} - Q_{0,42}}{4} \quad \text{for bogie II}$$

A separate determination of vertical wheel force changes due to twist arising from construction tolerances of the vehicle body and vertical wheel force changes due to lateral eccentricity of centre of gravity is not possible by analysis of the twist diagrams of twist on bogie wheel base.

A.9.4.4 Calculation of minimum vertical wheel force

The minimum vertical wheel force of the wheelset j can be calculated from the results of the two tests as follows:

$$Q_{j,\min} = Q_{0,j} - \Delta Q_{0j} - \Delta Q^+_{\mathrm{t},j} - \Delta Q^*_{\mathrm{t}} - \Delta Q_{\mu,j}$$

where

$Q_{0,j}$ is the average vertical wheel force evaluated by the twist test on bogie wheel base $2a^+$

$\Delta Q_{0,j}$ is the deviation from Q_0 on level track (twist g = 0)

$$\Delta Q_{0,j} = \left(\Delta Q_{t0}^{*} + \Delta Q_{eb0}\right)_{I} + \Delta Q_{t0,I}^{+}$$

where

ΔQ_{t0}^{*} is the deviation of vertical wheel force due to twist of the vehicle body as a result of tolerances

ΔQ_{eb0} is the deviation of vertical wheel force due to eccentricity of centre of gravity

ΔQ_{t0}^{+} is the deviation of vertical wheel force due to twist of the bogie frame as a result of tolerances

$\Delta Q_{t,j}^{+}$ is the deviation of vertical wheel force due to the twist on bogie wheel base $2a^{+}$ $\Delta Q_{t,j}^{+} = g^{+} \cdot c_{tA,j}^{+}$

ΔQ_{t}^{*} is the deviation of vertical wheel force due to the body twist on bogie centre distance $2a^{*}$

$$\Delta Q_{t}^{*} = g^{*} \cdot c_{tA}^{*} .$$

If the vehicle is able to reduce twist in vertical side bearer clearances:

$$\Delta Q_{t}^{*} = \left(g^{*} - g_{G}\right).c_{tA}^{*}$$

$\Delta Q_{\mu,j}$ is the vertical wheel force change due to torsional hysteresis

Annex B
(informative)

Computer simulations designed to examine whether the vehicle has an acceptable resistance to flange climbing derailment at low speed

B.1 General requirement

The process described in this annex, including simulation, shall only apply to the Method 3 as defined in 6.1.5.3. The validation required is separate from that described in informative Annex T and a separate model may be used.

A computer simulation which has been validated by suitable tests and/or practical experience shall be used to predict the behaviour of a vehicle running over the track geometry described below. The vehicle configurations covered by the simulation shall be such as to allow all significant representative conditions to be assessed. The speed shall be sufficiently low to allow the effect of full cant excess to be examined. Prior to this simulation, appropriate practical tests (normally laboratory-based) shall be carried out on the assembled vehicle and/or on components so as to ensure that the wheel unloading behaviour on twisted track and, where relevant, the bogie rotation behaviour are well understood, and that the parameters of the vehicle model to be used in the simulation have been adjusted to reflect the measured behaviour.

A wheel/rail coefficient of friction of 0,32 shall be used.

B.2 Computer output

The simulation shall be capable of generating a time history of $(Y/Q)_a$ ratio at the most unfavourable wheel. The $(Y/Q)_a$ ratio shall be computed using a sliding mean over a 2 m length of track.

B.3 Track input

The nature of the track input used for the computer simulation shall be as follows:

a) it shall consist of a length of straight track, a run-on transition, a constant curvature section with cant, a run-off transition and a length of straight track.

   A range of track curvatures sufficient to identify the worst case condition shall be investigated. The limits on cant associated with curves of different radii shall be assumed to be as follows:

	$R \geq 200$ m	150 mm maximum cant
200 m >	$R \geq 150$ m	100 mm maximum cant
150 m >	$R \geq 100$ m	50 mm maximum cant

b) the run-on and run-off transitions shall be linear with gradients of 1:300.

c) the track geometry shall be assumed to be perfect except that the high rail of the run-off transition shall have a 20 mm dip in it which is triangular in form and has a semi-span of 6 m. The lowest point of the twisted track (the dip) shall be positioned so as to create the most unfavourable situation

NOTE The high rail dip will normally give worst case behaviour when it is positioned so as to increase the effective twist on the vehicle (i.e. on the run-off transition). By placing it towards the top of the run-off transition, it will be negotiated by the leading bogie, which is the one generally most susceptible to derailment, while the vehicle is seeing maximum cant and curvature, but with little twist contribution from the transition. As the dip is moved down the run-off transition, twist increases whereas cant decreases, as does the curvature seen by the leading bogie. Some experience of the predicted behaviour will therefore be necessary in order to ascertain the likely worst case position for the dip, as this will be a function of the sensitivity of the vehicle to cant, twist and curvature.

For situations where the run-off transition is long compared with the vehicle, the worst case situation may occur when the dip is positioned such that the leading wheelset of the leading bogie is negotiating it just as the trailing wheelset is leaving the constant radius section. At this point the vehicle sees maximum cant excess and twist, while the leading bogie still sees significant curvature. Where the vehicle and run-off transition are of comparable length, or where the vehicle is longer (which may well be the case for the short transitions corresponding to low values of cant), the leading bogie will see little or no curvature as it negotiates the dip if the dip is positioned as suggested above. Here the worst case situation may well be with the dip close to the beginning of the run-off transition.

d) The constant radius portion of the track shall be gauge widened as a function of radius *R*, according to the following criteria.

R > 200 m	zero gauge widening
200 m to 176 m	6 mm gauge widening
175 m to 151 m	9 mm gauge widening
150 m to 126 m	13 mm gauge widening
125 m to 101 m	16 mm gauge widening
R ≤ 100 m	19 mm gauge widening

The transitions shall be considered to be gauge widened on a progressive basis so that there are no discontinuities of gauge. If the computer algorithm does not permit variation in the wheel/rail contact geometry along the length of track, sufficient simulations at different distinct wheel/rail geometries shall be performed so that the behaviour on the stated geometry can be understood.

B.4 Body-bogie yaw torque

While no lateral irregularity is specified, it shall be assumed that there is such an irregularity, at the most unfavourable position on the track, sufficient to ensure that the direction of rotation of the bogie during the critical period where flange climb may be induced is such that the velocity dependent part of the body-bogie yaw torque (i.e. that induced by viscous or frictional effects) acts in a sense which increases the $(Y/Q)_a$ value at the critical wheel. It shall be assumed that the corresponding instantaneous body/bogie yaw velocity is 1° per second. It shall be sufficient to model the effect of this irregularity by application to the bogie concerned of a steady-state external torque in the appropriate sense, or to modify the body/bogie yaw torque characteristics in a suitable manner, such that the net effort is to apply a torque to the bogie in a direction which promotes derailment at the critical wheel. There is no requirement to put the irregularity into the plan view track profile.

B.5 Performance requirement

The computed $(Y/Q)_a$ value shall nowhere exceed 1,2 for wheel profiles with flange angles equal to or greater than 68°. For vehicles with smaller flange angles the appropriate limiting value shall be determined on the basis of Nadal’s criterion (below), but taking into account any previous service experience which indicates that the angle increases rapidly as the profile wears, as has been found to be the case for the former British Rail BR P5 profile.

Nadal's formula indicates that the limiting value of $(Y/Q)_a$ above which derailment will occur is given by:

$$\frac{Y}{Q} = \frac{\tan\beta - \mu}{1 + \mu\tan\beta}$$

where

β is the flange angle
μ is the coefficient of wheel/rail friction (in this case 0,32).

Annex C
(informative)

Tests for determination of the torsional coefficient of a vehicle body

C.1 Force-deflection measurement directly at the vehicle body

The vehicle body is supported at four points; ideally the side bearers are used. If the vehicle body can be regarded as torsionally homogeneous, other points nearby may be used, for example the support points for rerailing. In any case the actual measurement locations shall be used for the Formula (1) in 6.3.

Figure C.1 shows the nomenclature of the support points.

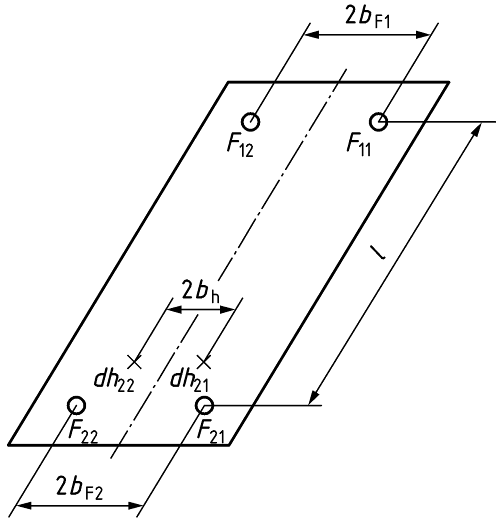


Figure C.1 — Nomenclature of the supporting points

<u>Method 1:</u> All support forces F_{ij} are measured and a torsional angle is applied by lifting and lowering one of the supports returning back to the initial position. The vertical deflection dh_{2j} of the moved point $2j$ is measured near to the related supporting point. This test is performed continuously or in small steps up to the test twist according to 6.1.5.2.2.3 or until one support is completely unloaded. The torque and the angle for Formula (1) in 6.3 are calculated by the following formulae:

$$M_t = ((F_{11} - F_{12})b_{\mathrm{F1}} - (F_{21} - F_{22})b_{\mathrm{F2}})/2 \qquad \text{(C.1)}$$

$$\vartheta = \mathrm{d}h_{2j} / 2b_{\mathrm{h}} \qquad \text{(C.2)}$$

<u>Method 2</u>: All support forces F_{ij} are measured and a torsional angle is applied at one end by lifting one support $2j$ and lowering the one on the opposite side at the same end by approximately the same amount returning to the initial position. The test is performed continuously or in small steps up to the test twist according 6.1.5.2.2.3 or until one point is completely unloaded. The related vertical deflections dh_{21} and dh_{22} are measured.

The torque and the angle for Formula (1) in 6.3 are calculated by the following formulae:

$$M_{\mathrm{t}} = ((F_{11} - F_{12}) \cdot b_{\mathrm{F1}} - (F_{21} - F_{22}) \cdot b_{\mathrm{F2}})/2 \qquad \text{(C.3)}$$

$$\vartheta = \left(\left|\mathrm{d}h_{21}\right| + \left|\mathrm{d}h_{22}\right|\right) / 2b_{\mathrm{h}} \quad \text{(C.4)}$$

C.2 Force-deflection measurement at the contact points between wheel and rail after blocking of the suspension(s) between wheelset (bogie frame) and vehicle body

The free movements and suspension deflections are blocked, ensuring the vehicle remains in the initial level, in order to create a rigid support system. In this case the longitudinal base l in Formula (1) becomes the distance between wheelsets or bogie distance $2a^*$ and the lateral bases $2b_{\mathrm{h}}$ and $2b_{\mathrm{F}i}$ become the lateral distance between the wheel rail contact points $2b_{\mathrm{A}}$. One of the methods described in C.1 is applied by analogy using the contact points at the wheels as supporting points. If a bogie vehicle is investigated, the sum of the two wheels of one bogie on one vehicle side is used as support force.

Annex D
(informative)

Determination of displacement characteristics for application with EN 15273

D.1 Introduction

The purpose of this annex is to define the test methods to be applied to generate the necessary data to enable the process defined in EN 15273 to be applied.

D.2 Determination of displacement characteristics

D.2.1 General

The tests described in this annex evaluate the vehicle body's displacement characteristics caused by lateral forces acting on the vehicle body arising from cant excess and cant deficiency. With the tests described here it is possible to determine inputs for gauging calculations, as defined in EN 15273-1 and required in EN 15273-2.

NOTE It could also be useful to apply the test to confirm that the displacements of the vehicle in roll around the x-axes and the characteristics for the installed suspension components are within the design limits. It is also possible to use the results for computer model validation.

In this annex, two alternative methods are specified that may be used to determine the displacement characteristics of the vehicle. Only one method is required to be used.

— **Method 1:** The determination of the displacement characteristics is carried out by measurements of the vehicle while standing.

— **Method 2:** Determination of the displacement characteristics during on-track tests is carried out either by measurement of accelerations in the vehicle body or by measurement of the relative movement of parts within the vehicle together with the cant deficiency.

D.2.2 Assessment Requirements

No assessment requirements are specified in this sub clause, only the methods of testing are defined. The appropriate assessment requirement is determined by reference to EN 15273.

D.2.3 Test conditions

D.2.3.1 General

Unless stated below, all conditions of the test vehicle shall comply with the requirements specified in 5.3.

D.2.3.2 Vehicle test conditions

Single vehicles that are not subject to the influence of adjacent vehicles shall be tested separately without any inter-vehicle constraints. Where a test on a single vehicle is not possible the influence of inter-vehicle constraints shall be analysed in order to determine their significance.

Other vehicles such as articulated trains shall be tested with the normal configuration of the connections to adjacent vehicles.

D.2.3.3 Load condition

The test vehicle shall comply with the requirements in 5.3.2 or with requirements specified in EN 15273 depending on the aim of the test.

Where test conditions do not allow the defined loading to be achieved it is permitted to simulate the loaded condition. This load simulation should include, as far as possible, a representation of the position of the centre of gravity of the loaded vehicle body, including height and offset.

D.2.3.4 Fault mode conditions

The requirements in 5.2.2 shall form the basis of determining which tests are to be carried out.

D.2.4 Method 1: Stationary test

D.2.4.1 General

The vehicle is tilted as on a real track, usually by shims under either the wheels or axle boxes. The collection of data are made during the tilting operation; subsequent analysis of the measurement data determines the displacement characteristics information.

The extent of data to be obtained from this test method is determined by two factors:

1) The presence of linear or nonlinear suspension characteristics within the operating range.

2) The gauging method (see EN 15273-2) for which the evaluated data are needed.

For certain gauging methods of EN 15273-2, the use of a theodolite and associated targets attached to various elements of the vehicle is recommended.

D.2.4.2 Vehicles with air springs

The effect of the air spring levelling system's response time shall be investigated. If the response time of the levelling system affects body roll of the vehicle during the test then the levelling valves shall be disconnected such that the air springs act as passive elements.

D.2.4.3 Test site

The test shall be carried out at a measurement place consisting of track that is level in both the longitudinal and transverse planes with provision to apply the inclination accurately. It shall be possible to incline the plane of all wheelsets in both directions to simulate cant excess and cant deficiency at all positions of the vehicle. The inclination of the wheelsets shall be applied simultaneously in steps to the maximum value.

The maximum applied test cant shall be sufficient to represent the forces arising from steady-state cant deficiency or excess.

The load path through the suspension shall be consistent with that experienced by the vehicle in operation.

D.2.4.4 Measured and derived quantities

Vertical deflections or angles of the vehicle body and one wheelset shall be measured on marked points in such a way that it is possible to derive:

— η^0 roll angle of the wheelsets relative to the un-canted track plane (cant angle);

— η^+ bogie roll angle relative to η^0;

— η^* vehicle body roll angle relative to η^0;

— $s = \eta^*/\eta^0$ flexibility coefficient;

Depending on the gauging method (see EN 15273-2) additional quantities shall be measured:

— Δy^+ lateral movement of the bogie at a defined point relative to the perpendicular axis of the wheelset;

— Δy^* lateral movement in the secondary suspension;

— y_P lateral movement of the vehicle body at a defined point P relative to the perpendicular axis of the wheelsets;

— h_P the height above the running plane of a defined point P in the longitudinal centre plane of the vehicle.

Figure D.1 shows the condition represented by the test. At each value of cant – from maximum negative to maximum positive value – measured values and derived values shall be measured and evaluated.

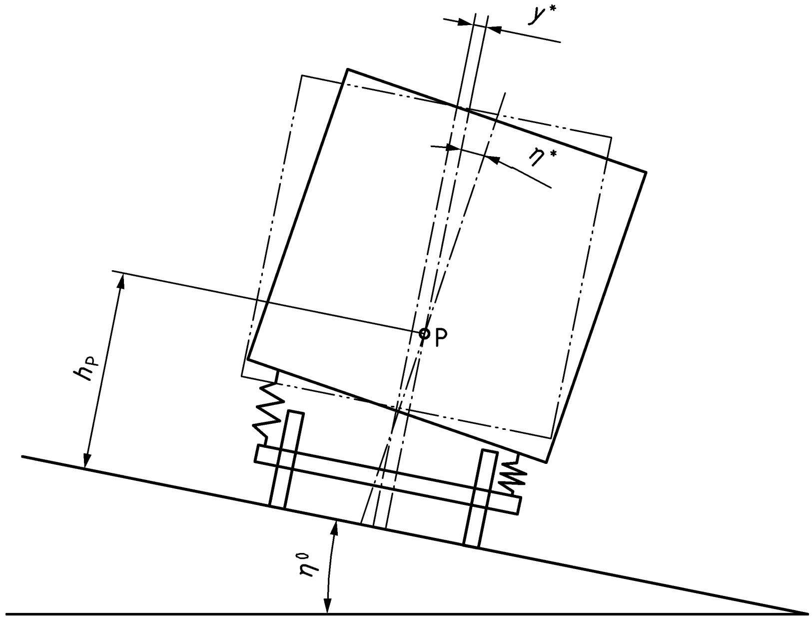


Figure D.1 — Standing vehicle on canted track (example of vehicle without bogies)

D.2.4.5 Data for evaluation of flexibility coefficient (for Defined Gauging)

For evaluation of the flexibility coefficient (as defined in EN 15273) diagrams shall be produced showing $\eta^* = f(\eta^0)$ and $y_P = f(\eta^0)$, if measured. To enable unambiguous evaluation of the flexibility coefficient the tests shall be carried out for positive and negative cant, the maximum (positive and negative) test cant shall be at least 10 % higher than the specified maximum operating cant deficiency or cant excess. The results shall be plotted. Generally, this takes the form of a hysteresis loop. A sufficient set of data shall be recorded to achieve a closed loop.

Figure D.2 shows an example of a diagram $\eta^* = f(\eta^0)$.

NOTE The crosses in the diagram indicate the measured values at different cant angles. It shows a hysteresis of the measured roll angles which is caused by friction in the suspension. If the behaviour is linear, the roll coefficient can be calculated by fitting a straight line.

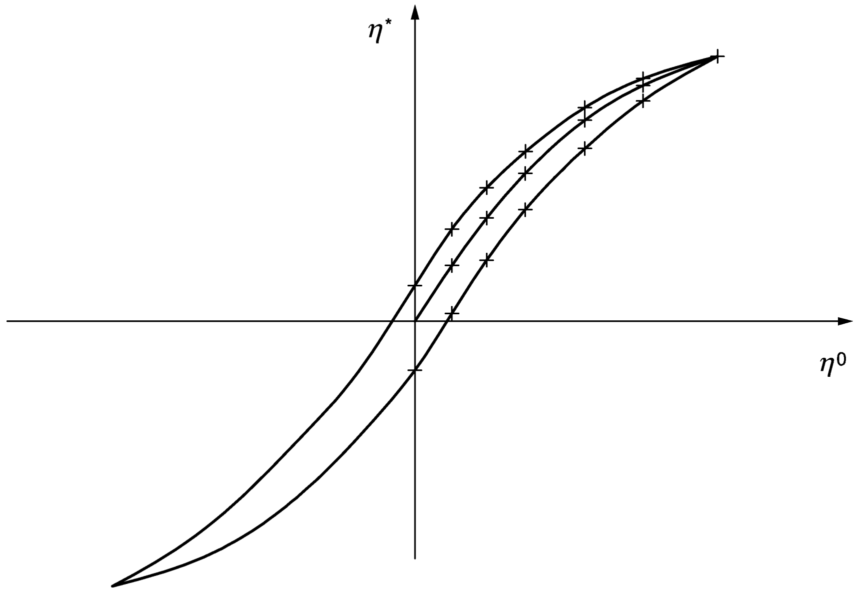


Figure D.2 — Example of roll angle diagram

In case of asymmetry as shown in Figure D.3, the y-intercept shall be associated with the calculation of the coefficient (slope of the regression line).

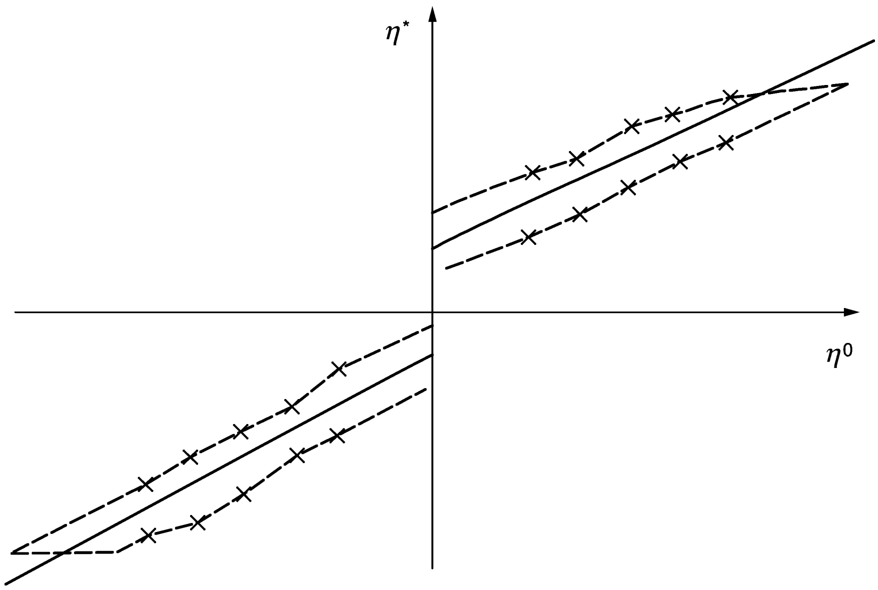


Figure D.3 — Example of roll angle diagram in case of asymmetry

D.2.4.6 Data for computation of displacements (for Dynamic Gauging)

For proof of displacement computations the following diagrams shall be produced:

— $\eta^* = f(\eta^0)$

— $y_p = f(\eta^0)$

— $\eta^+ = f(h^0)$

— $y_{bog} = f(h^0)$

To enable unambiguous proof of computations the tests shall be carried out for positive and negative cant, the maximum (positive and negative) test cant shall be at least 100 mm higher than the specified maximum operating cant deficiency or cant excess. The results shall be plotted, generally this takes the form of a hysteresis loop and sufficient test results shall be recorded to archive a closed loop. An example for a presentation is given in Figure D.4.

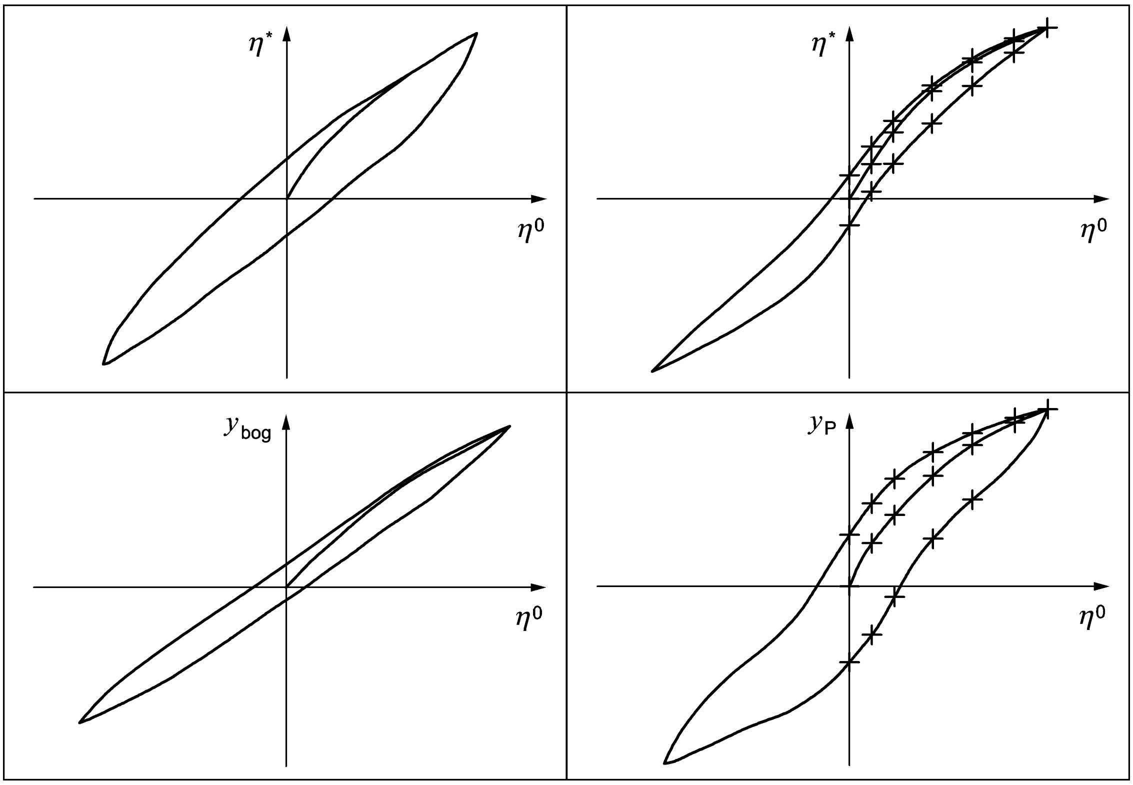


Figure D.4 — Examples of diagrams required for proof of computations

D.2.5 Method 2 – On-track test

D.2.5.1 General

The determination of the flexibility coefficient is done as the vehicle operates on the track with cant excess and/or cant deficiency. Two means of recording the associated vehicle response are permitted, either by:

— measurement of lateral accelerations; or by

— measurement of roll movements.

Measurements shall be made for at least 25 sections of curved track covering a range of cant deficiencies as large as available. Data from this method is suitable for use only for the Defined Gauging process.

D.2.5.2 Measurement of lateral accelerations

The vehicle displacement characteristics are determined by measurement of:

— $\ddot{y}^*$ lateral acceleration in vehicle body;

— $\ddot{y}$ lateral acceleration of the wheelsets (lateral acceleration on track level).

where both acceleration signals are low-pass filtered using the same cut-off frequency, below 1 Hz.

For this method particular attention shall be paid to an accuracy analysis based on the measuring uncertainty on the two input accelerations.

D.2.5.3 Measurement of roll movements

The vehicle displacement characteristics are determined by measurement of:

— $\Delta\eta^*$ roll angle difference between vehicle body and bogie frame for bogie vehicles or between vehicle body and wheelset for non-bogie vehicles;

— $\Delta\eta^+$ roll angle difference between bogie frame and wheelset for bogie vehicles; and

— $\ddot{y}$ lateral acceleration of the wheelsets (lateral acceleration on track level).

D.2.5.4 Evaluation

Analysis of the test data described in D.2.5.2 or D.2.5.3 shall be done using the mean values in track sections of curved track. Processing of the measuring signals shall be done as described in 7.6 using the two-dimensional evaluation for quasi static quantities. At least 25 track sections shall be used.

It is not necessary to make separate evaluations for the different test zones.

Since the levelling system of vehicles with air springs cannot be disconnected, the influence of the response time shall be analysed in the time history of the recorded signals. Depending on the result of this analysis it shall be decided how many sections of each curve are representative for the dynamic behaviour of the air spring system. Only representative sections shall be included in the statistical analysis.

The flexibility coefficient shall be derived from:

$$S_{\mathrm{R}} = \frac{\ddot{y}^*}{\ddot{y}} - 1$$

for measurement of vehicle body accelerations, or

$$s = \frac{g}{\ddot{y}} \cdot \left(\Delta\eta^+ + \Delta\eta^* \right)$$

for measurement of roll angle differences in primary and secondary suspension.

Annex E
(informative)

Assessment of the behaviour of vehicles with small wheels in curved crossings

E.1 Purpose

In crossings, unguided gaps exist, depending on crossing angle, height of check rails, wheel diameter and flange height of the wheel. In some European networks obtuse crossings are located also in curves. In such a situation lateral forces on the wheelset can occur, leading to a risk of misdirection of the wheelset. This risk can be described by the angle of attack and the lateral forces, or by the angle of attack at the entrance to the gap and the impact of the wheel on the crossing nose.

The assessment conditions are based on a description developed by ERRI (see Bibliography UIC 510-2 [10] and ORE-C9 [7]).

E.2 Area of application

Investigations according to this annex shall be performed only for vehicles:

- with minimum permitted wheel diameters $d \leq 840$ mm;
- which are intended to be operated in specific networks with obtuse crossings located in curves.

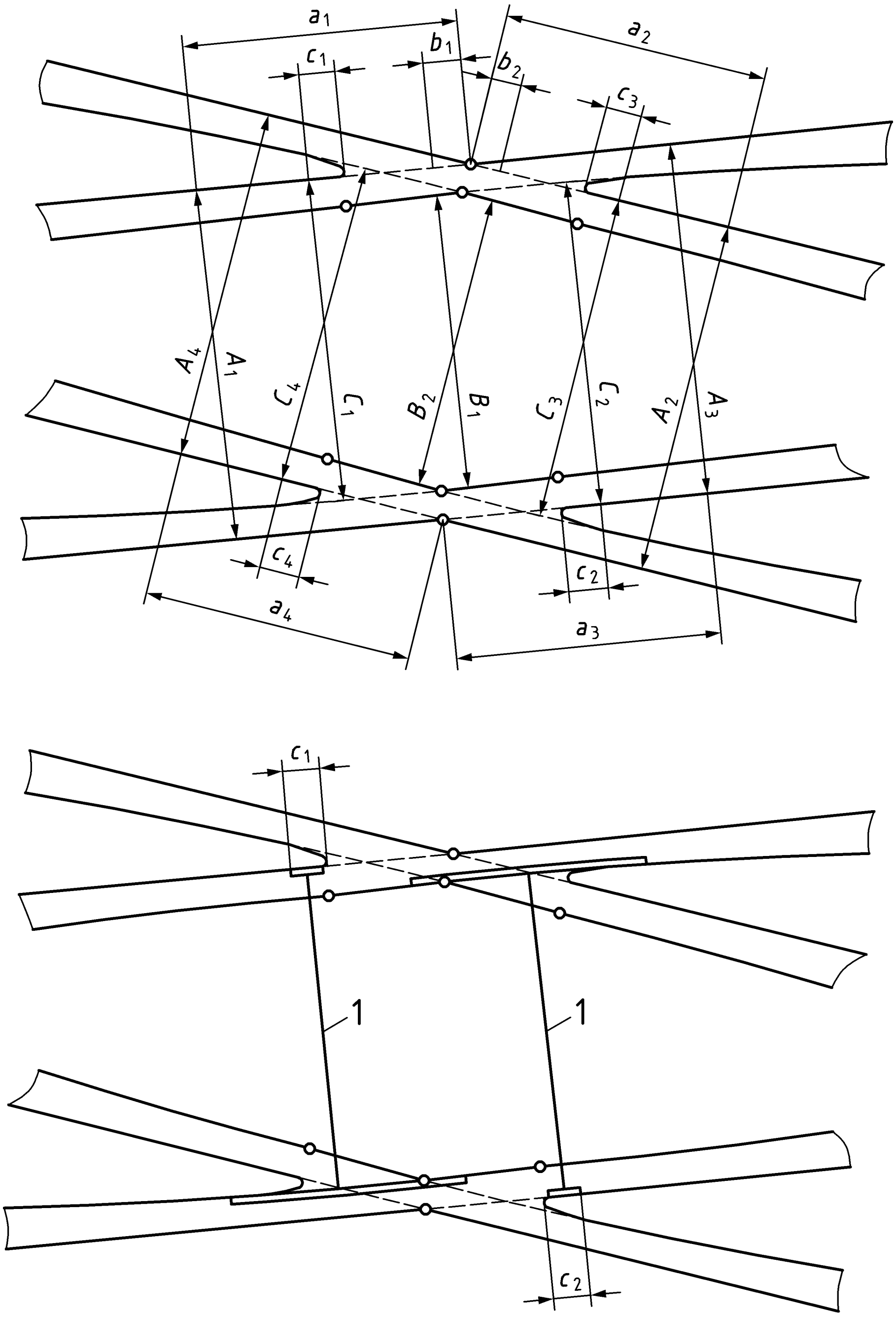
NOTE It is assumed that the following relationship between flange height and wheel diameter is respected.

Table E.1 — Relationship between minimum permitted wheel diameter and flange height

Minimum permitted wheel diameter	Nominal flange height
$d > 760$ mm	$S_h \geq 28$ mm
$630 < d \leq 760$ mm	$S_h \geq 30$ mm
$d \leq 630$ mm	$S_h \geq 32$ mm

E.3 Description of the crossing geometry

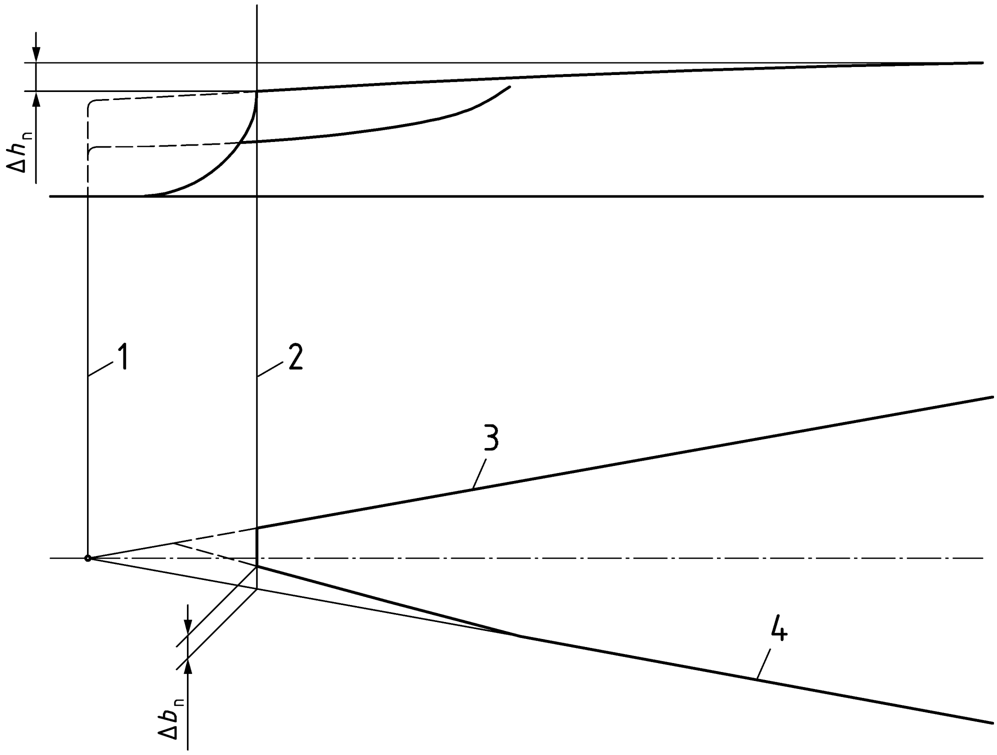
The vehicle's guiding behaviour is assessed for curved crossings with the parameters given in the following table (see also Figure E.1 and Figure E.2):



Key

1 measuring instrument

Figure E.1 — Geometry of curved crossing for testing of running safety



Key

1 mathematical nose
2 physical nose
3 running edge
4 check face

Figure E.2 — Detail of the crossing nose

Figure E.3 — Example for curved crossing (DB Systemtechnik, Minden)

Table E.2 — Parameters of curved crossing

Curve Radius	R = 450 m
Cant	u = 0 mm
Crossing angle	α = 1:9
Track gauge of the crossing (see dimensions A_1, A_2, A_3 and A_4 in Figure E.1)	$TG = 1\,435^{+4}_{-2}$ mm
Flangeway clearance	40^{+4}_{-4} mm
Dimensions for nose protection (see dimensions C_1, C_2, C_3 and C_4 in Figure E.1)	$1\,395^{+3}_{-2}$ mm
Dimensions for running clearance (see dimensions B_1 and B_2 in Figure E.1)	≤ 1 356 mm
Location of measurement (see dimensions a_1, a_2, a_3 and a_4 in Figure E.1)	750 mm
Location of measurement (see dimensions b_1, b_2, c_1, c_2, c_3 and c_4 in Figure E.1)	80 mm
Height of check rail above rails	$h_{cR} = 45^{+10}$ mm
Height reduction of the nose over a length of 200 mm – 500 mm (see Figure E.2)	Δh_n = 8 mm approximately
Width reduction of nose over a length of 150 mm (see Figure E.2)	Δb_n = 3 mm approximately

The specified set of data are related to the DB type of crossing described in UIC 510–2. For assessment of vehicles with small wheels in other types of crossings modified parameters should be used.

E.4 Test conditions

E.4.1 General

There are two methods specified in the following clauses to demonstrate safe behaviour of vehicles with small wheels in curved crossings according to E.3. Only one of the two methods is required to be carried out.

The tests shall be conducted with the empty vehicle in a curve with a nominal radius of 450 m with an installed cant of 0 mm. They shall be conducted with different speeds between 10 km/h and the vehicle's maximum service speed up to a maximum of 60 km/h, the test with the highest speed shall be performed three times.

The tests shall be performed with minimum traction forces to ensure a roughly constant speed and be repeated also in failure conditions unless the failure study proves that there is no negative effect.

The back to back distance and the flange thickness of the outer guiding wheel shall be documented.

The wheel diameter shall be between the nominal diameter D and the minimum permitted diameter d.

E.4.2 Method 1: Lateral forces and angle of attack

In Method 1 the assessment shall be based on the angle of attack and either the lateral axle box forces H or the sum of the lateral vertical wheel forces ΣY in the full curve. The H-forces and ΣY-forces (if measured with instrumented wheelsets) shall be processed as specified in 7.6.3.1. Alternatively it is possible to measure the ΣY-forces with track mounted equipment.

NOTE In this method it is not necessary to have a physical crossing installed in the curve.

The running clearance between wheel and rail shall be within the range 10 mm ≤ (TG - SR) ≤ 20 mm during the operation of the vehicle in the full curve. The test shall be performed in dry rail conditions to respect high lateral forces in the assessment.

E.4.3 Method 2: Examination of the impact on the crossing nose

In Method 2 the assessment shall be based on the angle of attack and the examination of the impact on the crossing nose. The assessment of the impact of the wheel on the nose should be done using paint to visualize the running path of the wheel in the relevant section of the crossing.

In that case it is necessary to assess the vehicle in the gap given by the crossing geometry above in wet and dry rail conditions to include the effect of different friction conditions.

E.4.4 Limit values

The limit value for the axle box H-forces is specified depending on the nominal static vertical wheelset force P_{F0}:

$$H_{\mathrm{y,lim}} = 0,25 \cdot P_{F0}$$

The limit value for ΣY-forces – measured either by local measuring points or by instrumented wheelsets – is increased by the quasi-static lateral force of the unsuspended mass m_0 of the wheelset:

$$\Sigma Y_{\mathrm{lim}} = 0,25 \cdot P_{F0} + m_0 \cdot I \cdot g / 2b_{\mathrm{A}}$$

Table E.3 gives the limits for the angle of attack depending on the minimum permitted wheel diameter.

Table E.3 — Limit values for angle of attack α_{lim}

Minimum permitted wheel diameter	Maximum angle of attack α_{lim}	For information: Required nominal flange height (see Note in E.2)
840 mm ≥ d > 760 mm	15,6 mrad	S_{h} ≥ 28 mm
760 mm ≥ d > 680 mm	18,5 mrad	S_{h} ≥ 30 mm
680 mm ≥ d > 630 mm	17,9 mrad	
630 mm ≥ d > 550 mm	18,1 mrad	S_{h} ≥ 32 mm
550 mm ≥ d > 470 mm	16,8 mrad	
470 mm ≥ d > 390 mm	15,0 mrad	
390 mm ≥ d ≥ 330 mm	14,6 mrad	

There is no specific limit value defined for the assessment of the impact on the nose.

E.4.5 Assessment

There are two different combinations of assessment criteria for the vehicle's behaviour using the respective limit values given in E.4.4. Only one of the combinations is required for the acceptance:

1) angle of attack and H-forces or ΣY-forces;

2) angle of attack and examination of the impact on the nose.

Alternatively an assessment using the H-forces or ΣY-forces together with the information about the impact on the nose is possible.

For the assessment of the impact on the nose there should be no abrasion of paint on the tip of the nose, but only on the nose flank.

Instead of H-forces or ΣY-forces measured in the test curve or test crossing, results from on-track tests under similar test conditions (curve radius around 450 m, cant deficiency around 94 mm, dry rails) may be used for comparison with the limit values.

E.4.6 Dispensation

If there is an already tested reference vehicle, dispensation shall be granted to a vehicle, if:

— the results of the reference vehicle were 10 % below the limit values; and

— the modifications of the following parameters remain in the ranges given in Table U.1 for dispensation from on-track testing:

  — distance between bogie centres/vehicle wheel base;

  — secondary suspended mass (vehicle tare for freight stock);

  — bogie wheel base;

  — axle guiding;

  — yaw resistance of bogie;

  — moment of inertia of whole bogie.

Dispensation shall also be granted for minimum permitted wheel diameters 760 mm ≤ d < 840 mm if a minimum permitted flange height of

$$S_{\mathrm{h,min}} = 32\ \mathrm{mm} + \frac{26\ \mathrm{mm} - 32\ \mathrm{mm}}{840\ \mathrm{mm} - 760\ \mathrm{mm}} \cdot (d - 760\ \mathrm{mm}) = 89\ \mathrm{mm} - 0{,}075 \cdot d$$

is applied.

E.4.7 Simulation

The proof of running safety in a curved crossing may be performed also by simulations in a full curve without crossing using a validated model (see informative Annex T). Therefore H-forces (or ΣY-forces) and angles of attack shall be calculated for a 450 m curve without cant for a running clearance between wheel and rail within the range 10 mm ≤ (TG - SR) ≤ 20 mm.

The friction coefficient shall be varied between 0,05 and 0,45 in steps of 0,1. The following speeds shall be investigated: 10 km/h, 25 km/h, 40 km/h and 60 km/h.

The assessment shall be made against the criteria given in E.4.4.

Annex F
(informative)

Test specification for assessment of vehicle behaviour in switches and crossings

F.1 Introduction

The aim of the test is to assess the dynamic response of the vehicle to the nominal switch layout. Therefore influences of track defects or wear should not be taken into account.

Where there is a requirement to carry out an assessment of the performance of a vehicle as it negotiates switches and crossings the following are the recommended procedures to be applied. Two methods are described, Method A and Method B. The assessment checks the forces generated by the vehicle from the point of view of rail fatigue of the diverging switch blade in switches and crossings with small curve radii.

NOTE No limit value is given in this document. The test method is derived from work carried out by DB AG which included fatigue tests and structural analysis of a finite element model of the switch blade. The DB work resulted in a limit of 150 kN which is derived for the specific details of the DB situation. This included the design of the track feature (a DKW 54 switch blade) and the operating conditions (speed of negotiation V_{test} = 40 km/h) and represents the limit loading to ensure an acceptable fatigue life for the switch blade.

This test procedure may be applied to all vehicle types.

F.2 Definitions

Measuring section:	For Method A – an instrumented section within the S-curve. For Method B – a part that is equivalent to the section of Method A where the forces measured with instrumented wheelsets are evaluated.
Test run:	When data are collected from all four measuring sections, this may be one run through an S-curve: — in one direction on an instrumented track with four measuring sections (see Figure F.1 as an example); — in one direction when the test is carried out with measuring wheelsets. — Or it may be two runs in both directions on an instrumented track with only two measuring sections (see Figure F.2 as an example).
Test section	One evaluated vehicle passage at a measuring section, there are four test sections in each test run.

F.3 Test conditions

When carrying out the tests at a test speed of V_{test} ± 3 km/h, vehicles are to be loose coupled without contact of the buffers in the curve and not powered. Any lubrication systems, trainborne systems and trackside equipment shall be switched off.

The test runs shall be carried out on dry rails. If the test is carried out on sections with little traffic flow it is recommended that the rails are conditioned by several runs over the test site before testing in order to achieve normal service rail conditions.

NOTE 1 In the event that rail friction is greater than 0,5 (regarded as 100 % dry friction), the results can be ignored if the intended level was exceeded and the tests repeated with a friction value of 0,5.

The test is to be carried out with at least 3 test runs. In the case of an asymmetrical vehicle at least 3 additional test runs with the vehicle in the opposite orientation are required.

The tests can be performed by using either of the two following methods:

Method A, which is the preferred method and which is carried out on a specially prepared test site with the track in new or in new maintenance status. The test site is to be constructed from plain track (without any switch or crossing included) incorporating a reverse curve (s-shaped curve) without transitions or cant, with a maximum radius of both curves of 190 m and with a 6 m straight track element between the curves. As a minimum, the outer rails shall be equipped with two measuring sections to measure the lateral and vertical track forces Y and Q both in curve entry and curve exit. Each measuring section is to start 5,86 m beyond the starting point of each curve having a length of approximately 3,5 m, (see Figure F.2 for an example of an instrumented track with two measuring sections). It is recommended that force measurements are carried out on outer and inner rails and four measuring sections are included in the test site.

Method B, which is carried out using load measuring wheels measuring the lateral Y and vertical Q track forces on outer and inner rails on an in service crossover consisting preferably of two crossings with slips or of two turnouts. The positions of the measured values are to be at the equivalent location as for Method A, but with measuring sections extended on both ends by 1 m length (see Figure F.1). Hence each measuring section is 5,5 m long and starts approximately 4,8 m after the starting point or ends approximately 4,8 m before the end point of each curved portion respectively. The test sites shall contain curves of a maximum radius of 190 m without transitions or cant, separated by between 6 m and 11 m of straight track.

NOTE 2 The precise track feature may differ in detail from the idealised test site of Method A, therefore the extended dimensions given are intended to account for these differences.

F.4 Assessment of the test results

For test data from Method B the signals shall be filtered with a 20 Hz low pass filter as specified in 7.6.3.1.

The measured Y and Q forces are assessed as follows:

1) Calculate ($|Y| + 0,5\ Q$) for each outer wheel in each measuring section (maximum value from the measuring devices or from the continuously recorded signal over the measuring section).

2) Determine the maximum value $(|Y| + 0,5\ Q)_{max}$ from all outer wheels (one value from each wheel and measuring section) in each measuring section.

3) Calculate the mean value of the determined maximum values of all test runs separately for each of the four measuring sections.

4) Select the largest mean value from all measuring sections.

An example of the assessment of fictitious test results is given in Figure F.3.

F.5 Documentation

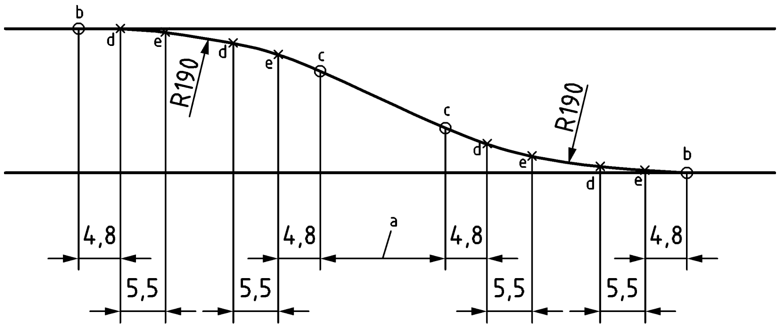
In addition to the measurement results the following items should be documented:

— $(Y/Q)_i$ at the inner rail in order to get an indication of the friction coefficient;

— the maintenance state of the S-curve, at least the variation of track gauge;

— when using an instrumented track the processing method of the measured signals.

Dimensions in m



Key

a intermediate straight track with a length of 6 m to 11 m

b limitation of S-curve

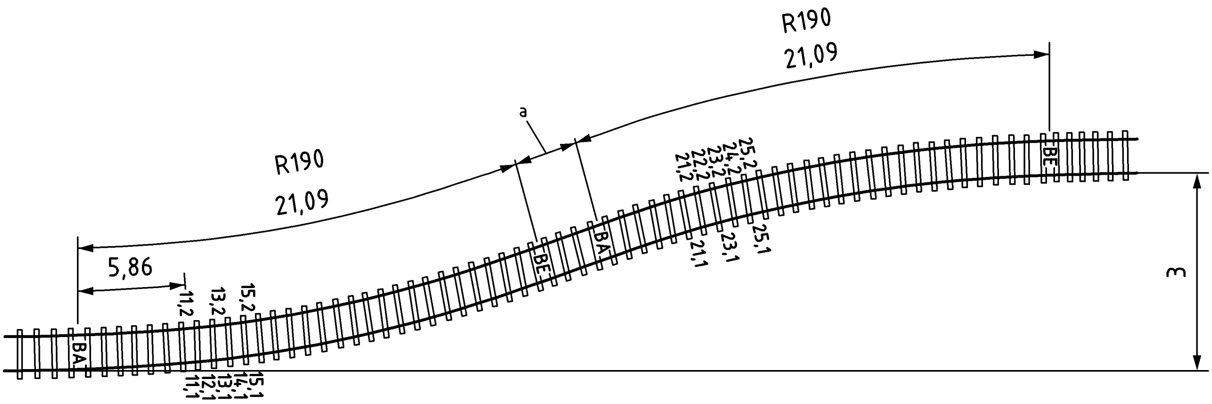
c limitation of intermediate straight track

d start of measuring section

e end of measuring section

Figure F.1 — Position of measuring sections

Dimensions in m



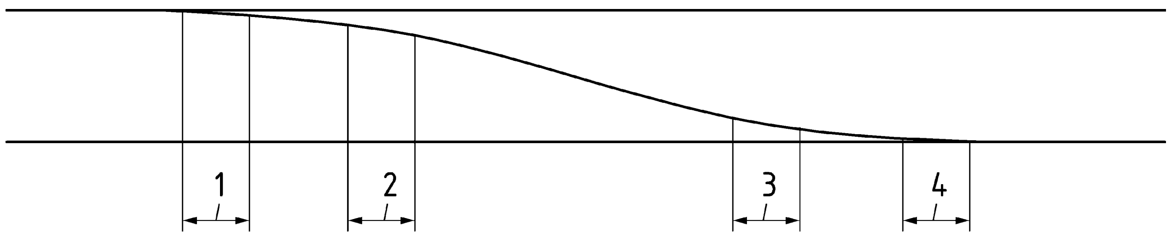
Key

a intermediate straight track

BA beginning of curve

BE end of curve

Figure F.2 — Example of instrumented track with two measuring sections (measuring devices 11.1 – 15.2; 21.1 – 25.2)



Key

1, 2, 3, 4 measuring sections

Test Run 1 **Test results (Y + 0,5 Q) in kN**

Measuring section	**1**	**2**	**3**	**4**
outer wheel 1	145	139	151	142
outer wheel 2	135	125	132	134
outer wheel 3	143	141	145	136
outer wheel 4	140	126	135	130
Maximum	**145**	**141**	**151**	**142**

Test Run 2

Measuring section	**5**	**6**	**7**	**8**
outer wheel 1	147	141	149	139
outer wheel 2	133	127	128	128
outer wheel 3	140	142	140	135
outer wheel 4	134	120	130	124
Maximum	**147**	**142**	**149**	**139**

Test Run 3

Measuring section	**9**	**10**	**11**	**12**
outer wheel 1	142	139	147	135
outer wheel 2	139	128	135	124
outer wheel 3	145	138	147	139
outer wheel 4	136	130	131	126
Maximum	**145**	**139**	**147**	**139**
Mean	**146**	**141**	**149**	**140**
Maximum	**149**			

Figure F.3 — Example of assessment

Annex G
(normative)

Coordinate system for measured quantities

Measured quantities and assessment quantities are identified in the system of vehicle coordinates according to Figure G.1.

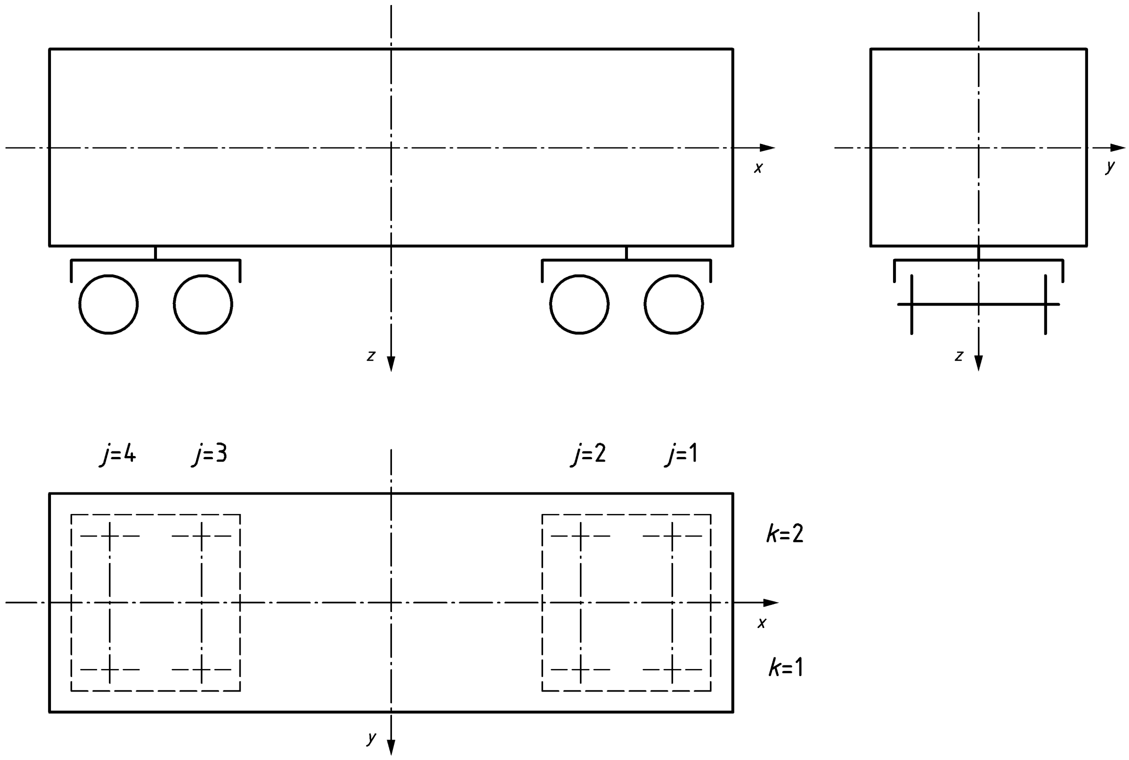


Figure G.1 — System of vehicle coordinates

The following has to be defined:

— positive direction for *Y* forces (wheel or wheelset dependant), and all other quantities;

— main measuring direction;

— allocation of wheelset and bogie numbers depending on the running direction or on the location in the vehicle.

Annex H
(informative)

Operational parameters

Assessment conditions specified in this standard are based on:

— V_{adm}, maximum operating speed intended for the vehicle being assessed;

— I_{adm}, maximum operating cant deficiency intended for this vehicle.

Using cant deficiency values corresponding to the train categories of ETCS (European Train Control System) optimizes the operational parameters for an international acceptance. These values are: I_{adm} = 80 mm, 100 mm, 130 mm, 150 mm, 165 mm, 180 mm, 225 mm, 245 mm, 275 mm or 300 mm.

For national operation, other values may be suitable.

In many European countries an operation within the standard timetables require a minimum performance of a vehicle as shown in Table H.1.

Table H.1 — Minimum performance (V_{adm} and I_{adm}) for standard timetables in many European countries

	V_{adm}	I_{adm}
Conventional freight stock (wagons and locomotives) with nominal static vertical wheelset forces P_{F0} ≤ 225 kN	≤ 120 km/h	130 mm
Conventional freight stock (wagons and locomotives) with nominal static vertical wheelset forces 225 kN ≤ P_{F0} ≤ 250 kN	≤ 100 km/h	100 mm
Conventional passenger stock (including locomotives)	≤ 200 km/h	150 mm

For some types of vehicles it may be necessary to test the vehicle for more than one combination of V_{adm} and I_{adm}, for instance tilting vehicles also intended to be able to operate at very high speed with a lower cant deficiency.

An example of area of acceptance is indicated in the following Figure H.1.

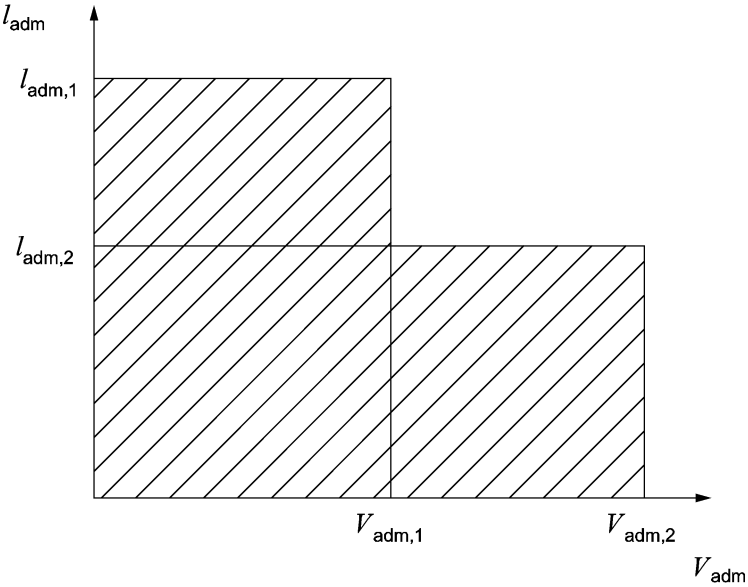


Figure H.1 — Proven Operation Envelope (or area of acceptance) resulting from two tested combinations of V_{adm} and I_{adm}

Annex I
(informative)

Position of the different wheelsets during test

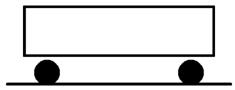
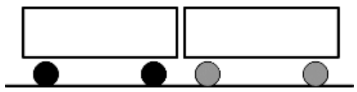
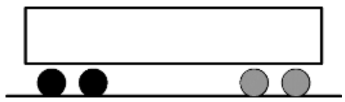
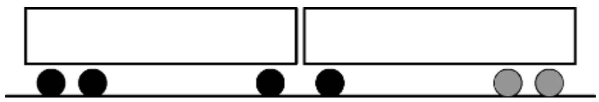
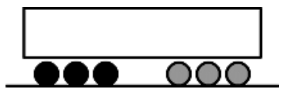
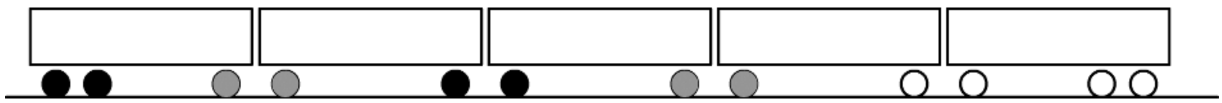
Instrumented wheelsets with special test profile for required contact conditions if applicable.	
Other wheelsets with special test profile for required contact conditions if applicable.	
Wheelsets with the profile (used in service, new,…..)	
Two axle wagons with two instrumented wheelsets with special test profile	
Coupling of two axle wagon with two instrumented wheelsets and two wheelsets with special test profile	
Wagon, coach or engine with two axle bogies with two instrumented wheelsets on one bogie and two wheelsets with special test profile on the other bogie	
Coupling of coach or wagon with two axle bogies	
Coach or engine with three axle bogies one with three instrumented wheelsets and the other with three wheelsets with special test profile	
 Instrumented wheelsets on one bogie of each type or location (end or intermediate), and wheelsets with special test profile at least on the part of the trainset between these instrumented wheelsets.	

Figure I.1 — Position of the different wheelsets during test (examples)

Annex J
(informative)

Additional track loading assessment quantities

J.1 General

Track loading assessment quantities as defined in the present standard aim to controlling various phenomena, including the following:

— rail internal fatigue, due to bending stresses in the rail considered as a continuous beam;

— abrasive wear of the rail flange corner;

— surface fatigue of the rail top (including crack initiation) due to high contact forces;

— failure of fastening components due to high lateral forces or torsion moment.

The existing assessment quantities Q_{max}, $Q_{\text{a,qst}}$ and $Y_{\text{a,qst}}$ may not adequately represent all the physical mechanisms involved in track component deterioration as quoted above. This is why additional quantities have been used in some countries, or have been proposed during the revision of UIC 518. These quantities, only assessed for the outer rail in curves, are the following:

— maximum lateral force $Y_{\text{a,max}}$;

— combined (lateral + vertical) forces B_{max} and B_{qst};

— $(Y/Q)_{\text{a}}$ used as a track loading assessment quantity.

The purpose and the analysis process of these quantities are described hereafter, as well as the proposed (informative) limit values.

NOTE These parameters can help to determine acceptable operating and vehicle conditions (cant deficiency, speed, friction conditioning, payload) depending on track layout, track design, track quality and track maintenance strategy.

J.2 Maximum lateral force

Rail fatigue due to bending stresses is the result of repeated loading in terms of maximum (total) forces occurring at the same location in the track, rather than mean (quasi-static) values of these forces. This is why, repeating the process used for vertical forces, in which both quantities Q_{max} and $Q_{\text{a,qst}}$ are assessed, the evaluation of the maximum value of $Y_{\text{a,max}}$ is carried out in some countries, in addition to the evaluation of the quasi-static value $Y_{\text{a,qst}}$.

$Y_{\text{a,max}}$ signal processing is performed in exactly the same way as Q_{max} signal processing, for the outer wheel of each measuring wheelset.

No harmonized limit value exists. Figures ranging from 80 kN to 110 kN have been quoted, the value being chosen according to the type and characteristics of the tested vehicle. However, a limit value of 100 kN looks consistent with the 60 kN limit value specified for $Y_{\text{a,qst}}$.

J.3 Combination of lateral and vertical forces

Considering that controlling the level of bending stresses in the rail was the main purpose of $Y_{\text{a,qst}}$ (or $Y_{\text{a,max}}$), it has been suggested that an index is defined which would be related to bending stresses more accurately than $Y_{\text{a,qst}}$. Stresses being expressed as a linear combination of lateral and vertical forces, two indices were actually proposed:

— $B_{qst} = |Y_{a,qst}| + 0{,}83 \cdot Q_{a,qst}$ for quasi-static values (complement to $Y_{a,qst}$);

— $B_{max} = (|Y| + 0{,}91 \cdot Q)_{max}$ for maximum values (complement to $Y_{a,max}$).

The coefficients of $Q_{a,qst}$ or Q_{max} respectively in these expressions are related to the calculation of the bending stresses in the rail section at the points where they reach their maximum values, and result from the typical shape of the rail profiles more commonly used.

As regards the use of $Y_{a,qst}$ however, many objections were raised to its mere replacement by an index representative of rail bending stresses. Indeed, bending stresses are only one among many track loading related concerns, also dealing with:

— lateral wear of the rail;

— resistance of rails, welds and joints to gauge spreading forces;

— resistance of the fastening system to rail overturning forces;

all of which are better assessed by a purely lateral criterion.

So the combined criterion was only introduced as a complement to $Y_{a,qst}$, with a dual purpose:

1) to allow an Infrastructure Manager mainly concerned by stresses in the rail (and accepting exceedance of individual limits on $Y_{a,qst}$ and $Q_{a,qst}$) to accept higher lateral forces when vertical forces are low (rather light vehicles), or higher vertical forces when lateral forces are low (vehicles with good steering capacity),

2) to help define speed (and cant deficiency) restrictions when forces are excessive, by using an index proportional to rail stresses, and adjustable to the type of rail locally used.

No limit values are applied. For the development of future limit values experience with evaluated data needs to be taken into account.

Annex K
(informative)

Evaluation and background of the rail surface damage quantity

One purpose of controlling the lateral and vertical wheel forces (Y and Q) is to limit the fatigue risk of rails. Originating from work carried out by ORE C138 a limitation of these parameters in general – and the lateral quasi-static force ($Y_{a,qst}$) in particular – has implicitly also been considered a measure for controlling the wear of rails. The interaction between wear and surface initiated rolling contact fatigue is referred to as rail surface damage (RSD).

However, both vehicle dynamic simulations and results from real tests show that the magnitude of lateral force varies largely with actual friction and contact conditions – often unknown and uncontrollable in testing procedures. It is also known that the correlation between RSD and $Y_{a,qst}$ sometimes is very poor. Although the force level may be high, the rail surface damage resulting from it may be moderate due to the low friction itself. Among other effects this leads to a situation where the test results may be unpredictable and vary largely within the range for allowed test conditions.

The parameter mostly used and accepted to indicate RSD is $T\gamma$ (or sometimes called the wear number) which is the product of tangential creep forces and creepages in the wheel/rail contact. $T\gamma$ is the essential input to prevailing wear modelling and is a measure of the friction energy dissipation in the wheel/rail contact. $T\gamma$ is often expressed in units of energy per unit of sliding distance (Nm/m) and can only be determined by vehicle dynamics simulation since it depends on the tangential creepages which are not measured today.

In order to overcome this problem during vehicle tests a new simplified approximation of $T\gamma$ is introduced. This quantity is called the rail surface damage quantity, denoted T_{qst}. It is a quantity combined from the lateral, longitudinal and vertical wheel forces. Thus the evaluation of this quantity can only be carried out when the force in the longitudinal direction, $T_{x,qst}$ is measured.

The advantage of the rail surface damage quantity is that it normalizes the influence of varying contact conditions and wheel/rail friction.

In developing the rail surface damage quantity vehicle dynamics simulations have been performed on a range of track and vehicle parameters, representative for a wide range of operational conditions. A generic vehicle model has been used varying the nominal static vertical wheelset force, wheelset yaw stiffness and wheelset distance covering friction conditions from 0,2 to 0,6 within the different test zones.

The damage quantity T_{qst}, has been established by regression based on simulated forces and $T\gamma$. In order to avoid the dependency of nominal static vertical wheelset force all quantities were normalized to the vertical wheel force before the regression of $T\gamma$ against the lateral and longitudinal forces was made.

The formulation of the rail surface damage quantity consists of Formulae (K.1) and (K.2) derived for the outer wheel of the leading wheelsets of each bogie or wheelset group. T_{qst} is a quasi-static parameter that depends on the quasi-static values of the T_x, Y and Q forces.

$$T_{qst} = \frac{Q_{qst}}{10\,000}\left(330 \cdot f^2 - 62 \cdot f + 4\right) \qquad \text{(K.1)}$$

where

$$f = \frac{Y_{\mathrm{qst}}}{Q_{\mathrm{qst}}} + 0,62 \cdot \frac{\left|T_{\mathrm{x,qst}}\right|}{Q_{\mathrm{qst}}} \tag{K.2}$$

The coefficients in the formulae are derived from the regression between T_{qst} and $T\gamma$ and are the best current estimates. The polynomial expressed by Formula (K.2) is dimensionless, meaning that the quantities T and Q have the same dimensions (N). Formula (K.1) is the result of linearizing the dependency between $T\gamma$ and Formula (K.2).

T_{qst} is evaluated in each track section using the Y/Q signal and the additional required T_{x}/Q signal with h_0 = 50 %.

T_{qst} and $T_{\mathrm{x,qst}}$ are then evaluated from the percentiles of the forces in the track sections using a one-dimensional analysis in test zones 2, 3 and 4 for the leading outer wheel of a running gear.

Any correction of measured forces due to mean curve radius or friction conditions in different test zones will also affect T_{qst}. Therefore, T_{qst} shall be calculated with the non-corrected Y forces.

If possible, using a validated simulation model, the regression for $T\gamma$ against T_{qst} (expressed in Formula (K.1)) should be verified against different test conditions and the regression coefficients reported.

For further reference on technical background refer to [19].

Annex L
(informative)

Typical maximum estimated values of ride characteristics

Locomotives and Passenger Vehicles

Locomotives and passenger vehicles operated in Europe typically show acceleration levels given in Table L.1.

NOTE 1 Ride comfort is also based on the measurement of accelerations and is handled by EN 12299 [3]. The health and safety requirements regarding the exposure of workers to risks arising from vibrations are regulated by the Directive 2002/44/EC [2].

Freight Wagons

The loading safety includes questions of load security (e.g. fixation and interaction between load and vehicle) and damage potential to the goods. It is handled by [15] based on investigations on the running characteristics of typical freight wagons operated in Europe, that mostly have dispensation from on-track testing. These vehicles typically show acceleration levels given in the table below.

This means that vehicles showing higher values need additional investigations to demonstrate the loading safety under the intended conditions of operation and track quality. On the other hand respecting the given ranges does not automatically indicate that loading safety is sufficient.

NOTE 2 For the demonstration of loading safety other quantities and limits might be relevant depending on the type of goods.

Table L.1 — Typical maximum estimated values of ride characteristics

Assessment, vehicle, test conditions	**Typical maximum estimated values for accelerations in vehicle body [m/s²]**	
Ride characteristics	$\ddot{y}^*_{q,max}$	$\ddot{z}^*_{q,max}$
Locomotives, power cars (without shunting locomotives)	2,5	2,5
Shunting locomotives	to be defined.	to be defined.
Multiple units, passenger coaches	1,5	2,0
Freight wagons with bogies, empty	< 3 (preliminary)	< 5 (preliminary)
Freight wagons with bogies, loaded	3,5	5,0
Freight wagons without bogies, empty	to be defined.	to be defined.
Freight wagons without bogies, loaded	to be defined.	to be defined.
NOTE The stated ranges for the vehicle types represent the maximum estimated values measured on several vehicles during tests according to UIC 518 [11] or EN 14363:2005. For each vehicle the highest evaluated values of the different measuring points according to Table 3 were used (in normal and not in fault mode condition).		

Annex M
(normative)

Track geometric quality – Selection of test tracks

M.1 Basis of evaluation

The basis for the evaluation shall be the measured signals of track geometric deviation obtained using normal track measuring methods with computerised recording and storage according to EN 13848-1 and EN 13848-2 which specify the wavelength ranges and required filter characteristics.

The data used for the evaluation of the track geometric quality shall be representative of the maintenance status of the test track during the test.

M.2 Assessment quantities for track geometric quality

Track geometric deviations are measured for each rail. Evaluation variables of track geometric deviation are:

a) alignment, lateral measuring direction:

   1) maximum absolute value $\Delta y^0_{\max}$ (mean to peak);

   2) standard deviation Δy^0_{σ}.

b) longitudinal level, vertical measuring direction:

   1) maximum absolute value $\Delta z^0_{\max}$ (mean to peak);

   2) standard deviation Δz^0_{σ}.

For test zone 1 the higher value of the two rails shall be used for the assessment of track geometric quality. For test zones 2, 3 and 4 the values of the outer rail shall be used.

No requirements are given for track twist in the evaluation sections. However, if the track twist in a section exceeds the *IAL*-value in EN 13848-5, the section may be excluded from the analysis.

Track geometric quality for each test zone is assessed on the basis of the distributions of standard deviations for alignment and longitudinal level evaluated for the wavelength range *D1* as specified in EN 13848-1. For reference speeds higher than 160 km/h track geometric deviations with longer wavelengths shall also be reported for test zones 1 and 2 as shown in Table M.1. No requirements are given for the track geometric quality values in ranges *D2* and *D3*.

Table M.1 — Wavelength ranges for different reference speeds

Wavelength range	Reference speed (see M.4)			
	$V \leq 120$ km/h	120 km/h < V ≤ 160 km/h	160 km/h < V ≤ 230 km/h	230 km/h < V
3 m to 25 m (*D1*)	Mandatory to comply with requirement in Table M.3			
25 m to 70 m (*D2*)	-	Recommended to be reported for test zones 1 and 2	Mandatory to be reported for test zones 1 and 2	Mandatory to be reported for test zones 1 and 2
> 70 m (*D3*)	-	-	-	Recommended to be reported for test zones 1 and 2

M.3 Different measuring systems

If a measuring vehicle having a transfer function deviating significantly from 1 in the wavelength range between 3 m and 25 m or between 3 m and 70 m is used for measurements, the track quality values shall be derived from measured values subsequently corrected to be compatible with the above system.

There are two methods permitted for the correction:

a) The transfer function of the measuring system may be used to obtain absolute values of measured track geometry. Here the measured signals are corrected using the transfer function and are compared with the required ranges in Table M.3.

NOTE Special attention has to be paid to wavelength regions with low values of transfer function. Some systems show even zeroes of the transfer function. In these cases the measured signals are multiplied with high numbers. This may lead to an unrealistic amplification of noise and incorrect results in some wavelength ranges.

or

b) If a railway has no ability to correct the measured values directly it is also permitted to use approximate scale factors k such that:

— standard deviation$_{(other)}$ = k · standard deviation$_{(transfer\ function\ 1)}$;

— the coefficients k to be applied in the wavelength band from 3 m to 25 m can be found in Table M.2 for certain measuring vehicles;

— the values in Table M.3 shall then be multiplied by the factors k of Table M.2 to give values comparable with the other measuring system.

Table M.2 — Correction factors for different track measuring vehicles

Measuring method / measuring vehicle	Longitudinal level		Alignment	
	k	Base	*k*	Base
Network Rail TRK/042 compliant measurement	1,14	inertial (wavelength up to 35 m)	1,20	inertial (wavelength up to 35 m)
GMTZ (DB)	1,24	2,6 m / 6 m	1,47	4 / 6 m
MAUZIN cars	0,91	12,2 m	1,47	10 m
MATISA M562	0,91	12,2 m	1,47	10 m

M.4 Target test conditions

As the test results are related to the track conditions during the test, the target test conditions shall be representative of the planned service operation. Therefore the distributions in test zone 2, and separate or combined zones 3 and 4 shall be such that the 90 % values of the standard deviation of alignment and longitudinal level fall above the minimum values of the ranges specified in Table M.3. In test zone 1 compliance with the above requirement is not mandatory.

Where multiple regression is used for the evaluation, the target values *TL50* shall be used to calculate the estimated maximum values to achieve comparable results with the one- and two-dimensional evaluation.

NOTE 1 The ranges specified in Table M.3 are based on information given in EN 13848–6 (class D). An intermediate speed class for 200 km/h – 230 km/h has been added. A sensitivity study showed ([DYNOTRAIN, D 2.6], chapter 8.3), that the influence on the resulting estimated maximum values of the vehicle reaction in curves can be neglected when compared to the limit values when the 90 % value of the standard deviation of track geometric quality is varied between the upper and the lower end of the ranges specified in Table M.3. Further in tangent track there is always sufficient margin to the safety and track loading limits (except stability testing where track quality is not the relevant influencing parameter).

The reference speed for application of Table M.3 and Table M.4 shall be determined in the following way:

— V_{adm} for test zones 1 and 2;

— $V \leq 120$ km/h for test zones 3 and 4.

For speeds above 300 km/h, the target test conditions shall correspond to better track quality than the track quality specified for the speed 300 km/h.

If the specified values cannot be reached, one option is the use of multiple regression (see normative Annex R), in order to assess the vehicle for the right track quality. In that case it is necessary to include some test results from sections with standard deviations above the upper ends of the specified *TL90* ranges.

Table M.3 — Target ranges for track geometric quality for international approval

Reference speed in km/h	**Target test ranges for standard deviation *TL90* in mm for wavelength range *D1***				**Target values *TL50* in mm for multiple regression: standard deviation**	
	Alignment Δy_{σ}^{0}		**Longitudinal level** Δz_{σ}^{0}		**Alignment** Δy_{σ}^{0}	**Longitudinal level** Δz_{σ}^{0}
	Min	***Max***	***Min***	***Max***		
$V \leq 120$ km/h	1,05	1,45	1,80	2,50	0,88	1,45
120 km/h < $V \leq 160$ km/h	0,75	1,00	1,40	1,85	0,65	1,13
160 km/h < $V \leq 200$ km/h	0,70	0,90	1,15	1,60	0,60	0,95
200 km/h < $V \leq 230$ km/h	0,65	0,80	1,05	1,45	0,55	0,87
230 km/h < $V \leq 300$ km/h	0,50	0,65	0,85	1,15	0,45	0,70

Results from track sections with amplitudes of discrete defects higher than the stated *QN3* values in Table M.4 may be excluded from the statistical evaluation to avoid a distortion of the statistical analysis.

Table M.4 — Limits for discrete track defects

Reference speed in km/h	Maximum absolute value (mean to peak) *QN3* in mm for wavelength range D1	
	Alignment Δy^0_{max}	Longitudinal level Δz^0_{max}
$V \leq 120$ km/h	13	16
120 km/h < $V \leq 160$ km/h	10	13
160 km/h < $V \leq 200$ km/h	9	12
200 km/h < $V \leq 300$ km/h	8	10

NOTE 2 Table M.3 and Table M.4 contain requirements for international approval. For local, national or multinational operation the values may be varied.

NOTE 3 The values in Table M.4 are taken from EN 14363:2005, therefore only 200 km/h is used as interval boundary. In addition 200 km/h is used as boundary also in Table M.3, deviating from EN 13848–6 where this boundary does not exist.

For the evaluation of track geometric deviations in the test route, the track sections selected for the testing of running characteristics shall be used.

Two analysis methods may be used:

— 1st method (recommended): The track sections used for the analysis are the same as those selected for the statistical evaluation of the vehicle behaviour.

— 2nd method: The track sections used for the analysis are derived from standard data from track-measuring vehicles (e.g. standard deviations in 200 m sections). In this case, it is not possible for track-related and vehicle-related sections to strictly coincide. The track quality data shall be assigned in the most appropriate way to the track sections used for evaluation of the test results. The process used shall be documented. This method may not be used if multiple regression is applied because it may produce an unpredictable measurement error.

For zones 3 and 4 it is strongly recommended to use the 1st method. In order to improve upon this, the use of standard deviation sliding values is recommended, with a rather low sliding interval such as 10 m for example.

M.5 Reporting

For each test zone a graphical representation of standard deviation values of longitudinal level and alignment in the wavelength range *D1*, section by section, together with the 90 % values, shall be documented.

It shall be stated, if any sections were excluded from the analysis due to amplitudes higher than the stated *QN3* values. A list of such excluded sections shall be given including information about radius, speed, cant deficiency and the four track geometric quality values.

Annex N
(informative)

Background of track quality description

During the early 1990s the UIC SC7G [14] working group “Geometric parameters” developed a method for describing the track geometric quality. Standard deviations over section length and absolute maximum amplitudes of individual defects were used as assessment quantities. A similar method is used by the EN 13848 series of standards.

It is well known that the correlation between the track geometry assessment quantities and the vehicle reaction is often poor. Reasons are that:

— limited wavelength range of 3 m to 25 m, although irregularities with wavelengths below 3 m and above 25 m may produce high vehicle reactions;

— vehicle reaction depends heavily on the wavelength of track geometry irregularities;

— superposition of the irregularities on both rails in both directions (vertical and lateral) may have a big influence.

Another problem is the comparison of results from different measuring systems. The report of UIC SC7G states: “However, the task of reviewing the measuring results to make them comparable would have been much more challenging, time consuming and costly. Harmonisation of measuring results would, in many instances, have required a modification to the measuring principle, for which most track-measuring vehicles owned by the railways are not suitable”.

It is now possible to obtain an improved comparison between measurement results for the following reasons:

— the distortion of measured values can be corrected more easily in certain conditions;

— new track-measuring vehicles, from which the results can be processed more easily, are now being used or being developed.

Normative Annex M therefore only deals with corrected geometrical values, either using the inverse transfer function of the measuring vehicle or using a correction factor (see Table M.2).

NOTE Work to develop methods of characterizing track geometry which have an improved correlation with vehicle behaviour are underway (for example in EU FP7 project DynoTrain) which may necessitate changes to this process.

Annex O
(normative)

Rail profile measurement

O.1 General

The measurements can be conducted with any measuring system for rail profile measurements which fulfils the requirements for profile measurements required for calculation of equivalent conicity according to EN 15302.

The assessment of the contact geometry parameters shall be made for a typical loaded condition of the track. As manual rail profile measurements are usually carried out on an unloaded track the possible effect of the loading (for example on rail roll) shall be assessed and reported. One method to consider the effect of track loading on the rail profile measurement is to carry out the rail profile measurements in the direct neighbourhood (within a distance of 1 m from the wheelset) of a rail vehicle with typical static vertical wheelset force which is loading the track.

O.2 Manual measurements

O.2.1 Measurements for equivalent conicity

Sufficient measurements of the profiles of both rails and the track gauge shall be made to demonstrate that the requirements for equivalent conicity are met. The rail profiles of both rails and the track gauge shall be measured at least every 25 m in each of the selected track sections.

NOTE This requirement for manual measurement is less demanding than required by the informative Annex I of EN 15302:2008+A1:2010.

O.2.2 Measurements for radial steering index

If measurements are made to assess radial steering index, the rail profiles of both rails and the track gauge shall be measured on at least 7 positions with a spacing of approximately 10 m in each measured section in zone 4.

O.3 Automatic measurements

As the accuracy of an individual measurement is often lower for automatic measurements than for manual measurement, automatic measurements shall be performed with a regular spacing not exceeding 6 m to improve the confidence.

Annex P
(normative)

Requirements for evaluation of equivalent conicity

If required, rail profiles shall be measured (see normative Annex O) and the equivalent conicity function $\tan \gamma_e = f(y)$ described in EN 15302 shall be determined.

Depending on the track gauge (TG) and the spacing of active faces (SR), the value of $\tan\gamma_e$ shall be determined for each rail profile for the following amplitude y:

$$y = 3 \text{ mm}, \qquad \text{if } (TG - SR) \geq 7 \text{ mm}$$

$$y = \left(\frac{(TG - SR) - 1}{2}\right), \qquad \text{if } 5 \text{ mm} \leq (TG - SR) < 7 \text{ mm}$$

$$y = 2 \text{ mm}, \qquad \text{if } (TG - SR) < 5 \text{ mm}$$

The sliding mean over 100 m of $\tan \gamma_e$ shall be determined, using a step equal to the spacing between rail profile measurements. The resulting values shall be considered as applying at the mid-point of the 100 m length.

NOTE If a detailed analysis of vehicles behaviour is performed, other values from $\tan \gamma_e$ relationship may also be useful.

Annex Q
(informative)

Radial steering index

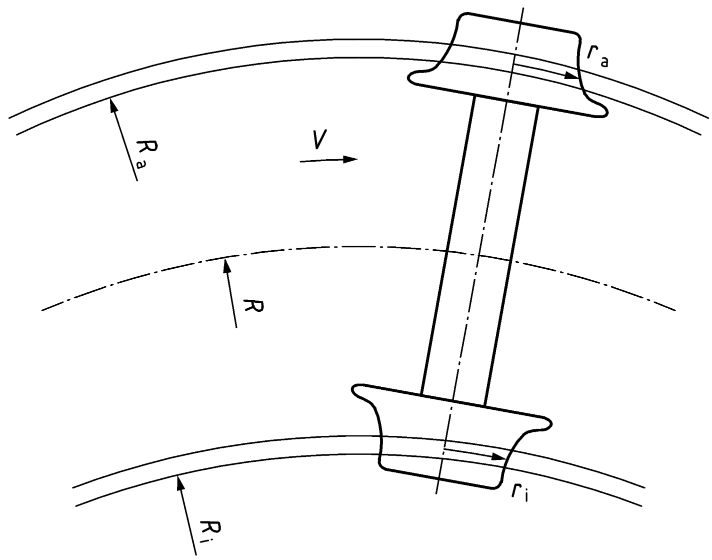
Q.1 Introduction

The behaviour of a vehicle in a curve is determined by a number of factors including the vehicle suspension characteristics and the wheel rail contact geometry. The radial steering index is one way to characterize the wheel rail contact geometry in a curve. Reporting the information may be useful in understanding the vehicle behaviour.

NOTE For the on-track testing of a vehicle as described in Clause 7 no specific requirements for the radial steering index are given. It is intended to handle the information of this annex later in a revised EN 15302.

The two wheels of a free unsuspended wheelset steering through a curve are rigidly connected via the wheelset and they are therefore constrained to rotate with the same angular velocity.

The running surfaces of the two wheels are profiled so that – normally – the rolling radius of the curve outer wheel becomes larger than the rolling radius of the curve inner wheel when the wheelset is displaced outwards in the curve. The larger the displacement, the larger is the rolling radius difference, Δr.



Key

R	mean curve radius	V	vehicle speed
R_a	curve radius of outer rail	r_a	outer wheel radius in contact plane
R_i	curve radius of outer rail	r_i	inner wheel radius in contact plane

Figure Q.1 — Wheelset rolling through a curve

To compensate for the slightly larger radius of the outer rail compared to the inner and to achieve a radial position of the wheelset (providing a minimum of wheel/rail force magnitude) the wheel on the outer rail of the curve needs to roll a greater distance than the wheel on the inner rail of the curve. To achieve this radial steering position, the rolling radius difference between the outer and inner wheels shall be sufficient to generate a greater rolling distance of the outer wheel that is at least as large as the difference between the length of the outer and inner rails in the curve, i.e.:

$$\frac{r_a}{r_i} \geq \frac{R_a}{R_i} \Rightarrow \frac{r_0 + \Delta r_a}{r_0 - \Delta r_i} \geq \frac{R + \frac{2b_A}{2}}{R - \frac{2b_A}{2}}$$

By removing everything except first order effects it can be shown that:

$$r_a - r_i = \Delta r \geq r_0 \frac{2b_A}{R}$$

or

$$R \geq r_0 \frac{2b_A}{\Delta r}$$

The inequality is exactly fulfilled when the following denotations are used:

$$R_E = r_0 \frac{2b_A}{\Delta r_E}$$

Where R_E is the smallest curve radius where radial steering is possible with given Δr_E. The radial steering index is defined as:

$$q_E = \frac{R_E}{R}$$

so that:

— when $q_E \leq 1$ radial steering is possible;

— when $q_E > 1$ radial steering is not possible but flange contact will occur before a rolling radius difference, Δr, big enough for the curve in question is achieved.

Q.2 Calculation of radial steering index

The radial steering index is based on pairs of wheel and pairs of rail profiles which are combined to generate a rolling radius difference function $\Delta r(y)$ where y is the lateral displacement of the wheelset (Δr function is described and defined in EN 15302).

By definition, the radial steering index is the ratio q_E between:

— the radius R_E of the curve with a possibility of kinematic rolling (rolling without slip), according to the Δr value at a defined lateral wheelset displacement y_E towards the outer rail (point E);

and

— the actual curve radius R of the track section.

The definition of point E assumes that an ideal radial steering capability of the wheelset is still guaranteed before the point of discontinuity (point A^0) is reached. Its defined y-coordinate is: $y_E = y_{A0} -$ 1 mm.

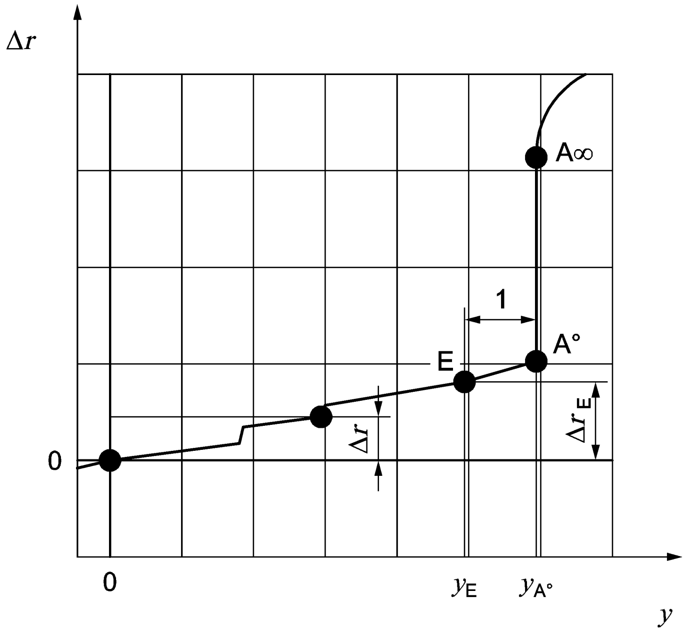


Figure Q.2 — Example of Δ*r*(*y*) function showing points related to the calculation of q_e

NOTE 1 In the example of Figure Q.2, a left hand curve is used.

The basis for calculating the radial steering index is the rolling radius difference function Δ*r*(*y*). The calculation of Δ*r*(*y*) is not defined by this document, except that it shall be calculated in a way such that at any given position *y* of the wheelset, there is only one contact point between the wheel and rail on each side (see EN 15302). The results of the Δ*r*(*y*) calculation shall provide the following information:

1) the lateral wheelset movement *y*;

2) the rolling radius difference Δ*r* between the left and the right wheel;

3) the contact point position on the wheel, at least for the curve outer wheel.

The calculation shall cover a range of *y* such that the Radial Steering Index can be calculated.

The start of the wheel flange is defined as the contact point on the outer wheel which results in 10 mm Δ*r* of the wheelset. This point shall be included in the Δ*r* function.

NOTE 2 For some Δ*r*(*y*) functions, such as those with multiple wheelset positions where Δ*r* = 0, this description may not be sufficient and the Δ*r*(*y*) function may need to be calculated for a wider range. This can be also relevant for a wider gauge with a wider clearance.

The Δ*r* function shall be checked for discontinuities. Depending on the curve direction, either the right or the left part of the Δ*r* function needs to be examined. This is because the wheelset will (in general) follow the curve outer rail rather than the curve inner rail.

For a left hand curve, the right part of the Δ*r* function is investigated and vice versa.

The discontinuity is found by following the procedure:

— search for points $A°$ (y_{A0}, Δr_{A0}) and A^{∞} ($y_{A\infty}$, $\Delta r_{A\infty}$) in the range $0 \leq \Delta r \leq 10$ mm for left hand curves and $-10 \text{ mm} \leq \Delta r \leq 0$ for right hand curves respectively with $|y_{A0} - y_{A\infty}| \leq 0{,}1$ mm and $|\Delta r_{A0} - \Delta r_{A\infty}| \geq 3$ mm. subject to the constraints $y_{A0} < y_{A\infty}$ for left hand curves $y_{A\infty} < y_{A0}$ for right hand curves

NOTE 3 The threshold value (3 mm) depends on the step value (0,1 mm).

— if there is no discontinuity then the point A^0 is defined as the point of $\Delta r = 10$ mm: $y_{A0} = y(|\Delta r| = 10 \text{ mm})$

NOTE 4 The analysis of one or two-point-contact condition is not necessary for the calculation of Radial Steering Index in this document but can give additional information for a more detailed assessment of the contact condition.

The definition of the points A^0 and A^∞ ensures that there can only be one possible location for the discontinuity, the one surrounding the relevant contact point jump.

The representative value q_E for a track section is the median value of all radial steering indices evaluated from all pairs of rail profiles in this section.

Annex R
(normative)

Statistical evaluation

R.1 Objectives and principles of statistical analysis

R.1.1 General

The objective of the statistical evaluation is to establish a consistent approach, the generation of reliable results for assessment quantities and thus create the prerequisites for testing conditions of acceptance. The statistical methods used are regression methods, where the behaviour modelled includes none (one-dimensional), one (two-dimensional) or more (multi-dimensional) influencing parameters (see [18].

The methods of calculating the estimated maximum values are generally based on a number of important assumptions for the sample (regression assumptions). In the case that an estimated value exceeds its limit value, there is a possibility to check compliance with the regression assumptions and apply adequate countermeasures. R.8 gives more details. It is also possible to use this procedure when the limit value is not exceeded.

R.1.2 One-dimensional method

If the values of the essential influencing parameters (independent variables) x_i have a small spread, the overall distribution of an evaluation parameter y can initially be considered as a one-dimensional distribution. This allows the use of the one-dimensional method, which is a regression with no influencing parameter.

R.1.3 Two-dimensional method or simple regression

If the distribution of the random sample indicates a greater dispersion, this has probably been caused by significant influences of parameters, despite restrictions imposed under test conditions. This can be expected in test zones 2 to 4, where tests are done in curves within some limited range of cant deficiency and curve radius. In this case and under defined conditions, cant deficiency I shall be included as the influencing parameter x_i in the statistical evaluation (two dimensional method or simple regression).

NOTE 1 In theory, a target parameter y is linearly dependent on the variable x_i, under the defined test conditions this is cant deficiency I. For many assessment variables a physical relationship to cant deficiency can be shown.

NOTE 2 Under the defined conditions the residuals between percentiles $y(h_j)_i$ and regression value $y(x_i)$ are considered to be normally distributed allowing the calculation of estimated maximum values.

R.1.4 Multiple regression

Generally cant deficiency is not the only important influencing parameter. There are very important influences of curvature, speed and track geometry. These can be included in the statistical analysis by the use of multiple regression. One advantage is that this method does not require restricting analysed data to a small range of influencing parameters. It allows the inclusion of much more data from a series of tests leading to more meaningful and robust results.

R.2 Determination of the percentiles for each track section

From the filtered measured signals, the following percentiles $y(h_j)$ shall be determined from the cumulative curve for each assessment quantity and measuring point in each track section:

— $y(h_0)$, frequency of cumulative curve h_0 = 50,0 %;

— $y(h_1)$, frequency of cumulative curve h_1 = 0,15 %;

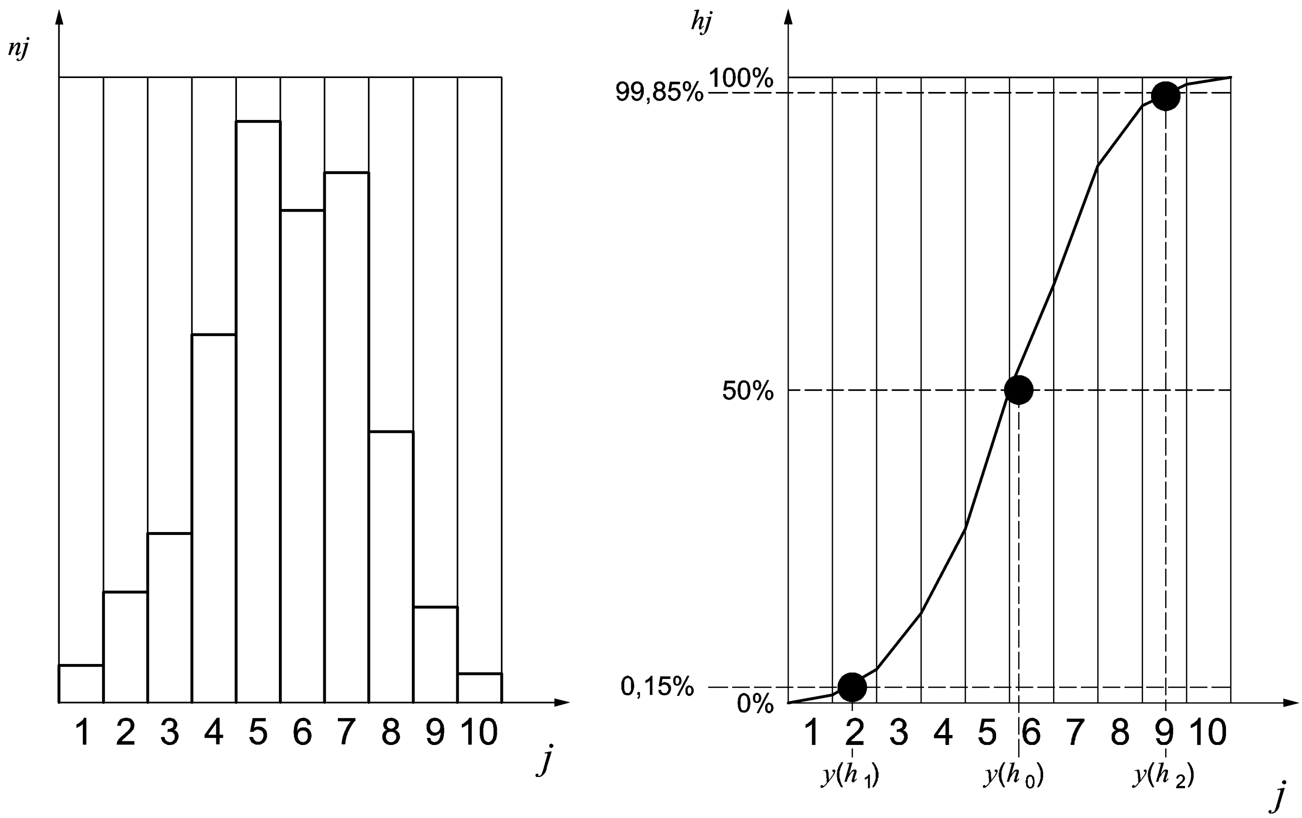
— $y(h_2)$, frequency of cumulative curve h_2 = 99,85 %;

and only for recalculation of $(Y/Q)_{a,max}$:

— $y(h_1)$, frequency of cumulative curve h_1 = 2,5 %;

— $y(h_2)$, frequency of cumulative curve h_2 = 97,5 %;

NOTE The percentiles are not calculated by the standard deviation of the distribution.



a) Classified instantaneous values or sliding means **b) Cumulative curve**

Key

n_j frequency
j class
h_j probability

Figure R.1 — Percentiles *y*(*hj*) of a frequency distribution

R.3 Preparation of the random samples

The percentiles and standard deviations specified in Table 5 of one assessment quantity for one measuring point in one test zone are treated as a random sample. Statistical evaluation is to be carried out separately for every random sample.

The complete sample consists of N or $2N$ values $y(x_i)_i$ and where applicable the associated values of the influencing parameters x_i.

R.4 One-dimensional analysis for estimated maximum values

The estimated maximum value is calculated from mean value and standard deviation:

$$Y(PA)_{\max} = \overline{y} + t(PA, f)\left(1 + \frac{1}{N}\right) s_y$$

Threshold values $t(PA, f)$ of the bilateral t-distribution are indicated in Table R.1. Their value is to be determined depending on the number of sections N and the confidence coefficient PA.

In the case of one-dimensional analysis the degree of freedom f is calculated from the number of values N_s of the independent parameter y (N) or ($2N$) depending on the independent parameter) $f = N_s - 1$.

Table R.1 — Threshold values *t(PA, f)* of the *t*-distribution for limits on two sides

Degree of freedom	23	24	25	26	27	28	29	30	35	40	50	60	70	80	100	200	∞
PA = 95 %	2,069	2,064	2,060	2,056	2,052	2,048	2,045	2,042	2,030	2,021	2,009	2,000	1,994	1,990	1,984	1,972	1,960
PA = 99 %	2,807	2,797	2,787	2,779	2,771	2,763	2,756	2,750	2,724	2,704	2,678	2,660	2,648	2,639	2,626	2,601	2,576

R.5 Two-dimensional analysis for estimated values

The estimated values in test zones 2 to 4 may be determined from a regression analysis assuming a linear relationship between influencing parameter x_i (here cant deficiency I) and target parameter $\boldsymbol{y}$ (assessment quantity).

Regression line: $\hat{y}(x) = a_0 + a_1\, x$

Coefficients: $a_1 = \frac{Q_{xy}}{Q_{xx}}$, $a_0 = \overline{y} - a_1\, \overline{x}$

Residual variance: $s^2 = \frac{Q_{yy}}{N-2}\left(1 - \frac{Q_{xy}^2}{Q_{xx}\, Q_{yy}}\right)$

The upper limit of predicted area at position $\boldsymbol{x'}$ is calculated as:

$$Y(PA, x')_{\max} = \hat{y}(x') + t(PA, f)\, s\, \sqrt{B}$$

with regression line $\hat{y}(x')$ and

$$B = B(x') = 1 + \frac{1}{N} + \frac{(x' - \overline{x})^2}{Q_{xx}}$$

Threshold values $t(PA, f)$ of the bilateral t-distribution are indicated in Table R.1. Their value shall be determined depending on the number of sections N and the confidence coefficient PA.

In the case of two-dimensional analysis the degree of freedom f is calculated from the N_s as:

$f = N_s - 2$

The regression line and the confidence intervals shall be calculated from the following statistical quantities:

Auxiliary sums:

$$S_x = \sum_{i=1}^{N} x_i \,, \qquad S_y = \sum_{i=1}^{N} y_i \,, \qquad S_{xx} = \sum_{i=1}^{N} x_i^2 \,,$$

$$S_{yy} = \sum_{i=1}^{N} y_i^2 \,, \qquad S_{xy} = \sum_{i=1}^{N} x_i \cdot y_i$$

Mean values:

$$\overline{x} = \frac{S_x}{N} \,, \qquad \overline{y} = \frac{S_y}{N}$$

Sum of squares of deviations:

$$Q_{\mathrm{xx}} = S_{\mathrm{xx}} - \frac{S_{\mathrm{x}}^2}{N} \,, \qquad Q_{\mathrm{yy}} = S_{\mathrm{yy}} - \frac{S_{\mathrm{y}}^2}{N} \,, \qquad Q_{\mathrm{xy}} = S_{\mathrm{xy}} - \frac{S_{\mathrm{x}} \cdot S_{\mathrm{y}}}{N}$$

Variances:

$$s_{\mathrm{x}}^2 = \frac{Q_{\mathrm{xx}}}{N-1} \,, \qquad s_{\mathrm{y}}^2 = \frac{Q_{\mathrm{yy}}}{N-1}$$

Covariance:

$$s_{\mathrm{xy}} = \frac{Q_{\mathrm{xy}}}{N-1}$$

The above formulae reflect the “ordinary least square” regression. Other recognized regression methods like “robust regression” may be used.

R.6 Multiple regression analysis for estimated values

The estimated values are determined from a regression analysis assuming a linear relationship between p influencing parameters x_i and the dependent parameter y (assessment value).

Table R.2 summarizes the parameters to be used for the multiple regression, according to the test zone and the assessment quantity considered:

Table R.2 — Selection of parameters

	Test zone 1	Test zone curves	Test zone curves assessment zone 2
ΣY	$V,\ \Delta y_{\sigma}^{0}$	$1/R, I +\ \Delta y_{\sigma}^{0}$	$V, I,\ \Delta y_{\sigma}^{0}$
Y/Q		$1/R, I +\ \Delta y_{\sigma}^{0}$	$V, I,\ \Delta y_{\sigma}^{0}$
$\ddot{y}_{s}^{+}$	$V,\ \Delta y_{\sigma}^{0}$	$1/R, I +\ \Delta y_{\sigma}^{0}$	$V, I,\ \Delta y_{\sigma}^{0}$
$\ddot{y}_{s}^{*}$	$V,\ \Delta y_{\sigma}^{0}$	$1/R, I +\ \Delta y_{\sigma}^{0}$	$V, I,\ \Delta y_{\sigma}^{0}$
$\ddot{z}_{s}^{*}$		$1/R, I +\ \Delta z_{\sigma}^{0}$	$V, I,\ \Delta z_{\sigma}^{0}$
Q	$V,\ \Delta z_{\sigma}^{0}$	$1/R, I +\ \Delta z_{\sigma}^{0}$	$V, I,\ \Delta z_{\sigma}^{0}$
$Q_{a,qst}$		$1/R, I$	-
$Y_{a,qst}$		$1/R, I$	-

The general multiple linear regression model with the response or dependent variable y and the independent or regressor terms $x_1, \ldots, x_p$ has the form:

$$\hat{y} = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_p x_p$$

The parameters a_j are called regression coefficients.

For the calculation of the regression coefficients a matrix notation can be used:

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{a}$$

with

$$\boldsymbol{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

measured values of the dependent variable,

$$\boldsymbol{X} = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1p} \\ 1 & x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & \vdots & & \\ 1 & x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix}$$

matrix of the measured values of the input variables,

$$\boldsymbol{a} = \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_p \end{bmatrix}$$

regression coefficients.

The least square estimate $\hat{\boldsymbol{a}}$ of the regression coefficients a can be calculated by solving the least square formula:

$$\hat{\boldsymbol{a}} = (\boldsymbol{X}'\boldsymbol{X})^{-1}\boldsymbol{X}'\boldsymbol{y}$$

NOTE 1 Most of the standard technical software tools include algorithms performing this calculation.

The upper limit of the confidence interval at $\boldsymbol{x} = \boldsymbol{x}_0$ can be calculated as:

$$Y(PA, \boldsymbol{x}_0')_{\max} = \hat{y}(\boldsymbol{x}_0') + t(PA, f)s\sqrt{1 + \boldsymbol{x}_0'(\boldsymbol{X}'\boldsymbol{X})^{-1}\boldsymbol{x}_0}$$

$$s^2 = \frac{RSS}{n - (p+1)}$$

$$RSS = \boldsymbol{y}'\boldsymbol{y} - \hat{\boldsymbol{a}}'\boldsymbol{X}'\boldsymbol{y}$$

where

$\hat{y} = \hat{a}_0 + \hat{a}_1 x_{01} + \hat{a}_2 x_{02} + \ldots + \hat{a}_p x_{\mathrm{op}}$ is the estimate of the regression value at $\boldsymbol{x}_0$

$t(PA, f)$ is the threshold value of the bilateral t-distribution.

The estimated value is calculated at the regressor values x_{i0} equal to the target conditions as stated in Table 2.

NOTE 2 The one dimensional and two-dimensional methods are examples of multilinear regression, where only one input parameter (cant deficiency I) ($p = 1$) or no input-parameter ($p = 0$) is used. The principles and formulae given in this section remain valid and lead to the formulae in R.4 and R.5.

R.7 Statistical evaluation for the overturning criterion

For the overturning parameter κ a bi-dimensional analysis of the maximum values versus cant deficiency shall be performed with the following rules:

— in curved zones, only full curve sections shall be used;

— only one analysis is made after all $y_j(h_i)$ of the same curve direction have been gathered whatever the radii are;

— for curve sections (test zones 2, 3 and 4), only $y_j(h_1)$ is used for negative cant deficiencies and only $y_j(h_2)$ is used for positive cant deficiencies. For straight track (test zone 1), both $y_j(h_1)$ and $y_j(h_2)$ are used. That means, that positive cant deficiencies will correspond to $y_j(h_2)$ and negative cant deficiencies will correspond to $y_j(h_1)$;

— the total mesh is divided into two parts: one for $y_j(h_1)$, the other for $y_j(h_2)$. Two trend lines are calculated, one for each mesh:

  $Y_B = a_B + b_B \cdot I$ and $Y_A = a_A + b_A \cdot I$;

— the standard deviations s_B of the vertical distance from the points $\{y_j(h_1), I = 1 \ldots N_1\}$ and s_A of the vertical distance from the points $\{y_j(h_2), i = 1 \ldots N_2\}$ to the corresponding trend line are calculated. Two new lines are determined, one for measurands corresponding to $y_j(h_2)$ ($+I$)

  $Y_P = Y_A + 3s_A$;

  the other for measurands corresponding to $y_j(h_1)$ ($-I$)

  $Y_N = Y_B - 3s_B$;

— the values for κ are to be read at $1{,}5 \cdot I_{\mathrm{adm}}$ and $-1{,}5 \cdot I_{\mathrm{adm}}$;

Figure R.2 shows an example.

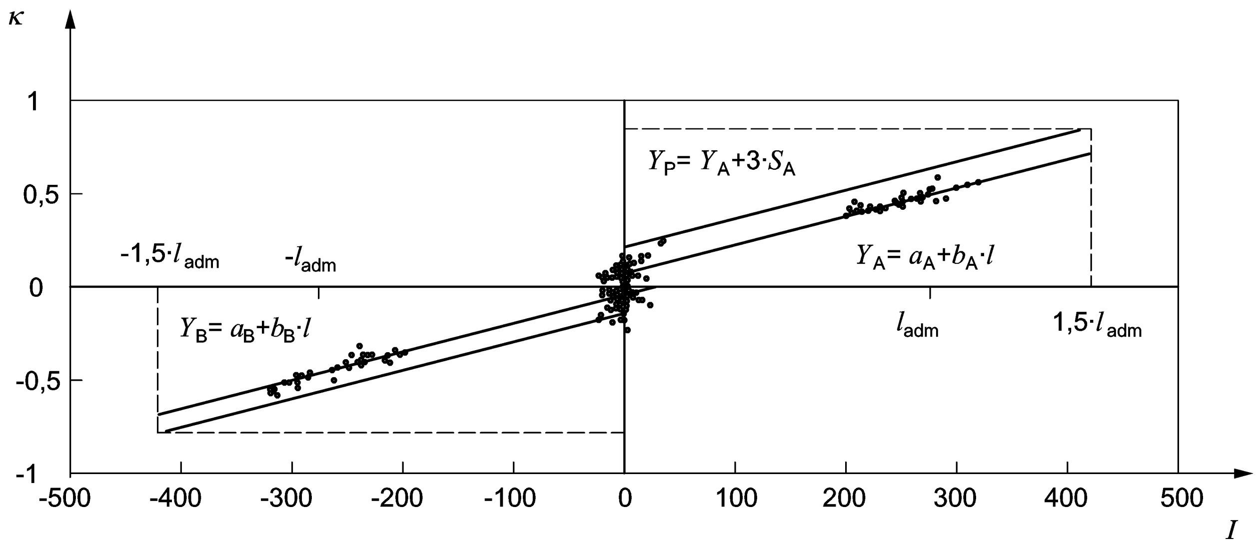


Figure R.2 — Plot and trend lines for evaluation of the overturning criterion

R.8 Regression assumptions

R.8.1 Regression assumptions and associated problems

All three regression methods rely on some important assumptions. When these assumptions are violated, the results are not valid and an application of them may lead to serious error (see [17] and [18]).

The methods here are based on a model describing the relationship between the response Y and the predictors $X_1, X_2, \ldots, X_p$. It is assumed to be linear in the regression parameters $a_0, a_1, \ldots, a_p$:

$$Y = a_0 + a_1 \cdot X_1 + \ldots + a_p \cdot X_p + \varepsilon$$

which implies that the i^{th} observation can be written as:

$$y_i = a_0 + a_1 \cdot x_1 + \ldots + a_p \cdot x_p + \varepsilon_i \text{ with } i = 1, 2, \ldots, n$$

The most significant regression assumptions and associated problems are:

— specification errors:

The relevant influencing variables have to be included, otherwise the regression coefficients of the included variables will become unreliable or wrong as they are biased estimates of the true ones. The validity of the assumed function, e.g. linear function has to be given.

— normality and independence of the errors:

The errors $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n$ are assumed to be both independently and identically distributed normal random variables each with a mean of zero and a common variance σ_2.

This implies four assumptions: The errors have a normal distribution, they have a mean of zero, they have a constant variance (heterogeneity or the heteroscedasticity problem) and they are independent to each other (autocorrelation problem)

— assumptions about independent variables:

The values $x_{1j}, x_{2j}, \ldots, x_{nj}$; $j = 1, 2, \ldots, p$, are measured without error. Errors in the measurement will affect the residual variance, the multiple correlation coefficient, and the individual estimates of the regression coefficients.

The predictor variables X_1, X_2, …, X_p, are assumed to be linearly independent of each other. This assumption is needed to guarantee the uniqueness of the least squares solution. If this assumption is violated, the problem is referred to as the collinearity problem.

— assumptions about the observations:

All observations are equally reliable and have approximately an equal role in determining the regression results and in influencing conclusions.

R.8.2 Identification and correction techniques

A simple and effective method for detecting model deficiencies in regression analysis is the examination of residual plots using standardised residuals. Residual plots will identify serious violations in one or more of the standard assumptions if they exist. The analysis of residuals may lead to an understanding of the data structure or shows information in the data that might be missed if the analysis is based on summary statistics only. An assessment of graphical presentations of residuals may often be the most useful part of the regression analysis.

— high leverage points and outliers should also be studied in detail;

— correction of specification errors:

Typical corrections are transformations (e.g. use $1/R$ instead of R), nonlinear models using interaction terms or with high order polynominal terms. If important independent variables are missing, the correction measure is to include them, unless they are collinear with already included variables.

— non-normality and heterogeneous variances of residuals:

Transformations of the dependent variable and possibly some of the influencing variables can solve the problem. More complex methods are the “weighted least square” technique, the “generalised least square” method or the “generalised linear models”.

— influential points and outliers:

Outliers in the dependent variable should be removed, but only if there is a clear indication of measurement or analysis errors. The influence of outliers and influential points will become smaller if the sample size is increased. The usual technique to solve problems with outliers and influential points is the technique called “robust regression”

— collinearity:

Collinearity between cant deficiency and curvature can be avoided by a careful planning of the tests. There is a natural collinearity between speed and track geometry (better track geometry at higher speeds). Again test planning can help by including lower speeds on lines for higher speeds with better track geometry. Generally also the increase of sample size reduces possible problems with collinearity. It can also be helpful to combine two or more variables that are highly correlated or delete one of the variables that are highly correlated. An alternative method is ridge regression and also other special high-level techniques are available for collinear data.

— measurement errors on the predictor variables:

They should be avoided as much as possible. Most of the predictors used in the assessment of running characteristics are measured very exactly (speed, cant deficiency, curvature). In the case of track geometry it should be kept in mind, that not only the measurement has to be as exact as possible, but also the mapping to the test sections. Special analysis of the measured track geometry for the tests according to this standard can avoid problems with measurement errors in the regression.

Annex S
(informative)

Running behaviour of special vehicles

S.1 General

The running behaviour of special vehicles shall be assessed according to the same principles as described in Clause 7 of this standard. Some simplifications are permitted and the following specifications override those stated in Clause 7 if they are contradictory.

The assessment for special vehicles includes also the possibility of simulation as described in EN 14033-1.

S.2 Vehicle design and classification

In order to make it suitable for its use, the design of a special vehicle may include specific features which may affect the running behaviour, such as:

— unusual distribution of wheelsets (e.g. combination of single wheelsets and bogies or use of bogies with more than 3 wheelsets);

— unusual and/or uneven distances between running gear (wheelsets or bogies) in running mode;

— unusual distribution of vertical wheelset forces with extreme or very uneven values;

— use of non-conventional devices inside the running gear or between running gear and structure;

— existence of articulated, movable or retractable parts in the structure or the working tools.

These features and experience with similar existing vehicles shall be taken into account when deciding if a special vehicle can be regarded as a conventional vehicle as specified in 3.14.

NOTE According to the process specified in 7.2.1 an assignment as a non-conventional vehicle results in the normal measuring method being applied.

For the application of Clause 7 of this standard, the vehicle shall be considered as belonging to one of the following vehicle types:

a) if the operating conditions are those of passenger trains, a powered vehicle shall be considered either as a locomotive and a non-powered vehicle as a passenger coach, or the whole train as a multiple unit.

b) if the operating conditions are those of freight trains, a powered vehicle shall be considered as a locomotive and a non-powered vehicle as a freight wagon.

A mix is possible for a special train made up of various vehicles.

EXAMPLE A tamping machine with a powered part on 2 bogies and a non-powered part on 2 wheelsets is considered as a locomotive combined with a 2-axle wagon. Only in case a), such a vehicle may also be considered in a whole as a multiple unit when its design is suitable.

S.3 Use of the simplified measuring method

For special vehicles the range of application of a simplified measuring method may be extended to nominal static vertical wheelset forces up to $P_{F0} \leq 225$ kN, if the design characteristics of the vehicle (see S.2) do not impose the use of the normal measuring method and:

— $V_{adm} \leq 120$ km/h;

— $I_{adm} \leq 130$ mm.

The following exceptions from Clause 7 apply, together with those listed in S.4:

If the vehicle parameters allow testing with the simplified measuring method using accelerations only, testing is only necessary in test zones 1 and 2.

If a special vehicle is equipped with conical wheel profiles (which always induces the same equivalent conicity independently of the rail profile), it is not necessary to perform a separate stability test. In that case, stability shall be assessed only on tracks used in test zone 1.

S.4 Test conditions

The provisions of Clause 7 for the relevant type(s) of vehicle shall apply, with the following exceptions:

— the test speed given in 7.3.2, Table 2 for zone 2 shall be V_{adm} with a tolerance range of ± 10 km/h;

— the specification for distribution of test cant deficiency given in 7.3.2, Table 2 shall be replaced by “The distribution shall include some values greater than I_{adm}”;

— for extension of approval of vehicles with only one load case and designed for maintenance, inspection or renewal of infrastructure elements, dispensation of on-track tests shall be granted if all parameter variations fall within the range of column 2c (“Freight stock”) of Table U.1 with the following modification: P_0 may vary in the range of −15 % to +10 % without exceeding 22,5 t.

S.5 Specific limit value

For special vehicles the factor $k_1 = 1$ shall be used for the determination of the limit value $\Sigma Y_{max,lim}$.

Annex T
(informative)

Simulation of on-track tests

T.1 Introduction

The dynamic performance of the vehicle shall normally be verified by tests (static tests and on-track tests), but the use of simulation in place of on-track test is permitted under controlled conditions. The objective when using simulation is to achieve the same level of confidence in the results as would be achieved by on-track tests. The simulation process described in this annex sets out one means by which this can be achieved. Other simulation procedures that achieve the same level of confidence are also permitted.

The range of conditions of the validation determines the scope for which the model is then approved for simulations. Therefore it is recommended that the simulation validation covers the widest practical range of test conditions.

The limits and guidelines related to simulation and validation stated in this annex are based on the current state of the art. This implies that the given criteria, conditions, methods, etc, are to be seen as preliminary to gain experience and may most probably be reconsidered at the next update of the standard.

The validation processes described in this annex relate only to the simulation of on-track tests described in Clause 7 of this EN.

T.2 Fields of application

T.2.1 General

Four cases of application where numerical simulations can be used in place of testing are detailed in this annex. These are:

— extension of the range of test conditions where the full test programme has not been completed;

— approval of vehicles following modification;

— approval of new vehicles by comparison with an already approved reference vehicle;

— investigation of dynamic behaviour in case of fault modes.

The scope of these cases of application and the conditions for use of numerical simulation is described in the following sub-clauses. Other cases of application may exist.

A vehicle model has to be developed and validated by comparison with the available test results in accordance with T.3.

T.2.2 Extension of the range of test conditions

Where on-track tests according to this standard have been carried out, but the full range of test conditions has not been satisfied, then it is permissible to use numerical simulations to cover the deficiencies as part of the vehicle approval. This situation could arise where:

— sufficient track length is not available to meet the requirements for some test zones;

— the full range of speed and cant deficiency has not been tested;

— the full range of wheel/rail contact conditions has not been covered;

— measuring channels failed, or provided unreliable results.

It is permitted to use numerical simulations for a single or multiple test zones where the test results are not complete, if the variance of the errors of measured sections is similar to those of the simulated sections. A sufficient number of track sections from each of simulations and measurements is necessary to compare the statistics.

NOTE This method assumes that measurements and simulation belong to similar basic populations. Checking heterogeneity or constant variance can partly prove this.

T.2.3 Assessment of vehicles following modification

Vehicle modifications may be carried out for a number of different reasons, for example:

— change of the use of the vehicle;

— upgrade of the vehicle;

— modifications to improve the running behaviour:

- during or following the approval test programme;
- when some tests were done in a preliminary vehicle configuration and the final configuration is defined afterwards.

A model of the original vehicle is developed and validated against the test results for that vehicle in accordance with T.3. The model of the vehicle is then modified to represent the physical changes to the vehicle as a result of the modification. Only the changes that influence the dynamic behaviour are required to be included in the modified model. The revised model is used to simulate the dynamic behaviour and the results are compared with the limit values for assessment.

Simulations for all test zones have to be carried out to demonstrate that the vehicle performance of the new vehicle is consistent when compared to the previously tested vehicle. The influence that the changed parameter(s) has (have) on the dynamic performance has to be examined for all zones. The results of this examination shall be reported and the influence on the performance indicated.

If a vehicle has been tested according to this standard and found to exceed some of the limit values, then it is permitted to use numerical simulations to demonstrate that modifications to the vehicle will improve the behaviour sufficiently to meet the limits. The values that previously exceeded the limits have to be under the limit values for track loading and at least 10 % below the limits for running safety. At the same time all other values shall remain below the limit and not increase by more than 1/3 of the previous margin to the limit value. In this situation the vehicle can be regarded as acceptable for the previously deficient limit values.

In any of the above cases it shall be independently confirmed (see T.3.3.6), that the modifications have been correctly applied to the model and that the resultant vehicle response is credible in the context of the original model. This shall be documented in the reviewer's report.

The data from the simulation is to be used to assess the modified vehicle.

T.2.4 Assessment of new vehicles by comparison with an already approved reference vehicle

Where vehicles are being introduced with a range of different types within the fleet (e.g. multiple units, etc.) then one vehicle type is defined as the reference vehicle. Vehicles that are similar to the reference vehicle can then be approved using numerical simulations, rather than on-track tests, to demonstrate the behaviour of the new vehicles, subject to the conditions given below.

Model(s) of the new vehicle(s) that are to be assessed are to be developed from the reference vehicle.

The existing and changed parameters are to be included in the simulation to demonstrate the influence of the changes on the performance.

Simulations for all test zones are carried out to demonstrate that the vehicle performance of the new vehicle is consistent when compared to the reference vehicle. The influence that the changed parameter(s) has (have) on the dynamic performance is to be examined for all test zones. The results of this examination are to be reported and the influence on the performance indicated.

If as result of the changes the dynamic response of the new vehicle does not increase any assessment quantity compared to the reference vehicle and the changes do not fundamentally affect the frequency or amplitudes of the dynamic response, then the influence of the change on the dynamic performance is considered insignificant. The model can be used for vehicle approval.

If the change to the dynamic performance results in:

— an increase in any assessment quantity compared to the reference vehicle;

— and/or a fundamental change in the frequency and/or amplitudes of the dynamic response;

then a full review shall be carried out.

This review shall include analysis that investigates the changes to the dynamic response(s) of the new vehicle compared to the reference vehicle and an associated explanation of the effects identified. This comparison has to be carried out for at least 3 sections of each test zone, if it demonstrates that:

— the assessment quantities for running safety (see 7.5.2) from simulations do not increase by more than 1/3 of the previous margin to the limit values;

— and at the same time the values for track loading (see 7.5.3) from simulations do not increase by more than 2/3 of the previous margin to the limit values;

then the simulation can be used for vehicle assessment.

NOTE Changes to individual components such as springs or dampers are likely to be acceptable provided the characteristics of the changed components are known and the changes are not extreme. Limited changes to masses, inertias or centres of gravity are also likely to be acceptable. A change to the concept of the suspension or introduction of components which were not present in the validated model for the tested vehicle is less likely to be acceptable.

Confirmation that the modifications have been correctly applied to the model and that the resultant vehicle response is credible in the context of the original model shall be independently reviewed and documented in the reviewer's report (T.3.3.6).

T.2.5 Investigation of dynamic behaviour in case of fault modes

The use of simulation to investigate fault modes in support of the requirements of 5.2.2 is permitted. In such cases the validity of the simulation of fault modes has to be independently reviewed and confirmed as being appropriate and the outcome of the review shall be documented in the reviewer's report. The process of selecting and assessing fault modes is independent from the assessment method (test method or simulations).

The model shall only be used within its range of validity.

T.3 Validation

T.3.1 General principles

Models used in numerical simulations are required to be validated by comparison with test results from the vehicle that is being modelled.

Information that is required to carry out the validation should include:

— design data for the modelled vehicle that is sufficiently detailed to enable the features that influence the vehicle dynamics to be incorporated into the model;

— test results for the modelled vehicle in a form that can be used for model validation including time history data in a digital form. It is necessary that these tests and data include a representative range of track conditions, curves, cant deficiency, speed and wheel/rail contact conditions;

— track data from the original test route to enable validation to be undertaken.

In case not all the information required in this annex can be used (e.g. because it is not available and cannot be obtained) in the validation of the model, the impact of the missing data on the model accuracy has to be assessed. As a consequence of this assessment, limitations on the application range of the model may need to be defined. This will need to be independently reviewed.

T.3.2 Vehicle model

The model shall include the main components such as wheelsets, bogies/running gear, vehicle body and all of the relevant connections between them (e.g. geometry, linear/nonlinear stiffness, damping, clearances, etc.). Data describing the vehicle body has to be included to the level of detail required to represent dynamic effects that are prominent in the dynamic performance (e.g. masses, inertias, position of centre of gravity, significant eigenmodes/flexible bodies).

The precision and level of detail that is appropriate in a model will depend on the particular assessment quantities that are to be evaluated.

Sufficient detail and precision is required to give confidence in the predicted vehicle performance under consideration.

T.3.3 Validation of the vehicle model

T.3.3.1 Introduction

In order to generate valid results, it is necessary that numerical simulations are carried out with care to ensure that:

— the vehicle model is a good representation of the actual vehicle;

— the software used is appropriate for the application;

— the correct conditions have been covered;

— the engineers undertaking the simulations are competent;

and therefore, the simulation results will be valid.

If numerical simulations are to be used for a vehicle in different conditions (for example tare, laden, inflated, deflated, etc.), separate models will need to be validated for each condition.

Two validation methods are described here; these are detailed in T.3.3.3 and T.3.3.4. Both are regarded as equally valid and when validation is carried out only one of the methods is required to be used. The technique that is given for each method only applies to that method.

T.3.3.2 Validation process, general

The validation process is based on comparisons between physical test results of the vehicle and numerical simulations of the same tests. The primary purpose of validating a numerical vehicle model is to use that model to simulate the vehicle behaviour in-lieu of actual on-track tests. Vehicle approval requires the assessment of the vehicle's static, quasi-static and dynamic behaviour. Therefore it is helpful if the model includes validation against the static, quasi-static and the dynamic tests.

The range of conditions of the dynamic validation determines the scope for which the model is then approved for simulations. Therefore it is recommended that the validation tests and simulation comparisons cover the widest practical range of conditions.

The validation process should also be made across the appropriate dynamic frequency range. All comparisons between simulation and actual on-track test results have to be made using the same vehicle model and software. A model that has been validated shall not be changed for subsequent simulations, except for the conditions given in T.2.3 and T.2.4.

It is required that the results of all appropriate work carried out to validate the vehicle model are presented in a validation report.

The following clauses describe the process to be used to ensure that the model is a good representation of the actual vehicle and it is suitable to be used for vehicle approval.

The data that can be required in order to undertake validation of the numerical simulations are given in Table T.1.

The processes of model validation according to Method 1 and Method 2 are illustrated in the following flowchart (Figure T.1). Details about the two methods are given in T.3.3.3 and T.3.3.4.

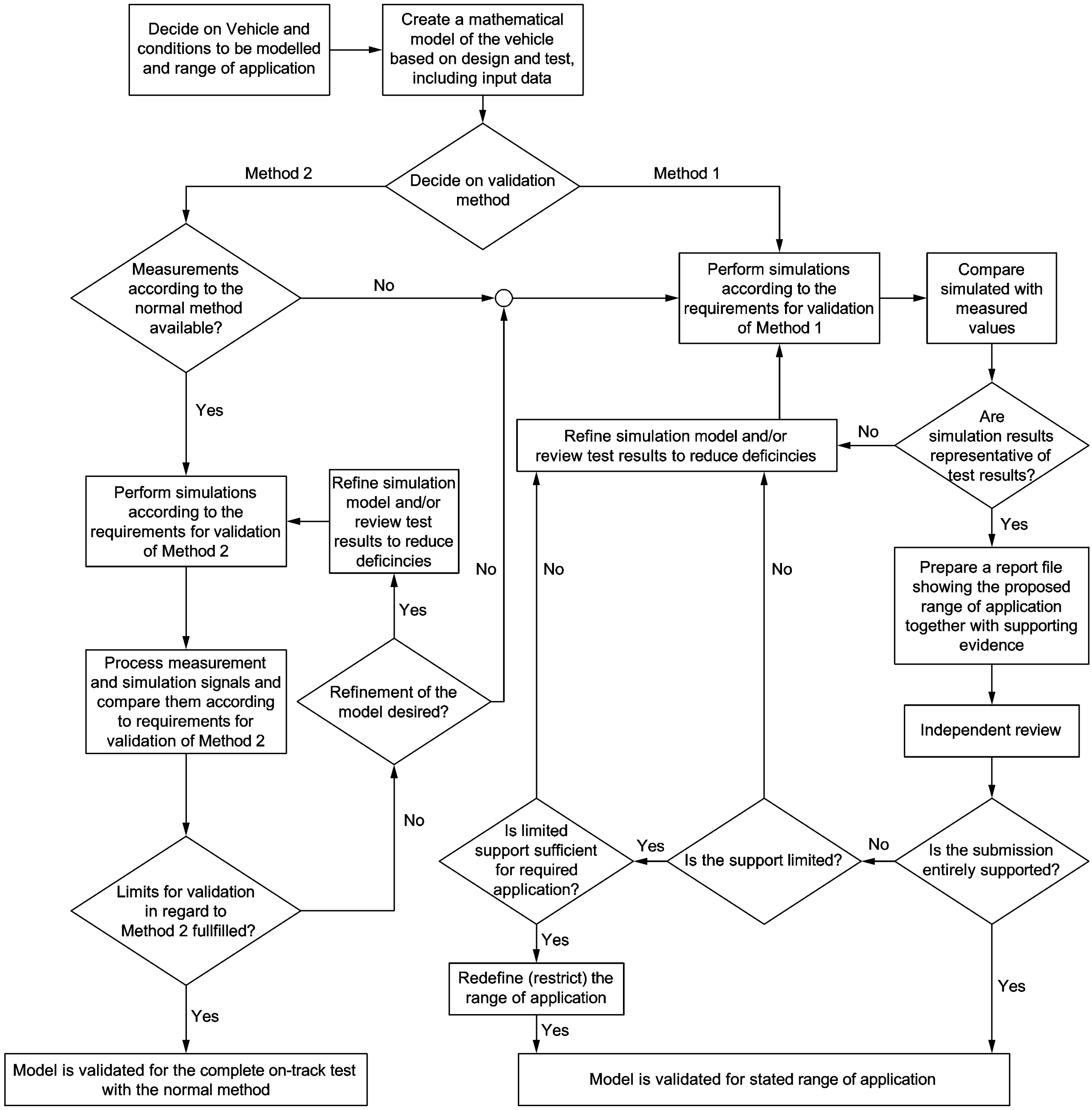


Figure T.1 — Model validation methods

T.3.3.3 Validation process according to Method 1

T.3.3.3.1 General

The validation process of Method 1 is based on the analysis of the vehicle model with respect to the vehicle response to various inputs. The results of this analysis are judged by an independent reviewer. The comparison of simulation and test results can include the following parameters:

— assessment quantities according to this standard (track section values, mean, standard deviation and estimated maximum) as appropriate – see normative Annex R;

— key frequencies of the following measurement quantities over a sample of track sections:

- vehicle body lateral and vertical accelerations at each end;

- vehicle body bounce and pitch accelerations (derived from in and out of phase values of body end vertical accelerations);
- calculated vehicle body lateral and yaw accelerations (derived from in and out of phase values of body end lateral accelerations);
- bogie lateral and yaw accelerations;
- bogie vertical and pitch accelerations (if available);
- ΣY forces (key frequencies);

— distribution plots of values for Y and Q forces as function of curve radius, cant deficiency, etc. (as appropriate). See examples in R.7;

— sample time histories over straight and curved track sections for all the measurement quantities.

The following Table T.1 contains suggested parameters to be considered in the validation process.

A comparison of vertical wheel force on each individual wheel is also reasonable. The deviations should be as low as possible. However, it should be recognized that the measurements of vertical wheel force will vary between successive measurements of the same vehicle, particularly for vehicles with friction damping like freight wagons. For such vehicles, maximum deviation up to 15 % could be acceptable.

Table T.1 — Parameters for model validation

Parameter		**Maximum deviation between simulation and measurement**		**Application for a successful validation**		**Remark**
		Maximum deviation	**Average deviation of all wheelsets, bogies, etc.**	**Required** [b]	**Recommended (informative)**	
Static wheelset force	P_{F0}	6 %	3 %	X		Based on [16]
Static bogie force	Q_{B0}	3 %	3 %	X		Based on [16]
Static side force	Q_{S0}	3 %	3 %	X		Based on [16]
Wheel force in twist	Q_t	15 %	7 %		X	Based on [16]
Wheel unloading in twist	ΔQ_t	10 %			X	
displacement characteristics		not specified	not specified		X	
Lateral forces in 150 m curve (or in a similar tight curve)	Y_a, Y_i	8 %	not specified		X [a]	
Bogie rotational resistance	X-Factor	not specified	not specified		X [a]	
Roll coefficient (and spring deflections)	s	not specified	not specified		X	Based on measurement of roll coefficient
Eigenfrequencies of the rigid body movements of vehicle body	f_0	not specified	not specified		X	Identified e.g. by wedge tests

Quasi-static lateral forces	Y_{qst}	max.{10 % or 4 kN}	not specified	X		Measured on on-track tests; Check of all measured wheels required!
Quasi-static wheel force	Q_{qst}	8 %	not specified	X		Measured on on-track tests; Check of all measured wheels required!
Lateral forces	Y	Assessment of the time histories and FFT results	not specified	X		
Vertical wheel force	Q	Assessment of the time histories and FFT results	not specified	X		
Vehicle body accelerations	$\ddot{y}$, $\ddot{z}$	Assessment of the time histories and FFT results	not specified	X		
Bogie accelerations	$\ddot{y}$, $\ddot{z}$	Assessment of the time histories and FFT results	not specified		X	

[a] At least one or the other.

[b] In case any of the required parameters is not evaluated, the application of the model should be limited accordingly.

T.3.3.3.2 Validation using static tests or slow speed tests

T.3.3.3.2.1 Objective

As part of the model's validation process, it is expected to use results from static or slow speed tests. The results of existing static and slow speed tests can be used, special tests are not required.

Depending on the analysis undertaken, these results are used to validate different aspects of the vehicle model, namely:

— vertical wheel forces and force distribution;

— behaviour on twisted track;

— bogie rotation;

— flexibility coefficient;

— other static test results.

T.3.3.3.2.2 Vertical wheel forces and force distribution

For vertical wheel forces and force distributions it is necessary that the following values are calculated and compared with the test results:

— vertical wheel force on each individual wheel;

— vertical wheel forces on each wheelset (sum of two wheels);

— vertical wheel forces on each bogie (sum of wheels);

— vertical wheel forces on each side of the vehicle (sum of wheels on that side).

It is required that the results of the comparison are reported including differences as a percentage of the appropriate test result.

Table T.1 presents the maximum differences between simulation and test results that are acceptable for a well validated model.

T.3.3.3.2.3 Behaviour on twisted track

Where tests are undertaken to determine the behaviour on twisted track it is recommended that the appropriate measurement quantities are calculated and compared with the test results. This will normally include (dependent on the method of test):

— vertical wheel forces during the testing;

— suspension displacement during the testing;

— plots of vertical wheel forces against applied twist;

— hysteresis;

— magnitude of any wheel lift.

The maximum deviation for wheel unloading is also given in Table T.1.

T.3.3.3.2.4 Bogie rotation

Where bogie rotation tests are undertaken it is recommended that the appropriate measurement quantities are calculated and compared with the test results. This can include:

— bogie rotation angle;

— applied force/torque;

— plots of applied force/torque against rotation angle;

— different rotational speeds.

T.3.3.3.2.5 Displacement characteristics

Where static tests to determine the displacement characteristics are undertaken, it is recommended that the appropriate measurement quantities are calculated and compared with the test results. This can include:

— vehicle body roll angle;

— bogie roll angle;

— lateral displacement of specific positions on body/bogie;

— vertical displacement of specific positions on body/bogie.

T.3.3.3.2.6 Other static tests

Additional test not defined in Clause 6 of this standard may include:

— force/deflection measurements of components;

— force/deflection measurements of the suspension when mounted in the vehicle;

— etc.

The results of these tests can also be used to validate the simulation model. Therefore the results have to be compared with the simulation results obtained under the same boundary conditions in an appropriate way.

NOTE Such tests can be performed for example in lateral and longitudinal directions. Examples are tests where the vehicle body is moved in lateral direction relative to the running gear or where the wheelset is moved in longitudinal direction relative to running gear frame. In many cases it is useful to test different values of amplitude and frequency in order to investigate hysteresis and damping.

T.3.3.3.3 Validation using dynamic tests

T.3.3.3.3.1 Range of validation

It is necessary to consider the parameters given below in determining the range of applicability of the validated model. The vehicle model is to be considered as validated for the range of conditions covered in the comparisons, presuming that satisfactory results are obtained.

The following parameters have to be considered and the range of conditions covered shall be reported in the validation report:

— track geometric irregularities – have to be sufficient to excite the vehicle suspension in all directions and have to include track with irregularity at both ends of the quality range;

— vehicle speed – validation is limited to the speed range tested;

— vehicle cant deficiency – validation is limited to the cant deficiency range tested;

— straight track – sufficient length and conditions, such as gauge and contact as well as friction conditions, to demonstrate vehicle stability are required;

— curve track sections – have to include maximum cant deficiency;

— very small radius curves – have to be included to assess behaviour in these conditions;

— wheel rail contact conditions – to cover the range required for approval;

— wheel rail friction conditions – have to include a significant length of dry rail conditions;

— vehicle load conditions – as required for approval;

— position of vehicle in the trainset – (if relevant – see T.4.10);

— suspension component fault mode – as required for approval.

Furthermore the vehicle model is to be considered as validated only for the outputs (accelerations, forces, etc.) included in the comparisons. Vehicle models validated without track force comparisons cannot be used for assessments using track forces in the context of this standard.

T.3.3.3.3.2 Validation basis

Normal method test results should generally be used for validating a model. It may be acceptable to use test results that do not include Y- and Q-forces. In such cases alternative data from tests can be used e.g. primary suspension displacements and associated suspension characteristics possibly combined with

H-force measurement. The test results used in the validation also need to fulfil the following conditions, as required for the range of application:

— maximum test speed (admissible speed +10 %) has been tested over track of a suitable length and quality to demonstrate stability;

— maximum cant deficiency (admissible cant deficiency limit +10 %) has been tested for some curves;

— tests have included some very small radius curves and a sufficient range of wheel/rail contact conditions;

— track conditions are sufficiently rough to excite the vehicle suspension.

T.3.3.4 Validation process according to Method 2

The validation process of Method 2 is based on a mathematical comparison between the results of on-track tests performed according to the normal measuring method and the corresponding simulation results.

The simulation and measurement results of the specified quantities shall be compared on at least 12 track sections, called validation exercises. A section can be either a test section according to 7.3.2 or part of a test track longer than the minimum length specified for track sections in the particular test. Moreover, this section shall fulfil the other test section requirements such as constant curve radius etc. The selected validation exercises shall contain sections from all 4 test zones, at least 3 sections from each test zone. The track geometric irregularities have to represent the conditions of the on-track tests.

Each quantity shall be evaluated using at least two signals, e.g. vertical acceleration above the leading and trailing bogie, thus, at least 24 simulated values S_v compared to the corresponding measured values M_v of each quantity. The comparison of wheel/rail forces considers both wheels of an instrumented wheelset and is not restricted to the forces on the outer side of the curve. Each compared simulated as well as measured quantity shall be filtered and processed according to the requirements in Table T.2. The percentiles shall be calculated from the cumulative curve. The definitions of simulated values S_v and the corresponding measured values M_v are shown in Table T.2. For the maximum value calculated as 0,15 % or 99,85 %-value, the higher magnitude of the 0,15 %- and 99,85 %-values (absolute value) is used. The 50 %-values (medians) are applied with their sign to show the agreement of both magnitude and direction of those quantities.

The difference D_v between the simulated value S_v and the corresponding measured values M_v shall be evaluated for each value and each quantity, whereby this difference shall be transformed so that, if the magnitude of the simulation value is higher than the magnitude of the measurement (simulation overestimating the measurement), the difference is positive, and vice versa:

$$D_v = (S_v - M_v)\frac{M_v}{|M_v|} \qquad \text{for} \quad M_v \neq 0$$

$$D_v = S_v \qquad \text{for} \quad M_v = 0$$

The following values shall be calculated for the whole set of differences D_v between the simulation and measurement for each quantity (e.g. for all Y_{qst} values):

— mean of differences between simulation value S_v and measurement value M_v

— standard deviation of the same set of differences.

Table T.2 — Quantities and limits for model validation in regard to simulation of on-track test

Quantity	Notation	Unit	Filtering	Processing	Definition of S_v, M_v	Validation limit for standard deviation [a]
Quasi-static guiding force	Y_{qst}	kN	Low-pass filter 20 Hz	50 %-value (median)	S_v, M_v = Y_{qst}	5
Quasi-static vertical wheel force	Q_{qst}	kN	Low-pass filter 20 Hz	50 %-value (median)	S_v, M_v = Q_{qst}	4 (1 + 0,01 Q_0) Q_0 - static vertical wheel force in kN
Quasi-static quotient *Y/Q*	$(Y/Q)_{qst}$	-	Low-pass filter 20 Hz	50 %-value (median)	S_v, M_v = $(Y/Q)_{qst}$	0,07
Quasi-static sum of guiding forces	ΣY_{qst}	kN	Low-pass filter 20 Hz	50 %-value (median)	S_v, M_v = ΣY_{qst}	6
Guiding force, maximum	Y_{max}	kN	Low-pass filter 20 Hz	0,15 %/99,85 %-value [b]	S_v, M_v = $\lvert Y_{max}\rvert$	9
Vertical wheel force, maximum	Q_{max}	kN	Low-pass filter 20 Hz	99,85 %-value [b]	S_v, M_v = $\lvert Q_{max}\rvert$	6 (1 + 0,01 Q_0) Q_0 - static vertical wheel force in kN
Quotient *Y/Q*, maximum	$(Y/Q)_{max}$	-	Sliding mean (2 m window, step 0,5 m)	0,15 %/99,85 %-value [b]	S_v, M_v = $\lvert (Y/Q)_{max}\rvert$	0,10
Sum of guiding forces, maximum	ΣY_{max}	kN	Sliding mean (2 m window, step 0,5 m)	0,15 %/99,85 %-value [b]	S_v, M_v = $\lvert \Sigma Y_{max}\rvert$	9
Vehicle body lateral acceleration, rms-value	$\ddot{y}^*_{rms}$	m/s²	Band-pass filter 0,4 to 10 Hz	rms-value	S_v, M_v = $\ddot{y}^*_{rms}$	0,15 k_a [c]
Vehicle body vertical acceleration, rms-value	$\ddot{z}^*_{rms}$	m/s²	Band-pass filter 0,4 to 10 Hz	rms-value	S_v, M_v = $\ddot{z}^*_{rms}$	0,15 k_a [c]
Vehicle body lateral acceleration, maximum	$\ddot{y}^*_{max}$	m/s²	Band-pass filter 0,4 to 10 Hz	0,15 %/99,85 %-value [b]	S_v, M_v = $\lvert \ddot{y}^*_{max} \rvert$	0,40 k_a [c]
Vehicle body vertical acceleration, maximum	$\ddot{z}^*_{max}$	m/s²	Band-pass filter 0,4 to 10 Hz	0,15 %/99,85 %-value [b]	S_v, M_v = $\lvert \ddot{z}^*_{max} \rvert$	0,40 k_a [c]

[a] Validation limit for mean of differences simulation-measurement is 2/3 of the limit for standard deviation.

[b] Absolute values of simulated value S_v and measured value M_v

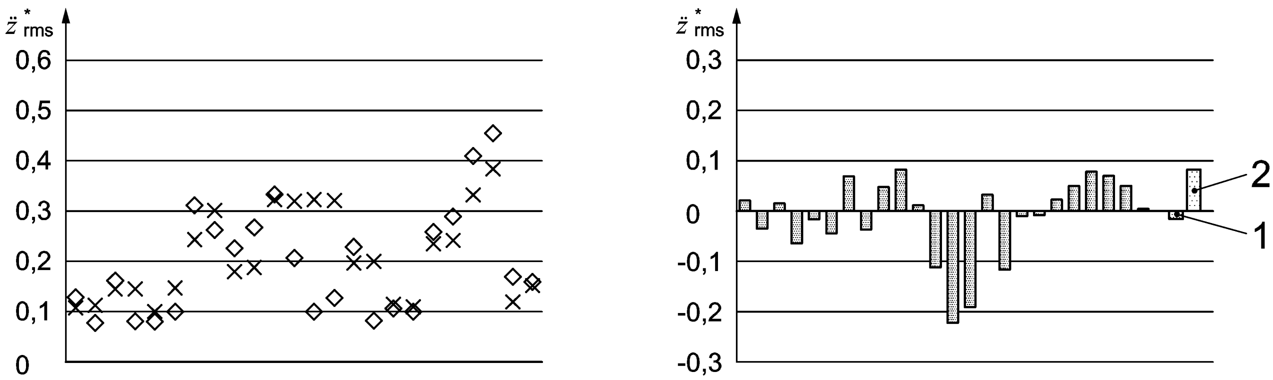
[c] k_a – coefficient in regard to vehicle design:

Freight vehicles and vehicles without bogies or without secondary suspension, respectively: k_a = 2, other vehicles: k_a = 1.

The standard deviation of the set of differences between simulation value S_v and the measurement value M_v for each quantity shall be not higher than their validation limit shown in Table T.2. For each quantity the mean of the set of differences between the simulation value S_v and the measurement value

M_v shall not be higher than the validation limit equal to 2/3 of the related limit for the standard deviation. The validation limits for accelerations (standard deviation as well as mean of differences) for freight vehicles or vehicles without secondary suspension are twice the relevant limit values for other vehicles.

As an example, Figure T.2, Table T.3 and Table T.4 explain the calculation of differences between the simulation value S_v and the measurement value M_v for the rms-value of vertical acceleration at the vehicle body. The left diagram displays the simulation values S_v and the measurement values M_v. The right diagram shows the differences D_v, their mean value and standard deviation, which are used for comparisons with the validation limits specified in Table T.2.



a) b)

Key

◇ simulation
× measurement
1 mean value
2 standard deviation

Figure T.2 — Example of differences between simulated and measurement values (left diagram) and calculation of their mean and standard deviation (right diagram)

The fulfilment of the validation limits can be easily assessed displaying the results divided by the corresponding validation limits, i.e. as normalized values. The vehicle model is validated, if the magnitudes of all normalized values are not higher than 1. Figure T.3 shows an example of the normalized values of mean and standard deviation of differences between the simulated and the measurement values for two different vehicle models. The Model 1 cannot be validated because of exceeding the validation limits for Y_{max}, $\ddot{z}^*_{rms}$ and $\ddot{z}^*_{max}$. The Model 2, which is the Model 1 adjusted according to comparisons with on-track tests, fulfils all validation limits and is thus validated.

Table T.3 — Calculation of differences between simulated and measured values of values displayed in Figure T.2 (rms values of vehicle body vertical acceleration)

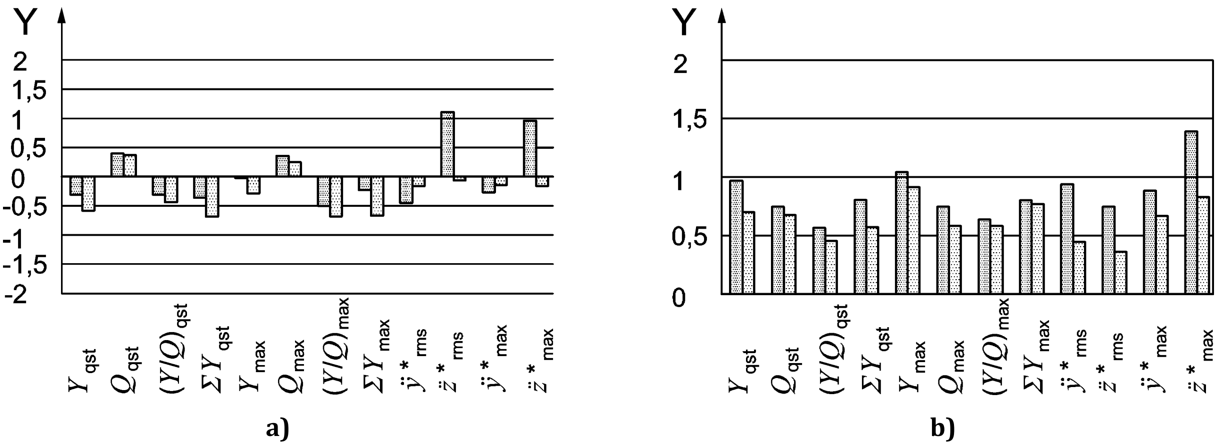
Dimensions in m/s²

Section	Simulation S_v	Measurement M_v	Difference D_v
1	0,129	0,110	0,019
	0,078	0,114	−0,036
2	0,163	0,147	0,015
	0,082	0,147	−0,065
3	0,082	0,101	−0,019
	0,102	0,149	−0,046
4	0,314	0,245	0,069
	0,624	0,304	−0,040
5	0,229	0,182	0,047
	0,271	0,190	0,081
6	0,335	0,326	0,009
	0,210	0,322	−0,113
7	0,101	0,326	−0,025
	0,128	0,322	−0,194
8	0,231	0,198	0,033
	0,083	0,202	−0,119
9	0,105	0,116	−0,011
	0,102	0,111	−0,009
10	0,259	0,237	0,022
	0,292	0,244	0,048
11	0,411	0,335	0,077
	0,457	0,386	0,070
12	0,172	0,122	0,050
	0,159	0,156	0,004

Table T.4 — Mean differences and standard deviation of values in Table T.3

Dimensions in m/s²

	Calculated value	Limit value	Normalized value
Mean of D_v	−0,014	0,10	−0,138
Standard deviation of D_v	0,081	0,15	0,542



Key

Model 1
Model 2

Figure T.3 — Example of normalized values of mean and standard deviation of differences simulation – measurement for two different vehicle models

T.3.3.5 Documentation of the validation

T.3.3.5.1 Content

The results of any validation have to be reported together with the information indicated in the following clauses.

T.3.3.5.2 Vehicle model description

A general description of the vehicle, together with the types of suspension elements (coil spring, air spring, friction elements etc.) shall be provided.

The components of the model, and their main characteristics, have to be described. As an example, this description may follow the structure of the table of main vehicle parameters as given in Table U.1 and cover all the parameters.

T.3.3.5.3 Wheel/rail contact model

The description of the wheel/rail contact model containing as a minimum creepage/creep force relationships, handling of material flexibility in the contact patch, handling of multiple contact patches and flange contact shall be provided.

T.3.3.5.4 Track model

A description of or a reference to the track model used and any input data (e.g. values of stiffness and damping) shall be provided.

T.3.3.5.5 Software used

The name of the software, version number and details of any special options or modules used shall be provided. Any particular input data required or assumptions made in using the software also have to be documented.

T.3.3.5.6 Validation tests

Details of the static tests and dynamic test routes (as appropriate for the chosen validation method), curvature ranges, speeds, cant deficiency ranges, track geometric quality etc. Wheel/rail contact conditions covered also have to be reported.

T.3.3.5.7 Results of the validation

For Method 1 the assessment quantities specified in T.3.3.3.2 and T.3.3.3.3, together with graphical results shall be provided. Sample time history graphs shall also be provided for both tests and simulations. An explanation of the presented results shall be given.

For Method 2 the results should be given in a table and also in a graph (see T.3.3.4). In this case, the mean and standard deviation of the set of differences between the simulation value S_v and the measurement value M_v for each quantity shall be reported together with the normalized value calculated by dividing the mean and standard deviation by the validation limits as illustrated in Table T.3, Table T.4 and Figure T.3.

T.3.3.5.8 Results of the independent review (only Method 1)

The conclusions of the review shall be reported.

T.3.3.5.9 Conclusions and scope of validated model

This section has to summarize the results of the validation exercise and state clearly the scope of application for which the model has been validated.

T.3.3.6 Review of the validation (only Method 1)

The results from the validation, together with the proposed range of application, have to be independently reviewed by a person, who is knowledgeable and experienced in the areas of running safety, vehicle dynamic behaviour (testing and simulation), vehicle-track interaction and the requirements of this, or equivalent, standards.

The review shall be performed by a separate person from those who undertook either the testing or the numerical simulations but may be part of the same organization/department (second party independence). The identity and experience of the reviewer shall be documented in the reviewer's report or in a covering letter.

The results of the comparison as reported shall be considered, any areas that are considered critical shall be investigated and it shall be determined whether the vehicle model is a good representation of the physical vehicle. If the independent review shows that the model is a good representation for the proposed range of application then the model can be declared as validated and suitable for use in numerical simulations for vehicle acceptance. Otherwise the review might also result in a limited range of application.

The conclusions shall be documented.

It is assumed that any additional review, with respect to simulations, would be limited to confirming that:

— the conditions under which it is permitted to use simulations are fulfilled, including any limitations identified during the independent review;

— the appropriate range of simulations have been carried out;

— the results from the simulations meet the required limits specified in the standard;

— the review was made with suitable independence and competence.

T.4 Input

T.4.1 Introduction

The input information requiring special attention for numerical simulation is given below. In all cases the used conditions, the explanations and assumptions of simulation and validation have to be documented. These are:

— vehicle model;

— vehicle configuration and modification state;

— track data;

— track model parameters;

— wheel/rail contact geometry;

— rail surface condition (friction coefficient);

— direction of travel;

— speed;

— position of the vehicle in the trainset;

— tractive effort, hauled or on its own power, as per on-track test.

The following sub-clauses consider these in more detail.

T.4.2 Vehicle model

A vehicle model has to be a correct representation of all the aspects of the actual vehicle that influence the dynamic behaviour. This requires a full 3-dimensional nonlinear model of the vehicle which includes:

— masses, inertias and mass distribution;

— suspension stiffness, damping, friction, bump-stops etc.;

— wheel/rail interface characteristics;

— when necessary, flexibility of the vehicle body or bogie structure.

T.4.3 Vehicle configuration

The vehicle configuration, load condition, etc. for the numerical simulation has to be in accordance with 5.3.

T.4.4 Track data

T.4.4.1 Introduction

In order to carry out numerical simulations of the vehicle dynamic behaviour the track data shall be suitable for use in simulations. This clause contains the requirements for the track data to be used and the processing requirements of that data.

T.4.4.2 Source of track data

It is not permitted to use the same track section for both tests and simulations in the statistical analysis. The combined track sections for each test zone from tests and simulations, or from simulations alone, have to meet the requirements of this standard.

When possible, the minimum number of track sections for each test zone as specified for the respective method for the determination of the estimated value shall be obtained from on-track tests:

— the track data that is used shall originate from measurements of actual track;

— the measurement of the track data has to be performed with one of the measuring systems defined in EN 13848-2;

— the track measurement accuracy, after transfer function filtering (if required), has to be in accordance with the requirements in EN 13848-1.

The track recording accuracy and resolution as specified in EN 13848–1 may not be sufficient for simulation purposes, especially for validation. A measurement uncertainty of 0,5 mm or better is recommended.

T.4.4.3 Characteristics of track data

— The location of track data shall be identified;

— for the validation of the model the track data shall comply with the requirements in T.3.3.3.3.1;

— for the vehicle acceptance the track data shall satisfy the requirements of this standard as stated in normative Annex M and shall reflect a naturally existing distribution;

— the track data shall represent the true three dimensional record of track, including vertical alignment, cross level, lateral alignment and track gauge;

— the phase relationship of all track data parameters has to be maintained to replicate the actual track data;

— the wavelength range of the measured track irregularity data, when taken in combination with the vehicle speed, should at least correspond to excitation frequencies of the vehicle over the range of 0,4 Hz to 20 Hz for all test zones.

T.4.4.4 Processing and editing of track data

— The processed track data shall represent the true magnitudes of the actual measured track;

— there shall not be any distortion of the data arising from the measuring system or the subsequent processing of the data when compared to the actual track data;

— it is permissible to separate the measured design geometry from the measured track irregularity when creating a track file. The re-combining of the data shall not change any characteristics of the representation of the track by change of phase relationship, duplication of data or any other means;

— the processing and editing applied to the track data shall be described in the simulation report.

T.4.5 Track model parameters

The track stiffness and damping properties used in the simulations have to be representative of practical conditions.

Recognized values from literature or experience from the past may be used.

T.4.6 Wheel/rail contact geometry

A range of rail profiles has to be used for the numerical simulations. The profiles used for particular track sections have to be appropriate to those sections (for example: high speed tangent track or very small radius curves).

The wheel profiles used for the numerical simulations have to be appropriate for the vehicle being assessed. These may be new wheel profiles or they may represent a wheel profile worn in service.

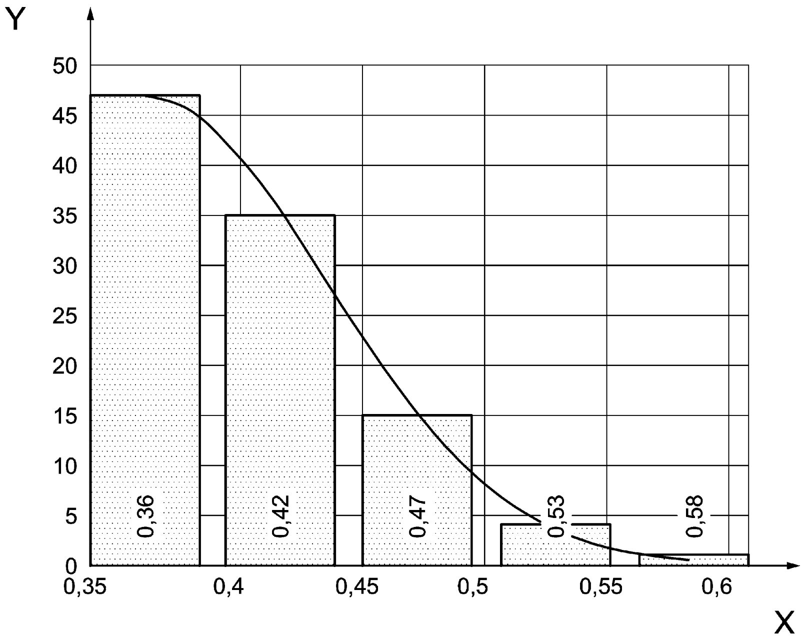
The wheel/rail contact conditions have to be consistent with the range of conditions that would be encountered during testing.

T.4.7 Rail surface condition

For a test on track there will be a natural variation in the wheel/rail friction conditions, while respecting the condition for dry rails. For numerical simulations some variation is required to avoid the possibility of the results being distorted by use of a single value. The range and distribution used shall be justified in the simulation and/or validation reports.

It is essential that the condition of dry rails is represented and therefore the wheel/rail friction has to be at least 0,36.

NOTE From measurements made by British Railways the following distribution was observed: Single sided normal distribution from 0,36 with standard deviation of 0,075. An example for a distribution of a total of 102 sections with 5 different values for the friction coefficient can be seen in Figure T.4:



Key

X friction coefficient μ

Y number of sections per constant friction

Figure T.4 — Example for the distribution of the friction coefficient

T.4.8 Direction of travel

For the case of a symmetrical vehicle, all necessary assessment quantities can be obtained for all required positions from the same simulation and so there is no requirement to reverse the direction of travel.

If the vehicle being assessed is significantly asymmetric then the numerical simulations have to be carried out with the vehicle in both directions of travel to determine the worst condition for each assessment quantity.

T.4.9 Speed

For a test on track there will be a natural variation in the vehicle speed. For numerical simulations some variation is recommended from one section to another to avoid distortion of the results from use of a single value. The method and amount of variation (according to Table 2) has to be representative of normal conditions and the process used has to be documented.

T.4.10 Position of the vehicle in the trainset

The need for connections to other vehicles has to be considered during the model validation and during the simulations:

- for articulated trainsets the numerical simulation will need to include a suitable number of vehicles in order to ensure that the effects are properly included;
- for single vehicles (which would be tested loose coupled) the vehicle can be simulated without respecting the influence of coupling devices;
- for trainsets with permanently coupled vehicles the characteristics of the coupling system will need to be assessed and the effects included in the model unless the influence of adjacent vehicles on dynamic behaviour is shown to be insignificant.

The conditions applied and the reasons have to be documented in the simulation report and to be covered by the model validation.

T.4.11 Frequency content of simulations

The assessment quantities output by simulations have to be subject to the same processing as for measured quantities in tests and have to satisfy the requirements for frequency content.

This requires controls on:

- the vehicle model;
- the input data (in particular the track);
- the output data.

It is necessary that the model represents accurately the frequency contents that are shown by the validation to be relevant and that the ranges of the filter characteristics specified in this standard are covered. The requirements for track input data to ensure that the required input frequency range is provided to the model were given in T.4.4. It is necessary that the sampling frequency of the output data from the model covers the frequencies specified in this standard without risk of aliasing.

T.5 Output

T.5.1 Methods to determine the estimated value from the simulation

T.5.1.1 General

There are three methods for developing the estimated values from the simulation for each zone. For different test zones different methods can be used.

T.5.1.2 Complete simulation of on-track tests

For the approval of new vehicles by comparison with an already approved reference vehicle respecting all the conditions in Clause 7 the complete on-track test can be simulated. The estimated values should be calculated with the normal statistical methods described in that clause. This method can be used for all areas of application of simulation (see T.2).

T.5.1.3 Combination of simulation and new on-track tests

For the extension of the range of test conditions (T.2.2) a combination of on-track test and simulation is required. The values are derived from simulation and on-track testing, the estimated values are determined from a statistical method according to Clause 7 by combining all track sections from test and simulation. The combination of all track sections shall respect the conditions in Clause 7 and the statistical checks described in T.2.2.

A minimum number of 15 track sections for each test zone have to be obtained from on-track tests.

T.5.1.4 Combination of simulation and previous on-track tests

For the approval of new vehicles by comparison with an already approved reference vehicle (T.2.4) and for approval of vehicles following modification (T.2.3) the simulated dynamic behaviour of the tested vehicle as well as for the new or modified vehicle shall be compared under identical boundary conditions on at least 3 sections of each test zone. For every required assessment quantity, the simulation results for both new or modified vehicle and the tested vehicle have to be evaluated. The new or modified vehicle's estimated value for the assessment quantity is calculated by adding the average difference of the compared sections from one test zone to the estimated value from the test results of the tested vehicle. This new estimated value has to be compared to the limit value.

T.5.1.5 Assessment quantities

Vehicle assessment quantities measured during the tests and obtained from the simulations shall include appropriate assessment quantities from this standard.

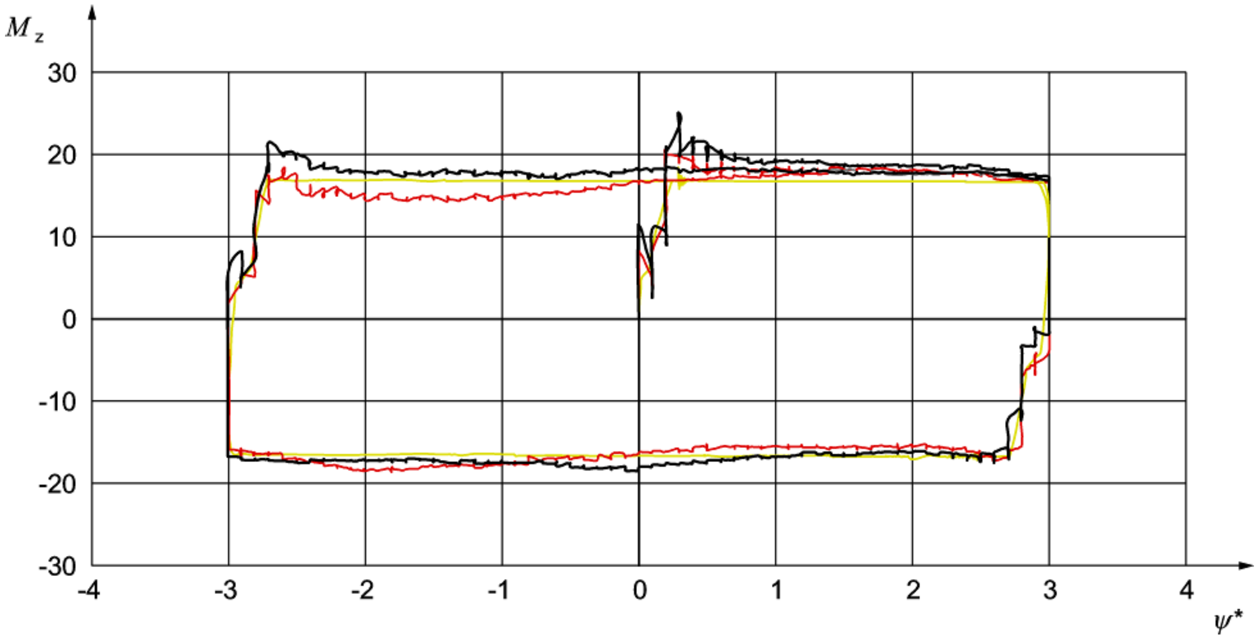
It may also be helpful for the validation process to include additional measurement quantities. It is strongly recommended to measure the primary and secondary vertical suspension displacements as well as the secondary lateral displacement. Also it may be helpful to measure the primary longitudinal and lateral suspension displacements. In addition, the length of yaw dampers and inter-car dampers can be of interest.

T.6 Documentation

The outcome of the simulations shall be reported together with the other results for the vehicle in an integrated manner. The report shall include the validation results (T.3.3.5)

T.7 Examples for model validation according to Method 1

The following diagrams are included to give examples of comparisons between test results and simulations. Some of them show good agreement, others illustrate some of the difficulties that may be encountered.



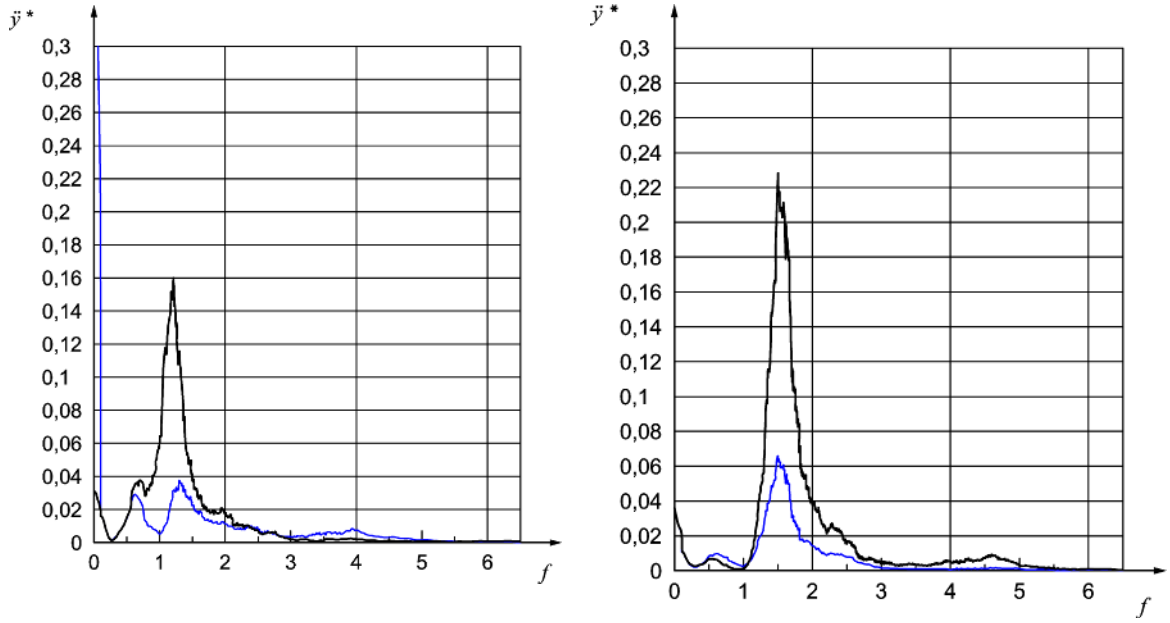
Key

black line	measurement bogie 1	Ψ*	body-bogie yaw angle [degrees]
red line	measurement bogie 2	*Mz*	yaw moment of bogie [kNm]
yellow line	simulation		

Figure T.5 — Example comparison for bogie rotation test

Figure T.5 shows an example of the comparison between measurement and simulations for a bogie rotation test. There are two test results and the simulation. The simulation is a very good fit with the test results showing a good match of the rotation angle, the torque values and the suspension behaviour at the ends of the hysteresis loop.

Figure T.6 and Figure T.7 show two examples of comparisons for FFT (Fast Fourier Transformation) Analysis of vehicle body lateral accelerations. In Figure T.6 the comparison for Bogie 2 (the blue line on each graph) is poor with neither the dominant frequency nor the amplitude correctly given by the simulations. The comparison for bogie 1 (the black lines) is better but is still not good as the dominant frequency of the simulations is 1,5 Hz compared to 1,2 Hz for the measurements and the amplitudes differ significantly. The comparison shown in Figure T.7 is better as the dominant frequency is correctly identified. Two test results are shown, with some variation between them and the simulation is closer to one than the other. For this case it would be helpful to indicate the reasons for the differing test results in the validation report.



a) Measured lateral vehicle body acc. (m/s²) over bogie 1 and 2

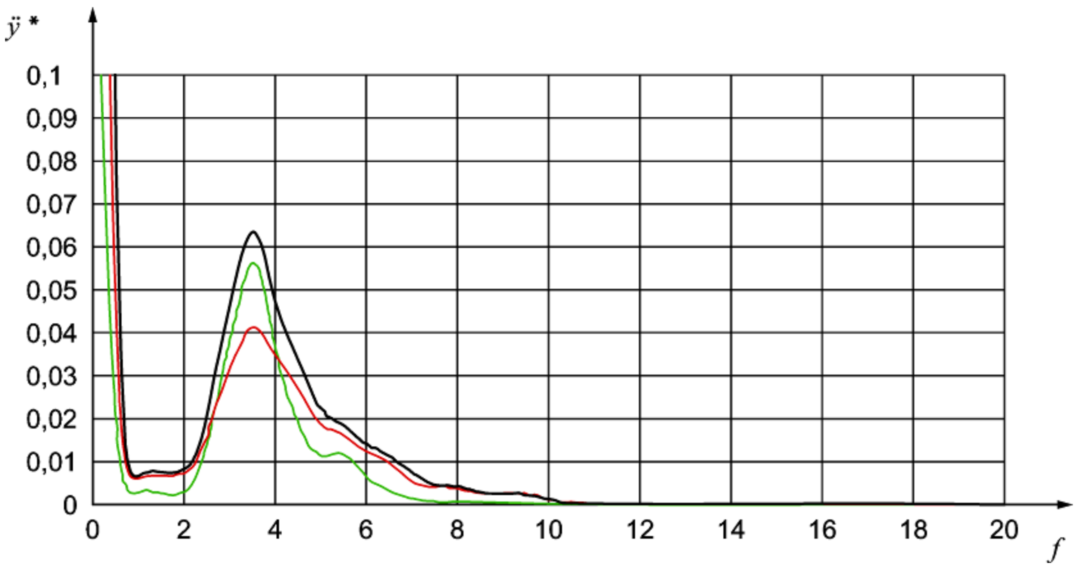
b) Calculated lateral vehicle body acc. (m/s²) over bogie 1 and 2

Key

f frequency [Hz]

$\ddot{y}^*$ lateral vehicle body acceleration [m/s²]

Figure T.6 — Example 1 of comparison of FFT for vehicle body lateral acceleration



Key

1 red curve: test 1

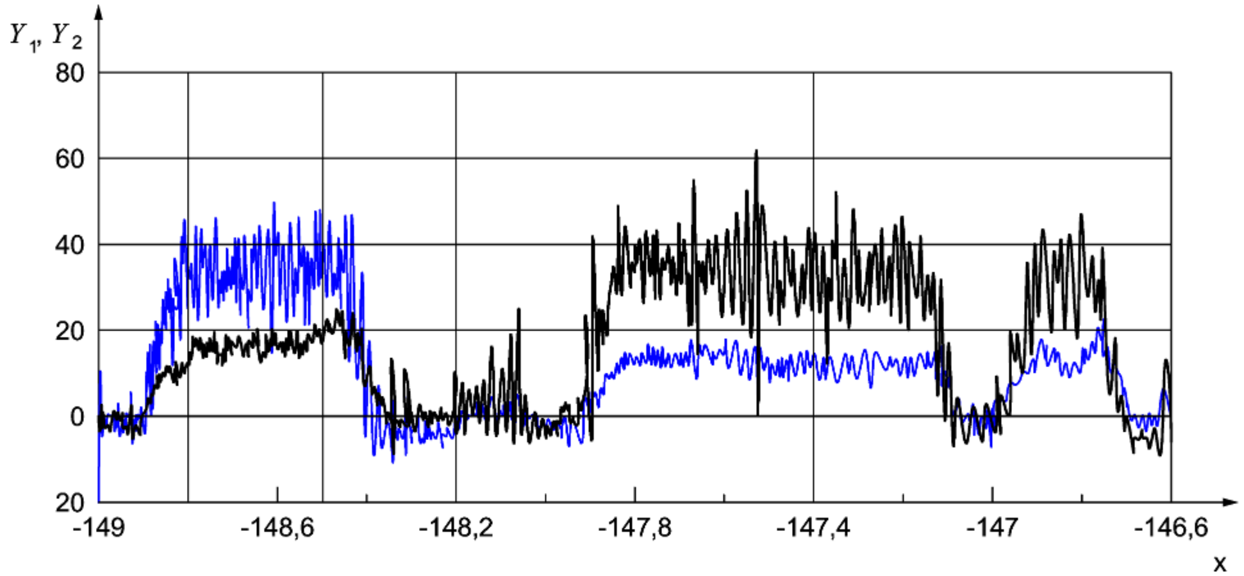
2 black curve: test 2

3 green curve: simulation

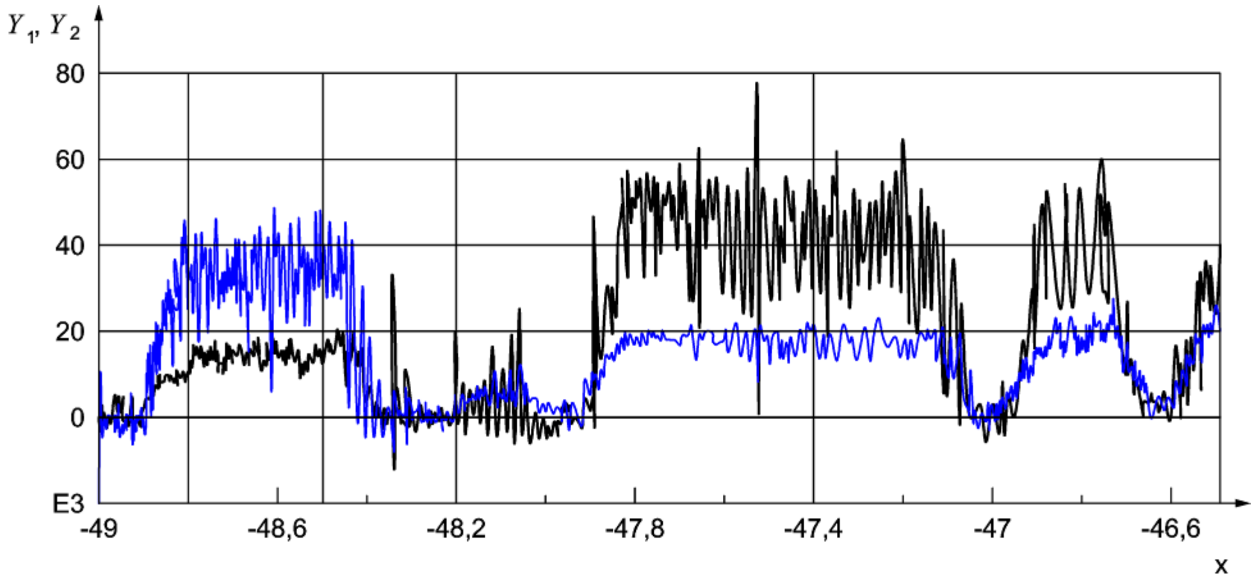
f frequency [Hz]

$\ddot{y}^*$ lateral vehicle body acceleration [m/s²]

Figure T.7 — Example 2 of comparison of FFT for vehicle body lateral acceleration



a) Measured Y_20 Hz [kN]



b) Calculated Y_20 Hz [kN]

Key

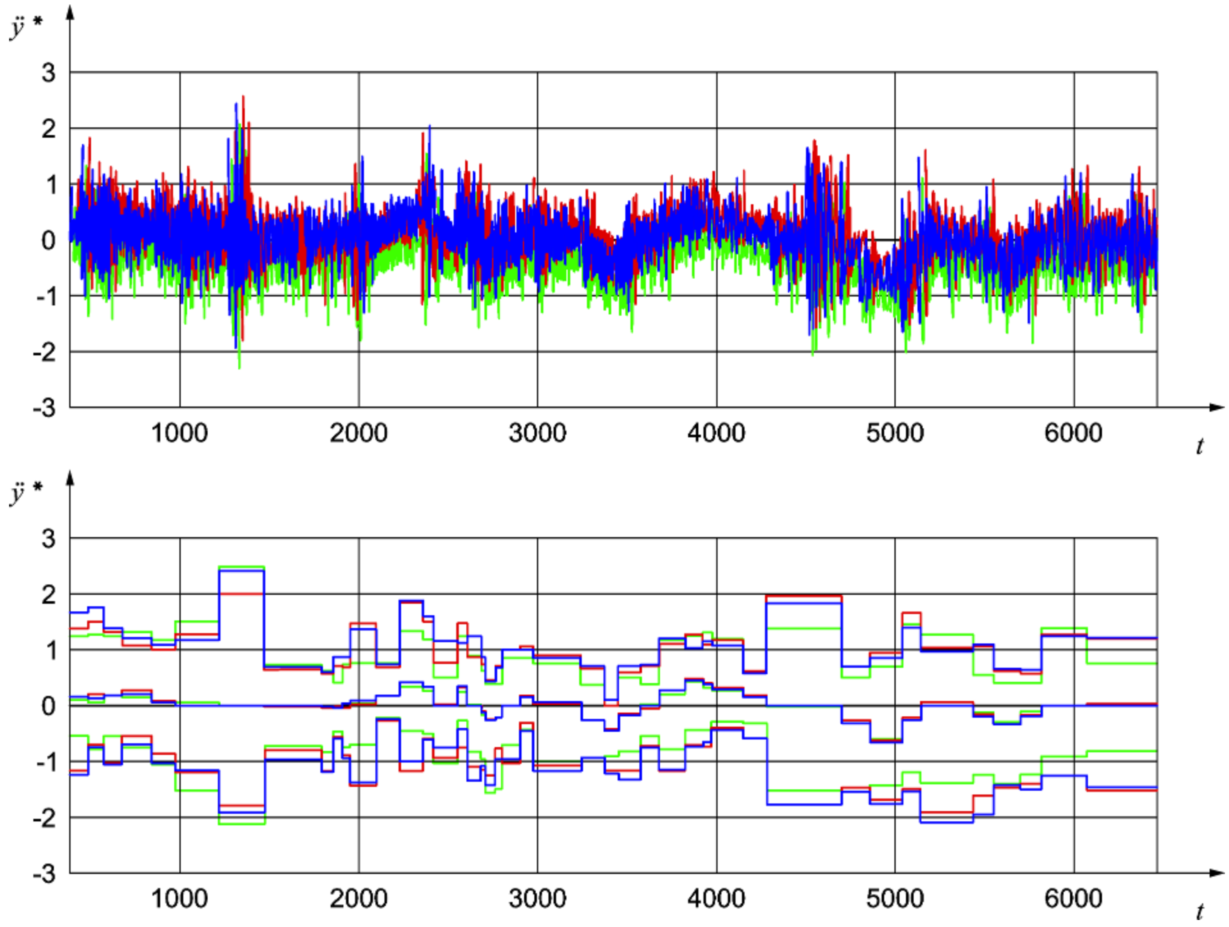
X line kilometre [km]

Y_1 lateral wheel force, right wheel [kN]

Y_2 lateral wheel force, left wheel [kN]

Figure T.8 — Example of comparison of time history for *Y* force

Figure T.8 gives an example of a time history comparison for the *Y*-forces through two curves, the two black lines should be compared with each other and similarly the two blue lines. There are some differences between the mean values and it would be helpful to find explanations for this in the validation report (for example: offsets in the measuring systems, lack of detailed rail profile measurements). However the dynamic frequencies and the locations and magnitudes of discrete events are well predicted and this gives confidence in the validity of the model.

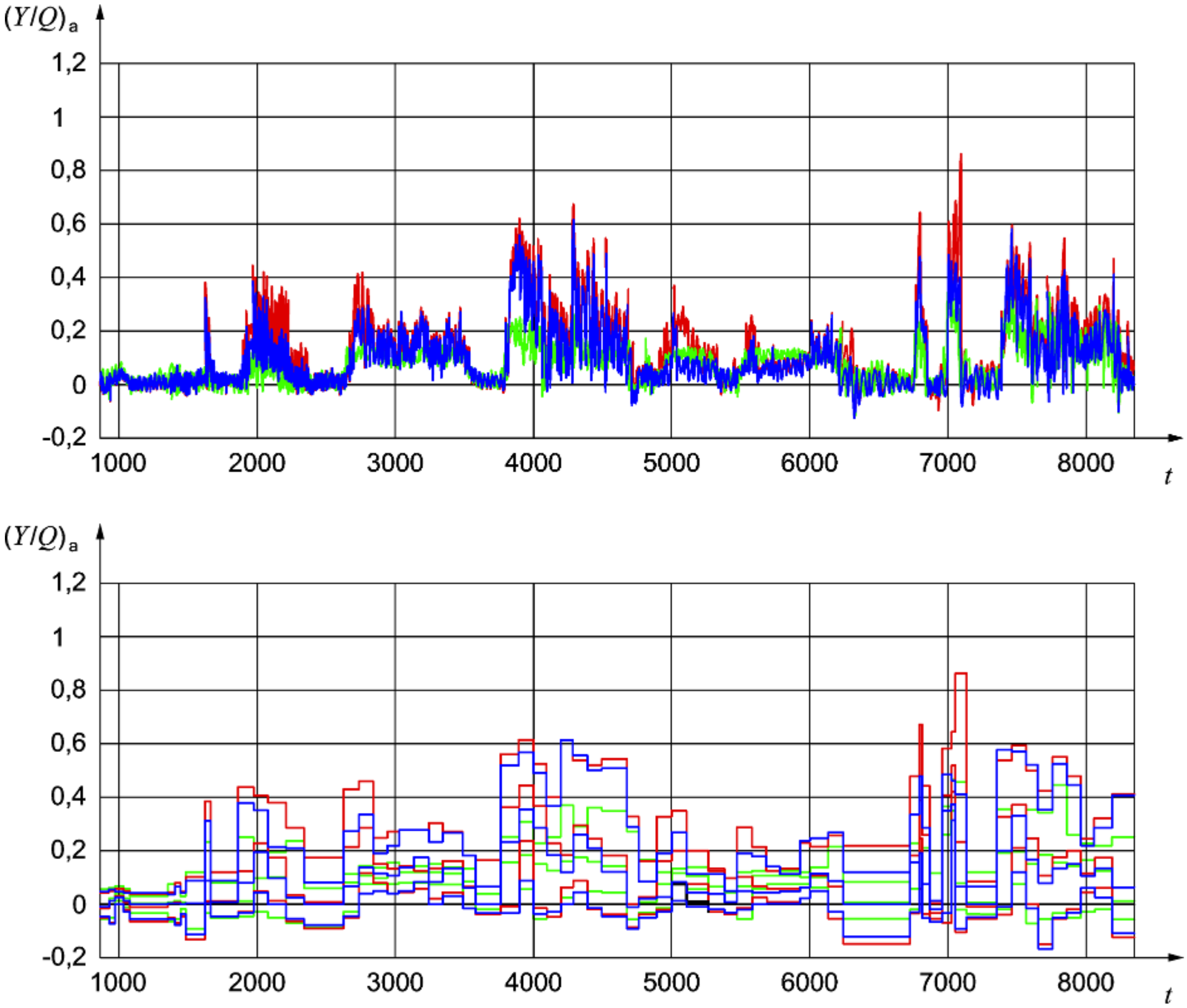


Key

t	time [s]	green line	simulation
$\ddot{y}^*$	lateral vehicle body acceleration [m/s²]	red line	test 1
		blue line	test 2

Figure T.9 — Example of comparison of time history for vehicle body acceleration

Figure T.9 shows an example of a time history comparison for lateral vehicle body acceleration. The presentation is very helpful in showing in the upper graph the time history trace and, in the lower graph, the mean, 0,15 % and 99,85 % percentiles per sections. This makes assessing of the comparison more easily than only through the time history plots where the general levels are difficult to see within the higher frequencies. The comparison here is good with the mean levels being well predicted and the variations also in good agreement.

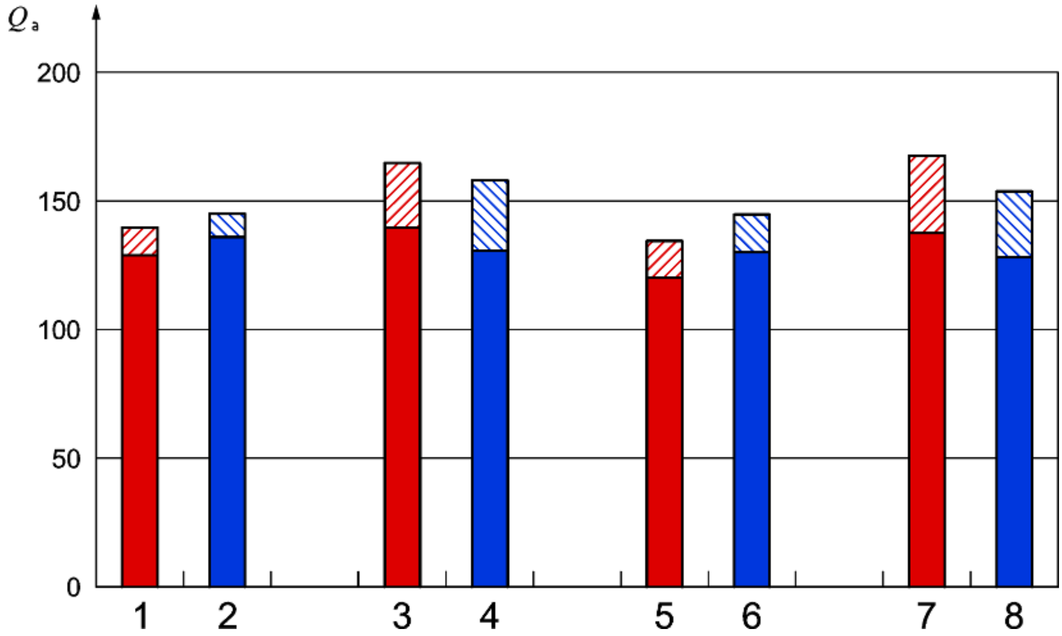


Key

t	time [s]	green line	simulation
*(Y/Q)*a	ratio of outer lateral and vertical wheel forces [-]	red line	test 1
		blue line	test 2

Figure T.10 — Example of comparison of time history for *Y/Q*

Figure T.10 uses the same style of presentation as Figure T.9 and here it is clear that the comparison is poor. The mean levels are not well represented and the 0,15 % or 99,85 % values are very different. The time history plot also shows these differences but it is more difficult to determine.

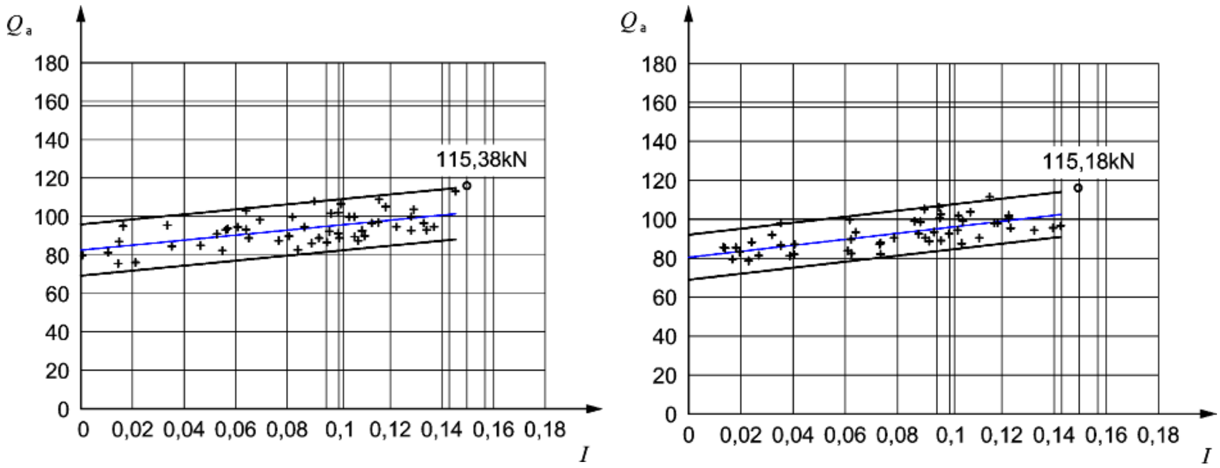


Key

1	measurement R1	5	measurement R3	■	mean value
2	simulation R1	6	simulation R3	▨	99,85 % value
3	measurement R2	7	measurement R4	Q_a	vertical wheel force [kN]
4	simulation R2	8	simulation R4		

Figure T.11 — Example of comparison of processed data for *Q*-forces

Figure T.11 shows an example of the comparison of statistical results for *Q*-force on a number of different curves. The comparison is good with both the mean values and the 99,85 % levels giving similar values for measurement and simulation.



a) Simulation **b) Measurement**

Key

I cant deficiency [m]

Q_a vertical wheel force [kN]

Figure T.12 — Example for distribution plot of track loading *Q*

Figure T.12 shows an example for a distribution plot of vertical wheel force over cant deficiency including a two dimensional statistical analysis. The values for the cant deficiency in the single sections do not match exactly, because the speed in the simulation and the test are not exactly the same. Although the maximum values for the force of the single sections do not match exactly, the overall distribution is very similar which results in a similar estimated value in the statistics.

Annex U
(informative)

Extension of acceptance

U.1 General

Once a railway vehicle has been approved, an extension of approval may be granted if the vehicle's operating conditions or design are changed.

To determine the extent of the test programme to be performed or the possibility of dispensation from tests, the following procedure is to be applied:

— a safety factor λ has to be determined using either initial test results (see U.2) or simulation results obtained with a validated model for the improved vehicle (see informative Annex T);

— the variations of the (operating or design) parameters under consideration shall be identified and compared with the ranges in Table U.1;

— depending on the initial approval method, the safety factor λ and the ranges of parameter variations, the test method (simplified or normal) for the extension of approval is to be determined and the range of test zones and loading conditions to be tested is defined.

NOTE In some cases this may require testing in the full range of test zones for an empty and loaded vehicle. In that case the procedure is equivalent to a new (initial) approval.

The process is described in detail in the following sections and also illustrated in the flowchart in Figure U.1.

Table U.1 gives details about the possibility of test dispensation or reduced test extent depending on the modifications and the safety margin of the reference vehicle. This table consists of three parts:

— the left-hand part (column 1) gives the modified parameters (modified since the initial approval);

— the centre part gives the conditions for either:

  — dispensation from the assessment (columns 2a and 2c); or

  — applying a simplified method (columns 2b and 2d);

according to the range of variation $(x_{\text{final}} - x_{\text{initial}})/x_{\text{initial}}$ expressed in % of the nominal values of the parameter(s) under consideration, according to the type of vehicle.

For a dispensation the permitted ranges specified in columns 2a and 2c are applicable for $\lambda \geq 1{,}1$ (and $\lambda' \geq 1$ for $P_0 > 225$ kN). For $1{,}1 > \lambda > 1{,}0$ these ranges shall be reduced by multiplication of their limits with the factor $10 \cdot (\lambda - 1)$.

— the right-hand part (columns 3a – 3e) gives the test extent to be applied. This includes the loading condition and the test zones to be considered. Column 3e defines the equivalent conicity range to be tested on tangent track.

If parameters that can influence the running behaviour, which are not included in Table U.1, are changed, it shall be demonstrated (by calculation or other means) that the influence is favourable or insignificant. If this is not possible on-track tests shall be carried out, the extent of which shall be established according to the expected influences of the changes on the vehicle's behaviour.

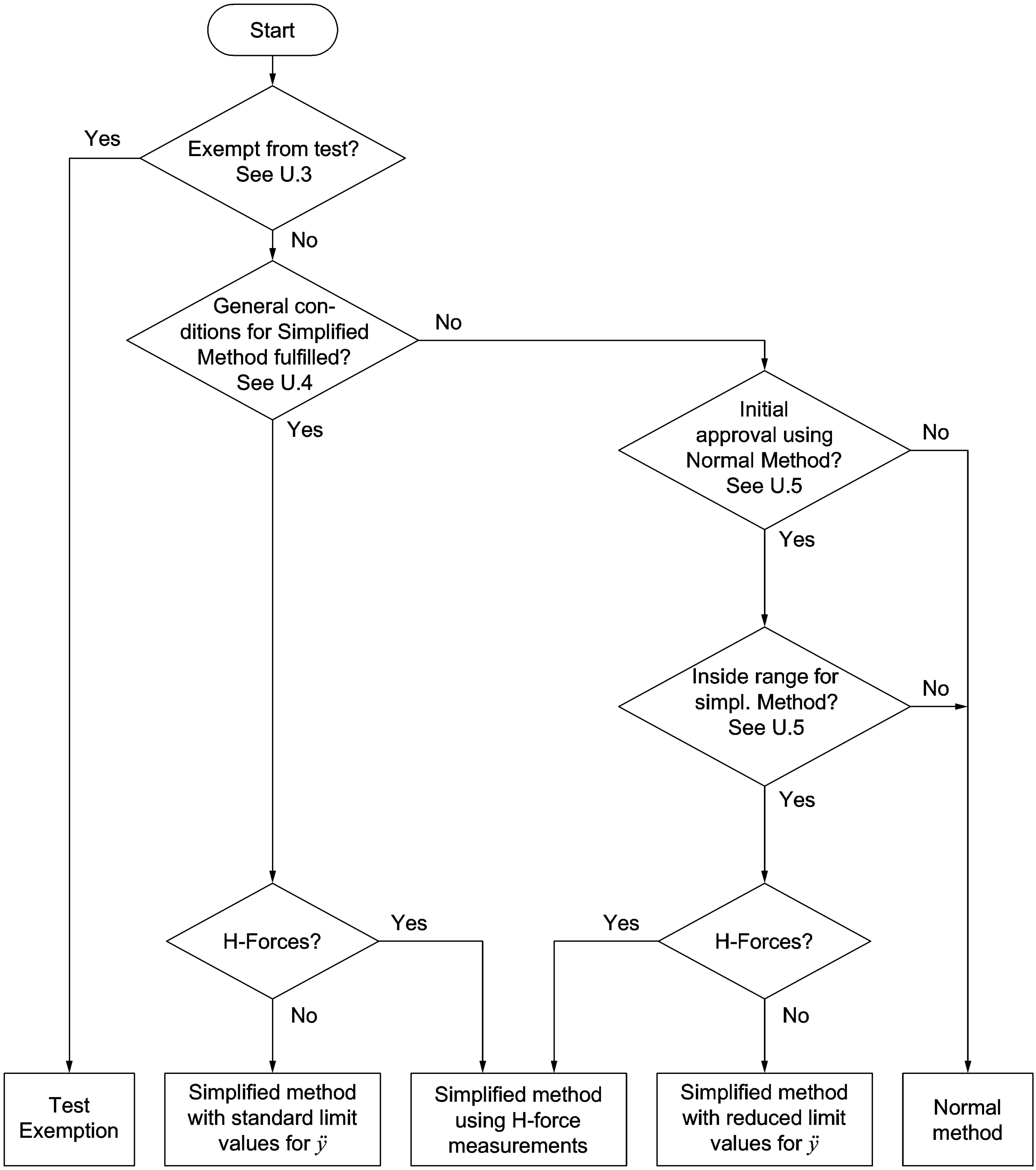


Figure U.1 — Flowchart to determine the minimum requirement for the measuring method

Table U.1 — Parameter change table

1	2a	2b	2c	2d	3a	3b	3d	3e
Modified Parameter	**Applicable range of parameter change** (related to nominal values)				**Test extent required**			
	Locomotives multiple units passenger coaches		Freight stock					
	for test dispensation	for testing with a simplified measuring method [a]	for test dispensation	for testing with a simplified measuring method [a]	Straight track Zone 1	Large-radius curves Zone 2	Small and very small-radius curves Zone 3, 4	Conicity range to be tested [b]
Operational parameters								
Increase of admissible maximum speed [c]	— [d]	0 km/h to 10 km/h	— [d]	not applicable	Empty	Empty	—	1)
		10 km/h to 20 km/h (*H*-Forces required)		0 km/h to 20 km/h (*H*-Forces required above 10 km/h)	Empty Loaded	Empty Loaded	—	1)
Increase of admissible cant deficiency	— [d]	— [e]	— [d]	— [e]	—	—	—	—
Vehicle parameters								
Distance between bogie centres for $2a^* \geq 9$ m [f]	not applicable	not applicable	−15 % to + A [g]	−30 % to + A [g]	Empty	—	—	3)
Distance between bogie centres for $2a^* < 9$ m [f]			−5 % to +A [g]	−10 % to + A [g]	Empty	—	—	3)
Distance between bogie centres general	−5 % to 20 %	−10 % to + A [g]	not applicable	not applicable	Empty	—	Empty [h]	3)
Vehicle wheel base (non bogie vehicle) for $2a^* \geq 8$ m [f]	not applicable	not applicable	−15 % to + A [g]	−30 % to +A [g]	Empty	—	—	1)
Vehicle wheel base (non bogie vehicle) for $2a^* < 8$m [f]			−5 % to +A [g]	−10 % to +A [g]				
Virtual position of centre of gravity Γ [i]	−20 % to 10 %	−40 % to 20 %	not applicable	not applicable	Empty	Empty	—	4)
Centre of gravity height - empty vehicle, h_g [j]	−20 % to 10 %	−40 % to 40 %	−100 % to 20 %	−100 % to A [g]	Empty	Empty	—	3)
Centre of gravity height - loaded vehicle, h_g [j]	−20 % to 10 %	−40 % to 40 %	−100 % to 50 %	−100 % to A [g]	Loaded	Loaded	—	3)
Centre of gravity height - loaded vehicle [l], χ [k]	not applicable	not applicable	−100 % to 0,8 (λ'-1) 100 %	−100 % to 0,8 (λ'-1) 100 %	Loaded	Loaded	Loaded	3)
Yaw Moment of inertia of vehicle body (bogie vehicles)	−10 % to 10 %	−10 % to 10 %	−10 % to 10 %	−10 % to 10 %	Empty Loaded	Empty Loaded	Empty Loaded	2) if < −10 % 3) if > 10 %
Moment of inertia around z-axis of vehicle body (non bogie vehicle)	not applicable	not applicable	−100 % to 10 %	−100 % to 20 % [m] (*H*-Forces required above 10 %)	Empty	—	—	2) if < −10 % 3) if > 10 %
Vehicle tare for vehicles with tare mass ≥ 12 t (non-bogie wagons) or ≥ 16 t (bogie wagons) [n]	not applicable	not applicable	−15 % to + A [g]	−30 % to + A [g]	Empty	—	—	2)

1	2a	2b	2c	2d	3a	3b	3d	3e
Modified Parameter	**Applicable range of parameter change** (related to nominal values)				**Test extent required**			
	Locomotives multiple units passenger coaches		Freight stock					
	for test dispensation	for testing with a simplified measuring method [a]	for test dispensation	for testing with a simplified measuring method [a]	Straight track Zone 1	Large-radius curves Zone 2	Small and very small-radius curves Zone 3, 4	Conicity range to be tested [b]
Maximum nominal static vertical wheelset force, vehicles with P_{F0} ≤ 250 kN [n]	not applicable	not applicable	−100 % to 5 %	−100 % to 10 % (*H*-Forces required above 5 %)	—	Loaded (only for nominal static vertical wheelset force P_{F0} > 225 kN [n])	Loaded	—
Torsional stiffness coefficient c_t^* ≤ 3 ·10[10] kNm²/rad [f]	not applicable	not applicable	−66 % to 200 %	— [e]	—	—	—	—
Torsional stiffness coefficient c_t^* > 3 ·10[10] kNm²/rad [f]	not applicable	not applicable	−50 % to + A [g]	— [e]	—	—	—	—
Running gear parameters								
Bogie wheel base (bogie vehicles)	0 % to 5 %	−5 % to 0 %	0 % to 10 %	−10 % to 0 %	Empty	Empty	—	2)
		5 % to 20 % (*H*-Forces required)		10 % to 20 % (*H*-Forces required)	—	—	Empty for freight, Loaded for all vehicles	4)
Nominal wheel diameter	−10 % to 15 %	−10 % to 15 %	−10 % to 15 %	−10 % to 15 %	Empty Loaded	Empty Loaded	Empty Loaded	2) if < −10 % 3) if > 15 %
Unsprung mass	−100 % to 5 %	−100 % to 10 %	not applicable	not applicable	Empty	Empty	—	2)
Primary suspended mass (only for vehicles with two suspension levels)	−5 % to 5 %	−10 % to 10 %	not applicable	not applicable	Empty	Empty	—	2)
Secondary suspended mass (or suspended mass for vehicles with only one suspension level)	−10 % to 10 %	— [e]	not applicable	not applicable	—	—	—	2) if < −10 % 3) if > 10 %
Sum of nominal static vertical wheelset forces per running gear, if vehicle has no secondary suspension level	−5 % to 5 %	−10 % to 10 %	not applicable	not applicable	Empty	Empty	—	2)
Yaw moment of inertia of whole running gear	−100 % to 5 %	−100 % to 10 %	−100 % to 10 %	−100 % to 20 %	Empty	Empty	—	2) if > +5 %
Ratio of stiffness of primary vertical suspension and its load (vehicles with two suspension levels) (F_z^+/c_z^+) over the whole load range	−20 % to 20 %	−40 % to 40 % [o]	−20 % to 25 %	— [e]	Empty	Empty	—	3) if < −20 %
Ratio of stiffness of secondary vertical suspension and its load (total stiffness at vehicles with one suspension level) (F_z^*/c_z^*) over the whole load range	−10 % to 10 %	−40 % to 40 %	−10 % to 25 %	— [e]	Empty	Empty	—	3) if < −10 %

1	2a	2b	2c	2d	3a	3b	3d	3e
Modified Parameter	**Applicable range of parameter change** (related to nominal values)				**Test extent required**			
	Locomotives multiple units passenger coaches		Freight stock					
	for test dispensation	for testing with a simplified measuring method [a]	for test dispensation	for testing with a simplified measuring method [a]	Straight track Zone 1	Large-radius curves Zone 2	Small and very small-radius curves Zone 3, 4	Conicity range to be tested [b]
Wheelset guiding (Stiffness)	0 % to 10 %	−10 % to 10 %	— [d]	— [e]	Empty	Empty	—	2) if < 0 % 4) if > 0 %
Yaw resistance of bogie	−10 % to 10 %	−20 % to −10 %	−20 % to 20 %	— [e]	Empty	Empty	—	2) if < −10 %
		10 % to 20 % (*H*-Forces required above 10 % for I_{adm} > 165mm)			—	—	Empty Loaded	4)
Secondary lateral suspension stiffness, clearances (considering fixed stops)	−10 % to 10 %	— [e]	— [d]	— [e]	—	—	—	1)
Secondary lateral damping	−30 % to 30 %	— [e]	— [d]	— [e]	—	—	—	1)

[a] Required *H*-force measurement is indicated.

[b] Test conditions according to Table 2:

1) Modifications have a possible influence on running gear stability and low frequency body motions:
   - — stability testing required;
   - — tests need to include sections for testing low frequency body motions;

2) Modifications have a possible influence only on running gear stability:
   - — stability testing required;

3) Modifications have a possible influence only on low frequency body motions:
   - — tests need to include sections for testing low frequency body motions;

4) Modifications have no influence on running gear stability and low frequency body motions;
   - — no specific requirements for contact geometry apply.

[c] The general conditions for the use of *H*-force measurement have to be respected (see 7.2.2).

[d] No dispensation from on-track test.

[e] No application of partial on-track test.

[f] Initial value.

[g] No limitation from this document, there may be restrictions from other regulations.

[h] Only if modification is greater than +20 % and $I_{adm} \geq 165$ mm.

i $$\Gamma = \left(\frac{I_{adm}}{2b_A} h_g + b \right)$$

h_g height of centre of gravity relative to top of rail in mm

$2b_A$ lateral distance between the contact points of the wheels in mm (1 500 mm for standard gauge)

$b = b_{nom} + b_{qst,}$

where

b_{nom} is the nominal lateral distance of the centre of gravity from the vehicle centre line in mm

b_{qst} is the quasi-static displacement of the centre of gravity due to curving, including effects from suspension displacement, a possible cant deficiency compensating system and any other similar system in mm.

This criterion applies only to vehicles with $I_{adm} > 165$ mm.

j Only for vehicles with $I_{adm} \leq 165$ mm.

k $$X = Q_0 \left[1 + 2,3\, h_g \frac{I_{adm}}{(2b_A)^2} \right]$$

Q_0 static vertical wheel force in kN

h_g height of centre of gravity relative to top of rail in mm

I_{adm} admissible cant deficiency, in mm

$2b_A$ lateral distance between the contact points of the wheels in mm (1 500 mm for standard gauge).

l For evaluation of χ: $I_{adm} = 130$ mm for $P_{F0} \leq 225$ kN and $I_{adm} = 100$ mm for 225 kN $< P_{F0} \leq 250$ kN.

m Simplified measuring method only if $P_{F0} \leq 225$ kN.

n Final value.

o For vehicles with $I_{adm} > 165$ mm: −20 % to +20 %.

U.2 Determination of the safety factor

The safety factor λ is defined as the minimum value obtained from all of the ratios "(limit value)/(estimated maximum value)" separately evaluated for each loading condition, test zone and running safety assessment quantity (as appropriate for the chosen measuring method):

— normal method: ΣY and $(Y/Q)_a$, and κ (if applicable)

— simplified methods:

  — for bogie vehicles: H and $\ddot{z}_s^*$ or $\ddot{y}_s^+$, $\ddot{y}_s^*$ and $\ddot{z}_s^*$

  — for non-bogie vehicles: H, $\ddot{z}_s^*$ and (for wagons and Special Vehicles) $s\ddot{y}_S^*$ or $\ddot{y}_s^*$, $\ddot{z}_s^*$ and $s\ddot{y}_S$

The factor λ' is defined for vehicles with $P_{F0} > 225$ kN as the minimum value obtained from all of the ratios "(limit value)/(estimated value)" of track loading assessment quantities Q_{max} and $Q_{a,qst}$ separately evaluated for each test zone.

The safety factor is not to be determined for fault modes.

If the initial acceptance has not been done with the method of EN 14363, the safety factor λ shall be determined and the method used shall be documented (e.g. taking into account previous test conditions and results together with experience from operation of the vehicles). The original acceptance tests shall comply in principle with the relevant requirements of this document.

U.3 Dispensation

U.3.1 General

A dispensation from testing is given, if all parameter variations fall within the ranges in the column 2a or 2c of Table U.1, possibly reduced as specified in U.1 for $\lambda < 1,1$. Otherwise a partial or full on-track test has to be performed.

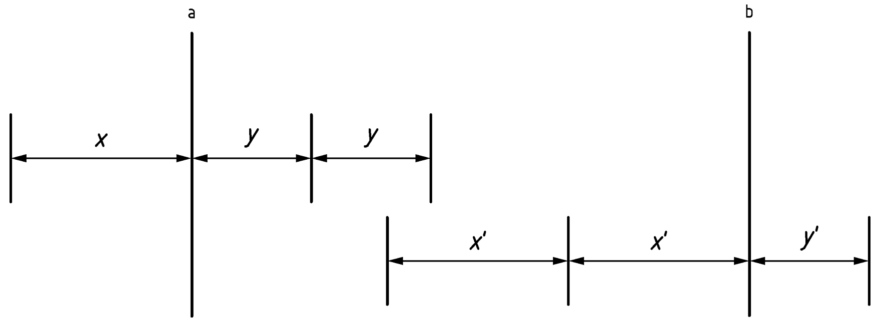
U.3.2 Special cases

If the following conditions are fulfilled, deviating from the conditions for test dispensation for a vehicle laid down in U.3.1, the permitted variations of a parameter may be doubled in the range between the values characterizing two already tested vehicles, when such an extension covers this whole range (see Figure U.2):

1) The vehicle has to be of the same family or design concept (in all aspects that influence the dynamic performance) as the tested vehicles.

2) At least two vehicles (a and b) have to be tested and approved according to this standard.

3) The tested vehicles have to be selected in a way that they are representative for the boundaries of the expected test results, e.g. the lightest and heaviest vehicle in a multiple unit.



Key

a value of parameter in question for first vehicle

b value of parameter in question for second vehicle

x lower percentage of permitted range for parameter change for first vehicle

y upper percentage of permitted range for parameter change for first vehicle

x' lower percentage of permitted range for parameter change for second vehicle

y' upper percentage of permitted range for parameter change for second vehicle

Figure U.2 — Extension of parameter range

For $a < b$ the condition $a \cdot (1 + 2y) \geq b \cdot (1 - 2x')$ shall be fulfilled.

It is possible to approve a third vehicle, if acceleration measurements according to the simplified method are performed and the level of acceleration is comparable to the acceleration level of the vehicles approved with the normal method. In this case the vehicle to be approved has to be in the same test train as the vehicles tested with the normal method. The above conditions 1) and 3) also apply.

In the case of passenger vehicles assessed at empty and loaded conditions and as intermediate states were not historically tested, it is recognized that these intermediate states are safe. In the case of vehicles with a mass between empty and loaded mass, it can be considered as assessed.

NOTE An application for this can be for example a multiple unit where not all bogies are equipped with measuring wheelsets.

U.4 Check for base conditions for simplified method

When a test is required, and provided that after the parameter change(s) the base conditions for a simplified method are fulfilled, such a method can be applied for the cases stated in columns 3a to 3d for the modified parameters, even if the parameter changes are outside the limits of columns 2b or 2d. *H*-forces shall be measured if required by the base conditions for *H*-force measurement, see 7.2.2.

U.5 Requirements depending on the initial approval

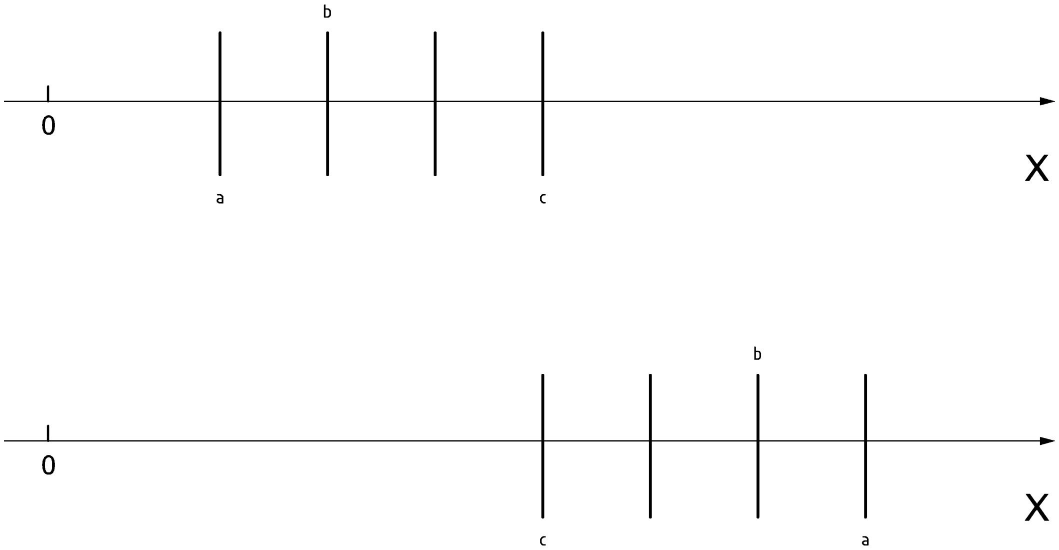
If the base conditions for applying a simplified method are not fulfilled, or if in the initial approval the acceleration measurements were above the limit values a simplified method can still be applied, if the following conditions are fulfilled:

— the initial approval was based on the normal method;

— all parameter variations are inside the ranges of Table U.1, columns 2b or 2d, possibly reduced as specified in U.1 for $\lambda < 1{,}1$.

H-forces shall be measured if required by Table U.1.

The normal method shall be applied for the cases indicated in columns 3a to 3d of Table U.1 only, if one or more of the above conditions are not fulfilled.



Key

a estimated maximum value
b new limit value
c initial limit value
X value of changed parameter

Figure U.3 — Recalculation of limit values for lateral acceleration

For the measurement of accelerations only, a new limit value is determined for the following safety parameters: $\ddot{y}_{\mathrm{s}}^{+}$ and $\ddot{y}_{\mathrm{s}}^{*}$ (for bogie vehicles) or $\ddot{y}_{\mathrm{s}}^{*}$ (for non-bogie vehicles).

The new limit value is at one third of the difference (whether positive or negative) between the estimated maximum value of the initial approval and the initial limit value. This determination is also demonstrated in Figure U.3.

Annex V
(normative)

Symbols

The Table V.1 contains a summary of the symbols of the quantities and characteristic figures for testing of the running behaviour and stationary tests as well as supplementary information and terms.

NOTE The notation of the symbols was simplified and adapted to the requirements of data processing; other notations with indices and exponents are permissible.

Table V.1 — Symbols

Operational parameters	
V	speed
I	cant deficiency
Indices:	
adm	admissible
Vehicle parameters	
P_{F0}	nominal static vertical wheelset force
D	nominal wheel diameter
d	minimum permitted wheel diameter
$2a^{+}$	wheelset distance in a bogie
$2a^{*}$	running gear distance
$2b_{A}$	lateral distance of wheel/rail contact points
h_{g}	height of centre of gravity
m_{0}	unsuspended mass of wheelset
m^{+}	bogie mass
S_{h}	flange height
β	flange angle
Assessment quantities and measured values	
T_{x}	longitudinal wheel force
Y	lateral wheel force
ΣY	sum of lateral forces per wheelset
$\Sigma\Sigma Y$	total sum of lateral forces per bogie
H	sum of lateral axle box forces per wheelset
Q	vertical wheel force
ΣQ	sum of vertical wheel forces per wheelset
$\Sigma\Sigma Q$	total sum of vertical wheel forces per bogie

Y/Q	ratio of lateral and vertical wheel forces
B	combined rail load quantity
T_{qst}	rail surface damage quantity
κ	overturning parameter
Assessment quantities and measured values	
$\ddot{y}$	lateral acceleration on axle box
$\ddot{y}^{+}$	lateral acceleration on bogie frame above axle box
$\ddot{y}^{*}$	lateral acceleration in vehicle body
$\ddot{z}^{*}$	vertical acceleration in vehicle body
Δz	wheel lift
ΔQ	wheel unloading
Q_0	average vertical wheel force for a wheelset on level track
ΔQ_0	deviation from Q_0 on level track
$\Delta\Psi$	body-bogie yaw angle
M_z	yaw moment of bogie
M_R	yaw hysteresis magnitude of rotational torque
X	bogie yaw resistance factor
α	angle of attack
c_t^{*}	torsional coefficient of vehicle body
c_{tA}^{+}	torsional stiffness of a bogie
c_{tA}^{*}	torsional stiffness of a vehicle
s	flexibility coefficient
m_{Veh}	overall mass of the vehicle
Δq	relative wheel force deviation
λ	safety factor
λ'	track loading factor
Indices:	
a	outer side of curve
i	inner side of curve
j	wheelset index
k	side index (k = 1: right, k = 2: left)
I, II, III,...	bogie index
M	centre of vehicle body
S	safety related
q	related to ride characteristics

f	normalized by friction
nf	normalized by friction and mean curve radius
max	maximum value
min	minimum value
mean	mean value
rms	rms-value
qst	quasi-static value
lim	limit value
rec	recalculated value
Test conditions, Track features	
R	curve radius
$TL50$	target level for 50 %-value of standard deviation
$TL90$	target level for 90 %-value of standard deviation
$QN3$	quality limit for discrete track defects
Δy^0	lateral track irregularities (alignment)
Δz^0	vertical track irregularities (longitudinal level)
TQ	Track irregularities (track quality level)
$\tan \gamma_e$	equivalent conicity
q_E	radial steering index
y	amplitude for evaluation of equivalent conicity
$(TG\text{-}SR)$	gauge clearance
TG	track gauge
SR	distance between active faces of flanges
L_{ts}	length of track section
n_{ts}	number of track sections
u	cant
g	track twist
g^+_{lim}	bogie test twist
g^*_{lim}	vehicle test twist
$2a$	longitudinal dimension for twist
h	twist height
d	shim size
τ_{dry}	friction coefficient on dry rail
γ	contact angle at the contact point of the inner rail
g	gravitational acceleration

Indices	
m	mean value in test zone
max	maximum value (discrete disturbance)
σ	standard deviation

Annex W
(informative)

List with the main technical changes compared to EN 14363:2005, EN 15686:2010 and EN 15687:2010

Besides the introduction of a new structure of the standard, many technical changes were introduced in this revision. The following list gives an indication of these changes. It is not complete and formulations do not supersede any formulation given inside the standard. More details will be given in a Technical report published after the publication of this standard.

	Clause
The definition of running gear masses are included for clarification	3.2-7
The definition of “empty” and “loaded” vehicle status is included with reference to EN 15663	5.3.2
The definition of test tracks for testing of safety against derailment in twisted track is refined	6.1
The bogie test twist for method 3 testing is reduced from 7 $^0/_{00}$ to 6,67 $^0/_{00}$	6.1.5.3.2.2
High speed trains are to be tested for different combinations of speeds and cant deficiencies to cover the behaviour under different track quality levels	7.3.3
Stability testing is now handled as a separate “test zone”	7.3.1
Test zone 2a of EN 15686 is no longer to be evaluated	7.3.1
The minimum number of track sections for test zone 3 is reduced to 25	7.3.1
It is clarified, that track sections in curves are restricted to full curve sections	7.3.2
A new achievable specification of target test conditions related to geometric track quality (consistent with EN 13848-6) replace the requirements for *QN1* and *QN2*, that were often not achievable	7.3.1 M, N
On-track tests are reduced to testing in one rail inclination. Therefore representative wheel profiles need to be used and extreme low equivalent conicities need to be included in the evaluation. High conicities need to be included in the stability proof.	7.3.1
The target values for equivalent conicity values for stability assessment are modified slightly. They are related to the target system of lines compliant with TSI INF. For other lines national rules may require higher values.	7.3.1
Introduction of recalculation of $(Y/Q)_a$ results	7.6.3.2.5

Introduction of normalisation of Y_{qst} results	7.6.3.2.6
Introduction of new track loading parameters Y_{max}, B_{qst}, B_{max}, T_{qst} to be documented without limit values	7.5.3, J, K
Introduction of quantities ΣY_{qst}, $\Sigma\Sigma Y_{qst}$, Y/Q_{qst} H_{qst} ΣQ_{qst} and $\Sigma\Sigma Q_{qst}$ for plausibility checks on instrumented wheelsets	7.6.3.1
The evaluation of quasi-static quantities is now done at $1,0 \cdot I_{adm}$	7.6.3.2.1
Multiple regression is introduced as an option for evaluation of test results	7.6.3.2.3 R.1.4
The combined test twist (superimposition of bogie and vehicle test twist) of method 2 testing of safety against derailment in twisted track is corrected to exclude roll moments from the results of wheel unloading	A.6 A.9.3
A specification for measurements of the torsional coefficient is included	C
Displacement characteristics is made more consistent with EN 15273	D
The assessment of running safety in curved crossings from UIC 510-2 is introduced with some practical extensions	E
A specification for testing of behaviour in switches and crossings is introduced as an (informative) option	F
An informative “operational envelope” for combinations of speed and cant deficiency is introduced. It replaces the operational requirements with fixed cant deficiencies. A note indicates, that minimum requirements exist in many networks as operational rules	H
Examples for instrumentation of vehicles with instrumented wheelsets are included	I
The limit values for ride characteristics are replaced by non-mandatory typical values for max- accelerations of different vehicle categories for assessment	L
Reporting of track geometric quality in wavelength range *D2* is now required for speeds > 160 km/h	N
Details about rail profile measurements and the evaluation of the equivalent conicity are specified	O, P
The description of radial steering index is included without any requirement for test conditions (Intention to shift this definition to EN 15302 for the future)	Q
The range of cant deficiencies for two-dimensional evaluation of test results is extended	R.1.3

For special vehicles in some cases an instrumentation with instrumented wheelsets is required	S.2
An improved possibility to reduce the test extent to one load condition is introduced for special vehicles	S.4
Simulation with validated models is introduced	T
In order to allow dispensation also for cases with safety factors between 1 and 1,1, reduced parameter change ranges for dispensation of on-track tests and reduced test extent are introduced.	U.1
For interpolation between two tested vehicles of the same family or the same design concept, the parameter change ranges are extended	U.3
The parameter secondary vertical stiffness is replaced by the quotient of stiffness and supported mass	U.1
The measurement of wheel forces and wheelset forces is removed from this standard. It will be replaced by new EN 15654-2	-

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of EU Directive 2008/57/EC

This European Standard has been prepared under a mandate given to CEN]/CENELEC/ETSI by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Directive 2008/57/EC[1).

Once this standard is cited in the Official Journal of the European Union under that Directive and has been implemented as a national standard in at least one Member State, compliance with the clauses of this standard given in Table ZA.1 for freight wagons and Table ZA.2 for locomotive and passenger RST, confers within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive and associated EFTA regulations.

1) This Directive 2008/57/EC adopted on 17th June 2008 is a recast of the previous Directives 96/48/EC 'Interoperability of the trans-European high-speed rail system' and 2001/16/EC 'Interoperability of the trans-European conventional rail system' and revisions thereof by 2004/50/EC 'Corrigendum to Directive 2004/50/EC of the European Parliament and of the Council of 29 April 2004 amending Council Directive 96/48/EC on the interoperability of the trans-European high-speed rail system and Directive 2001/16/EC of the European Parliament and of the Council on the interoperability of the trans-European conventional rail system'.

Table ZA.1 — Correspondence between this European Standard, the Commission Regulation (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem 'rolling stock – freight wagons' of the rail system in the European Union and repealing Decision 2006/861/EC (published in the Official Journal L 104, 12.4.2013, p.1) and Directive 2008/57/EC

Clause/subclauses of this European Standard	Chapter/§/annexes of the Technical Specification for Interoperability (TSI)	Corresponding text, articles/§/annexes of the Directive 2008/57/EC	Comments
The whole standard is applicable	4.Characterization of the subsystem 4.2 Functional and technical specifications of the subsystem. 4.2.3 Gauging and track interaction 4.2.3.5 Running safety 4.2.3.5.1 Safety against derailment running on twisted track 4.2.3.5.2 Running dynamic behaviour 6 Conformity assessment and EC verification 6.2 Subsystem 6.2.2 EC verification procedures 6.2.2.2 Safety against derailment running on twisted track 6.2.2.3 Running dynamic behaviour 7 Implementation 7.1 Authorization for placing into service 7.1.2 Mutual recognition of the first authorization of placing in service § a) Appendix B Specific procedures for running dynamics	Annex III, Essential requirements 1 General requirements 1.1 Safety Clauses 1.1.1, 1.1.2 1.5 Technical compatibility §1 2 Requirements specific to each subsystem 2.4 Rolling stock» 2.4.2 Reliability and availability 2.4.3. Technical compatibility §3	This TSI refers to the Clauses 5 and subclauses 4.1 and 4.2.3.5.2 of the 2005 issue of this EN 14363, and it defines in its appendix B Specific procedures for running dynamics. This issue of EN 14363 deals with the same subjects as those referred to in this TSI from EN 14363:2005 and its appendix B. If this EN is applied, the requirements of the mandatory references of this TSI on this subject are fulfilled.

Table ZA.2 — Correspondence between this European Standard, the TSI Locomotive and Passenger Rolling Stock (approved by the RISC68 on 23 October 2013), and Directive 2008/57/EC

Clause/ subclauses of this European Standard	Chapter/§/annexes of the technical specification for interoperability (TSI)	Corresponding text, articles/§/annexes of the Directive 2008/57/EC	Comments
The whole standard is applicable	4.Characterization of the Rolling stock subsystem 4.2 Functional and technical specifications of the subsystem 4.2.3.Track interaction and gauging 4.2.3.4 Rolling stock dynamic behaviour 4.2.3.4.1 Safety against derailment running on twisted track 4.2.3.4.2 Running dynamic behaviour 6.Assessment of conformity or suitability for use and 'ec' verification 6.2.Rolling stock subsystem 6.2.3 Particular assessment procedures for subsystems 6.2.3.3 Safety against derailment running on twisted track 6.2.3.4 Running dynamic behaviour Appendix C.3 Appendix J.1 Index 16 Index 17 Index 18 Index 19 Index 83 Index 84 Appendix J-2 Index 2	Annex III, Essential requirements 1 General requirements 1.1 Safety Clauses 1.1.1, 1.1.2 1.5 Technical compatibility §1 2 Requirements specific to each subsystem 2.4 Requirements specific to each subsystem 2.4 Rolling stock» 2.4.2 Reliability and availability 2.4.3. Technical compatibility §3	This TSI refers to clauses and subclauses of the 2005 issue of this EN 14363, and it refers to the ERA /TD/2012–17/INT which deals with running dynamics. This issue of EN 14363 deals with the same subjects as those referred to in this TSI from EN 14363:2005 and ERA /TD/2012–17/INT. If this EN is applied, the requirements of the mandatory references of this TSI on this subject are fulfilled.

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

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[2] Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the *minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)* [3]

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