Resistance of Railway Vehicles to Derailment and Roll-Over

Synopsis
This document mandates requirements for rolling stock to ensure acceptable resistance against flange climbing derailment and against roll-over induced by overspeeding.
Railway Group Standard
GM/RT2141
Issue Three
Date June 2009

Resistance of Railway Vehicles to Derailment and Roll-Over

Issue record

<table>
<thead>
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<th>Date</th>
<th>Comments</th>
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<td>June 2009</td>
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<td>Includes a new vertical acceleration curve for bogie freight</td>
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<td>vehicles tested on jointed track</td>
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Amended or additional parts of revised pages have been marked by a vertical black line in the adjacent margin.

Superseded documents

The following Railway Group documents are superseded, either in whole or in part as indicated:

<table>
<thead>
<tr>
<th>Superseded documents</th>
<th>Sections superseded</th>
<th>Date when sections are superseded</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM/RT2141, issue two</td>
<td>All</td>
<td>01 August 2009</td>
</tr>
<tr>
<td>Resistance of Railway Vehicles to Derailment and Roll-Over</td>
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</table>

Supply

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Resistance of Railway Vehicles to Derailment and Roll-Over

Contents

Section | Description | Page
--- | --- | ---
Part 1 | Purpose and Introduction | 4
  1.1 | Purpose | 4
  1.2 | Introduction | 4

Part 2 | Requirements for Resistance of Railway Vehicles to Derailment and Roll-over | 7
  2.1 | Resistance to derailment | 7
  2.2 | The effect of vehicle conditions on resistance to derailment | 7
  2.3 | The effect of traction and propelling forces on resistance to derailment | 7
  2.4 | Resistance to roll-over induced by overspeeding | 8
  2.5 | Application to vehicles undergoing modification | 9
  2.6 | Application to vehicles having characteristics similar to those of other vehicles | 9

Part 3 | Application of this document | 10
  3.1 | Application – infrastructure managers | 10
  3.2 | Application – railway undertakings | 10
  3.3 | Health and safety responsibilities | 10

Appendices | | 11
  Appendix A | Static or Quasi-static Measurement of Wheel Unloading on Twisted Track | 11
  Appendix B | Measurement of Bogie Rotational Resistance | 13
  Appendix C | Computer Simulations Designed to Examine Whether the Vehicle has an Acceptable Resistance to Flange Climbing Derailment at Low Speed | 15
  Appendix D | On-track Ride Tests | 18
  Appendix E | On-track Dynamic Measurement of Y/Q Ratio and Analysis of the Results | 24
  Appendix F | Guidance on Alternative Routes to Compliance with this Document | 26

Definitions | | 28

References | | 29

Tables | | 5
  Table 1a | Allowable methods of acceptance for different vehicle types | 5
  Table 1b | Appendices applicable to the methods in Table 1a | 5
Part 1  Purpose and Introduction

1.1  Purpose

1.1.1  This document mandates requirements for rolling stock to ensure acceptable resistance against flange climbing derailment and against roll-over induced by overspeeding.

1.2  Introduction

1.2.1  Resistance to derailment

1.2.1.1  This document defines the criteria by which acceptable derailment resistance of vehicles is to be demonstrated. The most direct method of assessing derailment propensity is by on-track measurement of the ratio of lateral to vertical force at the wheel-rail interface, but long experience has shown that rather more indirect methods can provide adequate assurance of safety against derailment. Such methods are usually easier to implement than on-track wheel / rail force measurements, but will generally lead to more conservative engineering solutions.

1.2.2  Derailment resistance compliance methods

1.2.2.1  This document sets out three methods for gaining acceptance. It allows the user to opt, where appropriate, for the most easily implemented method, but with the possibility, where it is not possible to demonstrate acceptability in this way, to move to a more direct method or ultimately to an on-track force measurement.

1.2.3  Derailment resistance compliance method 1

1.2.3.1  This combines laboratory based wheel unloading and (where appropriate) bogie rotation tests with on-track ride tests so as to check compliance with defined criteria which have been shown by practical experience to confer satisfactory derailment resistance. If all the criteria are met, this is a sufficient condition for the vehicle to be acceptable in respect of derailment resistance. However, this method does not give any indication of the ability of certain vehicles to cope with the geometric chord offset effect which arises in negotiating curves. Hence it is not applicable to vehicles with a multi-bogie / axle configuration. Moreover, the indirect criteria used in the wheel unloading, bogie rotation and ride tests which have been developed by largely empirical methods may not be applicable to vehicles with novel suspension or running gear. The method is therefore not applicable to vehicles with a novel suspension or running gear.

1.2.4  Derailment resistance compliance method 2

1.2.4.1  Replaces the acceptance criteria contained in the wheel unloading and bogie rotation tests by a criterion based on predicted wheel/rail forces (Y/Q) using a computer simulation. A computer model of the vehicle, which has been validated against the laboratory ΔQ/Q and X-factor tests, is used to predict the Y/Q ratio as a time history when negotiating prescribed track inputs. If all the criteria are satisfied, completion of a ride test is then a sufficient condition for the vehicle to be acceptable in terms of derailment resistance. As the method gives an indication of the ability of vehicles to cope with the geometric chord offset effect it is applicable to vehicles with a multi-bogie / axle configuration, but should not be applied to vehicles with a novel suspension or running gear.
1.2.5 Derailment resistance compliance method 3

1.2.5.1 Replaces the wheel unloading, bogie rotation and ride tests and the computer simulation by a direct on-track measurement of derailment propensity derived from the ratio of lateral to vertical dynamic force (Y/Q) at the wheel / rail interface. This method is applicable to any vehicle. If the Y/Q criterion is met, this is a sufficient condition for the vehicle to be acceptable in terms of derailment resistance.

1.2.6 Route to compliance

1.2.6.1 From the above, it can be seen that for certain types of vehicle there is more than one possible route to compliance. Tables 1a and 1b summarise those routes, as follows:

a) Allowable methods of acceptance for different vehicle types

b) Appendices applicable to the methods indicated above.

<table>
<thead>
<tr>
<th>Method 1</th>
<th>Method 2</th>
<th>Method 3</th>
</tr>
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<tbody>
<tr>
<td>Vehicles having neither novel suspension or running gear nor a multi-bogie / axle configuration</td>
<td>X</td>
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<tr>
<td>Vehicles having a multi-bogie / axle configuration but not having a novel suspension or running gear</td>
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<td>Vehicles having a novel suspension or running gear</td>
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</tbody>
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Table 1a Allowable methods of acceptance for different vehicle types

<table>
<thead>
<tr>
<th>Appendix A</th>
<th>Appendix B</th>
<th>Appendix C</th>
<th>Appendix D</th>
<th>Appendix E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static or quasi-static measurement of wheel unloading on twisted track</td>
<td>Measurement of bogie rotational resistance</td>
<td>Computer simulations designed to examine whether the vehicle has an acceptable resistance to flange climbing derailment at low speed</td>
<td>On-track ride tests</td>
<td>On-track dynamic measurement of Y/Q ratio and analysis of the results</td>
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Table 1b Appendices applicable to the methods in Table 1a
1.2.6.2 Guidance on the procedure to be followed in choosing the compliance route is given in Appendix F.

1.2.7 Resistance to roll-over induced by overspeeding

1.2.7.1 This document also sets out criteria by which acceptable resistance of vehicles to roll-over induced by overspeeding is to be demonstrated.

1.2.8 Supporting documents

1.2.8.1 The following Railway Group document supports this Railway Group Standard:

Part 2 Requirements for Resistance of Railway Vehicles to Derailment and Roll-Over

2.1 Resistance to derailment

2.1.1 Requirements for tilting trains

2.1.1.1 These requirements apply to both tilting and non-tilting trains. For tilting trains the assessment of derailment risk shall consider the possibility of counter-acting tilt failure leading to vehicle body twist on a single vehicle or group of vehicles. Measures shall be implemented to minimise the possibility of tilt failure and the consequences should it occur.

2.1.2 Vehicles not having a novel suspension or running gear and not having a multi-bogie / axle configuration

2.1.2.1 Such vehicles shall satisfy all the requirements of method 1, or all the requirements of method 2 or all the requirements of method 3 (see 2.1.5).

2.1.3 Vehicles not having a novel suspension or running gear but having a multi-bogie / axle configuration

2.1.3.1 Such vehicles shall satisfy all the requirements of method 2, or all the requirements of method 3 (see 2.1.5).

2.1.4 Vehicles having a novel suspension or running gear

2.1.4.1 Such vehicles shall satisfy all of the requirements of method 3 (see 2.1.5.3).

2.1.5 Derailment resistance compliance method details

2.1.5.1 Method 1 - This requires that the vehicle shall satisfy the requirements of Appendix A and the requirements of Appendix B and the requirements of Appendix D.

2.1.5.2 Method 2 - This requires that the vehicle shall satisfy the requirements of Appendix C and the requirements of Appendix D.

2.1.5.3 Method 3 - This requires that the vehicle shall satisfy the requirements of Appendix E.

2.2 The effect of vehicle conditions on resistance to derailment

2.2.1 Vehicle conditions and loads can affect the resistance to derailment and therefore consideration shall be given to the range of test conditions necessary.

2.2.2 The range of vehicle test conditions shall take account of the effect of:

a) Inter-vehicle connections on wheel unloading performance (for example in certain articulated trains where the design may have a significant effect on this performance)

b) In built vehicle design asymmetry (either longitudinal or lateral)

c) Differences in the suspension system behaviour at the two ends of the vehicle (including different levelling valve systems, where appropriate)
d) Vehicle weight distribution (for example tare, laden, partially laden)

e) Range and effect of possible in-service loading configurations (for example distribution of containers, stiffness effect of the load)

f) Any other design feature or in-service condition that might significantly affect the wheel unloading performance.

2.2.3 In cases where the magnitude of the effect is outside the range of previous service experience, such that it casts doubt on the validity of the simplified test or simulation methods (set out in 2.1.5), on-track Y/Q measurements (as required by method 3 of 2.1.5) shall be made in order to demonstrate acceptability.

2.3 The effect of traction and propelling forces on resistance to derailment

2.3.1 Where the magnitude of traction or propelling force is outside the range of previous service experience, such that it casts doubt on the validity of the simplified test or simulation methods (set out in 2.1.5), on-track Y/Q measurements (as required by method 3 of 2.1.5) shall be made in order to demonstrate acceptability.

2.4 Resistance to roll-over induced by overspeeding

2.4.1 Design requirements for resistance to roll-over

2.4.1.1 Vehicles shall be designed with mass distribution and suspension characteristics which ensure the capability to run round smooth curves at constant speed, without rolling over, at:

a) Not less than 16.5° cant deficiency for freight vehicles designed to operate at speeds no greater than 75 mph

b) Not less than 21° cant deficiency for all other vehicles.

2.4.1.2 For all vehicles that operate at a cant deficiency greater than 6° particular attention shall be given to maximising, so far as is reasonably practicable, the margin between the operating cant deficiency and the roll over resistance.

2.4.2 Determination of required resistance to roll-over

2.4.2.1 Vehicles' resistance to roll-over shall be demonstrated by theoretical methods, practical tests, comparison with other vehicles, or a combination of these.

2.4.2.2 In all cases the curve shall be taken as smooth, such that quasi-static centrifugal effects are taken into account, but not the effects of transitions or track irregularities. Wind effects shall not be taken into account.

2.4.2.3 Vehicles not meeting the requirements of 2.4.1 shall not be permitted to operate.

2.4.2.4 Where vehicles are intended to operate at cant deficiencies greater than 6° additional measures to control the risk of roll-over are required. These are set out in GC/RT5021, GE/RT8012 and GM/RT2142.
2.4.3 Supply of information to the infrastructure manager

2.4.3.1 Railway undertakings shall make available to the infrastructure manager the resistance to roll-over of all vehicles required to operate at cant deficiencies in excess of 6°. They shall also make available the maximum service cant deficiency at which the vehicles are designed to operate.

2.4.3.2 The above information is required by the infrastructure manager to determine the enhanced permissible speed of vehicles through curves in accordance with the requirements detailed in GC/RT5021. Additional information requirements for this purpose are set out in GM/RT2142.

2.5 Application to vehicles undergoing modification

2.5.1 In respect of vehicles undergoing modification, where the modification is such that it may have an effect on the resistance to derailment or roll-over, there shall be an analysis of the potential consequences of that modification. This analysis shall assess the significance of the modification on the derailment or roll-over behaviour and, where appropriate, shall be used to decide which aspects of the behaviour of the modified vehicle require to be re-examined so as to demonstrate compliance with the requirements of this document.

2.6 Application to vehicles having characteristics similar to those of other vehicles

2.6.1 Where vehicles being newly introduced or being modified have characteristics similar to those of other vehicles having an authorisation for placing into service, or other vehicles having a Certificate of Engineering Acceptance, or to those of vehicles which, whilst pre-dating that process, have been shown to be satisfactory by the methods mandated in this document or by sufficient service experience, it is permissible to reduce the amount of analysis and testing required by Part 2 of this document. This shall apply for vehicles built or modified to previously accepted designs, and to variants of a base design (such as might appear in a multiple unit having driving trailers, non-driving trailers, motor trailers etc) where the full process is applied to the ‘base’ vehicle and a reduced process to the others. In all such cases, there shall be an analysis of the potential consequences of:

a) The changes from the previous or ‘base’ design which may have an influence on the propensity to derail or roll-over

b) Changes in the proposed duty which may have an influence on the propensity to derail or roll-over.

2.6.2 Where the potential consequences are significant, the analysis shall be used to decide which aspect of the behaviour of the vehicle require to be re-examined so as to demonstrate compliance with the requirements of this document.
Part 3  Application of this document

3.1  Application – infrastructure managers

3.1.1  There are no requirements applicable to infrastructure managers.

3.2  Application – railway undertakings

3.2.1  Scope

3.2.1.1  The requirements of this document apply to new rolling stock, and to altered rolling stock where the alteration could affect the propensity of a vehicle to derail or roll-over.

3.2.1.2  Action to bring existing rolling stock into compliance with the requirements of this document is not required.

3.2.2  Exclusions from scope

3.2.2.1  The requirements in this document are not applicable to rolling stock authorised for placing into service under The Railways (Interoperability) Regulations 2006 (as amended), or any subsequent regulations replacing these regulations, unless the requirements in this document are a relevant notified national technical rule.

3.2.2.2  GE/RT8270 mandates requirements and responsibilities for the assessment of compatibility between infrastructure and rolling stock. Where existing infrastructure has not been assessed as conforming to the applicable Infrastructure TSIs conformity with the requirements of GM/RT2141 are a method of demonstrating compatibility between rolling stock and infrastructure.

3.2.3  General compliance date for railway undertakings

3.2.3.1  This Railway Group Standard comes into force and is to be complied with from 01 August 2009.

3.2.3.2  After the compliance dates or the date by which compliance is achieved if earlier, railway undertakings are to maintain compliance with the requirements set out in this Railway Group Standard. Where it is considered not reasonably practicable to comply with the requirements, authorisation not to comply should be sought in accordance with the Railway Group Standards Code.

3.3  Health and safety responsibilities

3.3.1  Users of documents published by RSSB are reminded of the need to consider their own responsibilities to ensure health and safety at work and their own duties under health and safety legislation. RSSB does not warrant that compliance with all or any documents published by RSSB is sufficient in itself to ensure safe systems of work or operation or to satisfy such responsibilities or duties.
Appendix A  Static or Quasi-static Measurement of Wheel Unloading on Twisted Track

The content of this appendix is mandatory when it is a requirement of the compliance method used.

A.1 General requirement
A.1.1 Recommendations relating to this test are set out in GM/RC2641.
A.1.2 The test shall be such that it permits the measurement of the wheel load changes which are induced by the passage of the vehicle at very low speed over the track irregularity defined in Figure A.1. A test which simulates the behaviour by raising or lowering of the wheels of a stationary vehicle shall be acceptable.

A.2 Test conditions
A.2.1 The vehicle configurations covered by the test programme shall be sufficient to allow all significant representative conditions to be assessed. This shall include consideration of:

a) Whether it is necessary to test with the track input in all of its four possible orientations (that is, with the dip at each end and at each side of the vehicle) or whether a more restricted test will suffice

And

b) The range of load conditions for which the vehicle shall be tested.

A.3 Test measurements
A.3.1 The test system shall be capable of measuring the vertical load at the wheel seeing the greatest percentage off-loading as the track irregularity is negotiated, or as its effect on the vehicle is simulated. It shall be permissible to predict, via suitable analysis or simulation, the wheel or wheels which are likely to see the greatest percentage off-loading, and thereby restrict the load measurements to these wheels.

A.4 Required performance
A.4.1 The off-loading of any wheel shall be such that, for any axle, the difference between the nominal wheel load (on level track) and the wheel load measured in the test does not exceed 60% of the nominal wheel load.
Figure A.1  Track twist geometry

Where:

\[ \Phi_1 = \text{Long wavelength track twist angle between running rails} = 1:300 \]

\[ \Phi_2 = \text{Short wavelength track twist angle between running rails} = 1:150 \]

\[ T = \text{Semi-span of short wavelength discontinuity} = 6\text{m} \]

Note: The short wavelength discontinuity can occur at any position relative to the vehicle as the vehicle moves over it.
Appendix B  Measurement of Bogie Rotational Resistance

The content of this appendix is mandatory when it is a requirement of the compliance method used.

B.1  General requirement

B.1.1 Recommendations relating to this test are set out in GM/RC2641.

B.1.2 The test shall be such that it permits the measurement of the body / bogie yaw torque which is generated by the passage of the vehicle through curves, switches and crossings etc.

B.2  Test conditions

B.2.1 The vehicle configurations covered by the test programme shall be sufficient to allow all significant representative conditions to be assessed. Tests shall be carried out up to a body / bogie yaw angle which, for vehicles with two bogies, is equal to the spacing of the bogie centres divided by twice the minimum curve radius, and using angular velocities representative of curve entry and exit in service conditions.

B.2.2 For vehicles with three bogies, the outer bogies shall be treated as defined above. The centre bogie behaviour shall be analysed on the most unfavourable track geometry in order to define suitable test conditions.

B.3  Test measurements

B.3.1 The test arrangements shall be capable of measuring the body / bogie yaw torque and yaw angle as the bogie is rotated beneath a vehicle.

B.4  Analysis of results

B.4.1 The bogie X – factor shall be computed from the formula:

\[ X - \text{factor} = \frac{\text{Body / bogie yaw torque}}{\text{wheelbase} \times \text{axle load}} \]

where, for a bogie with more than two axles, the wheel base is the distance between the outer axles.

B.5  Required performance

B.5.1 The X - factor shall not exceed 0.1 for a passenger vehicle, parcels vehicle or locomotive. For a freight vehicle it shall be below the limits shown in Figure B.1.
Resistance of Railway Vehicles to Derailment and Roll-Over

Figure B.1 Maximum permissible freight vehicle X-factor as a function of axle load
Appendix C  
Computer Simulations Designed to Examine Whether the Vehicle has an Acceptable Resistance to Flange Climbing Derailment at Low Speed

The content of this appendix is mandatory when it is a requirement of the compliance method used.

C.1  
**General requirement**

C.1.1  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.

C.1.2  A wheel / rail coefficient of friction of 0.32 shall be used.

C.2  
**Computer output**

C.2.1  The simulation shall be capable of generating a time history of Y/Q ratio at the most unfavourable wheel. The Y/Q ratio shall be computed using a sliding mean over a 2 m length of track.

C.3  
**Track input**

C.3.1  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.

b)  The run-on and run-off transition gradients shall be 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 form of this dip is the same as that shown in Figure A1). This dip shall be positioned so as to create the most unfavourable situation (see C.5.2).
d) The constant radius portion of the track shall be gauge widened as a function of radius \( R \), according to the following criteria:

\[
\begin{align*}
R &> 200 \text{ m} & \text{zero gauge widening} \\
200 &- 176 \text{ m} & 6 \text{ mm gauge widening} \\
175 &- 151 \text{ m} & 9 \text{ mm gauge widening} \\
150 &- 126 \text{ m} & 13 \text{ mm gauge widening} \\
125 &- 101 \text{ m} & 16 \text{ mm gauge widening} \\
R &< 100 \text{ m} & 19 \text{ mm gauge widening}.
\end{align*}
\]

C.3.2 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.

C.3.3 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:

\[
\begin{align*}
R &\geq 200 \text{ m} & 150 \text{ mm maximum cant} \\
200 &> R \geq 150 \text{ m} & 100 \text{ mm maximum cant} \\
150 &> R \geq 100 \text{ m} & 50 \text{ mm maximum cant} \\
100 &> R & 25 \text{ mm maximum cant}
\end{align*}
\]

C.4 Body / bogie yaw torque

C.4.1 Whilst no plan view 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 (that is, that induced by viscous or frictional effects) acts in a sense which increases the \( \frac{Y}{Q} \) 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.

C.5 Performance requirement

C5.1 Limiting values for derailment quotient \( \frac{Y}{Q} \)

C.5.1.1 The computed \( \frac{Y}{Q} \) 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 BR P5 profile.

C.5.1.2 Nadal’s formula indicates that the limiting value of $Y/Q$ above which derailment will occur is given by:

$$\frac{Y}{Q} = \frac{\tan \alpha - \mu}{1 + \mu \tan \alpha}$$

where $\alpha$ is the flange angle and $\mu$ is the coefficient of wheel / rail friction (in this case 0.32).

C.5.2 Positioning of the high rail dip

C.5.2.1 The high rail dip will normally give worst case behaviour when it is positioned so as to increase the effective twist on the vehicle (that is, 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, whilst 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.

C.5.2.2 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, whilst 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.
Appendix D  On-track Ride Tests

The content of this appendix is mandatory when it is a requirement of the compliance method used.

D.1 General requirement

D.1.1 The test shall be such as to permit measurement of the vehicle body vertical and lateral accelerations which will be generated during service operation of the vehicle.

D.2 Test conditions

D.2.1 The vehicle configurations covered by the test programme shall be sufficient to allow all significant representative conditions to be assessed. The test shall be conducted at least over routes representative of those to be used in service, using a sufficient length of track to ensure that a wide range of track conditions has been encountered. The tests shall be carried out on dry rails. Representative parts of the route shall be covered at a range of speeds up to and including the intended maximum operating speed and sufficient to identify any resonance effects which might cause the behaviour to be worse at intermediate speeds than at the intended maximum operating speed.

D.2.2 In considering whether the test programme allows an assessment of all significant representative conditions, particular care shall be taken to take appropriate account of the effect of wheel profile wear on the effective conicity. The results from theoretical prediction methods and practical experience of the behaviour of similar vehicles shall be used, as necessary, in deciding the extent to which tests need to be carried out with fully or partially worn wheel profiles and, where the likely worn profile cannot be predicted with sufficient confidence, whether tests need to be undertaken after the accumulation of service mileage in order to check that the vehicle remains acceptable.

D.3 Test measurements

D.3.1 The tests shall measure the lateral and vertical body accelerations at under-frame level at a position directly above the centre of each bogie (or each axle in a two-axle vehicle), or as near to this point as it is practicable to place the necessary transducers. The signals shall be filtered at 6 Hz, low pass, with a 36 dB/octave rejection rate.

D.4 Analysis of results

D.4.1 The acceleration signals shall then be subjected to a peak count zero crossing analysis and compared with the permissible values as follows:

a) Vertical accelerations

i) Except for bogie freight vehicles when tested on jointed track, the comparison is against Figure D.1a (created from the values given in Table D.1a).
ii) For bogie freight vehicles when tested on jointed track, the comparison is against Figure D.1b (created from the values given in Table D.1b)

b) Lateral accelerations

i) The lateral comparison shall be made against Figure D.2 (created from the values given in Table D.2).

D.4.2 The analysis shall be carried out as follows:

a) For vertical accelerations - only the accelerations which off-load the suspension are taken into account:
   i) The peak value of acceleration between each zero crossing is logged
   ii) A peak value below 0.025 g is ignored
   iii) A peak value between 0.025 g and 0.075 g is regarded as having a level of 0.05 g
   iv) A peak value between 0.075 g and 0.125 g is regarded as having a level of 0.1 g and so on
   v) Peak values above 1.025 g are regarded as having a level of 1.0 g.

   The number of peak values equal to or exceeding 0.05 g is then calculated and expressed as a percentage of the total number of peak values which have been taken into account.

   This process is repeated for 0.1 g, 0.15 g etc up to 1.0 g.

   The results are plotted and compared with the curve shown in Figure D.1a, or Figure D.1b where the vehicle is a bogie freight vehicle tested on jointed track.

b) For lateral accelerations - accelerations in both senses are included.

i) The peak value of acceleration between each zero crossing is logged. It is regarded as positive irrespective of the direction of the acceleration
   ii) A peak value below 0.0125 g is ignored
   iii) A peak value between 0.0125 g and 0.0375 g is regarded as having a level of 0.025 g
   iv) A peak value between 0.0375 g and 0.0625 g is regarded as having a level of 0.05 g and so on
v) Peak values above 0.5125 g are regarded as having a level of 0.5 g.

The number of peak values equal to or exceeding 0.025 g is then calculated and expressed as a percentage of the total number of peak values which have been taken into account.

This process is repeated for 0.05 g, 0.075 g etc up to 0.5 g. The results are plotted and compared with the curve shown in Figure D.2.

For vehicles with a soft lateral suspension, where bogie or wheelset hunting motions may not generate unacceptable body accelerations despite producing wheel-rail forces which are significant in derailment terms, representative time history records shall be examined. The bogie or axlebox acceleration measurements shall be made, if appropriate, in order to decide whether wheel / rail forces arising from instability are likely to be important in terms of derailment risk that is whether there is potential for the Y/Q ratios to rise to unacceptable levels (see Appendix C). If the conclusion from this analysis is that such effects are significant, the vehicle shall be deemed to have failed to meet the requirements of this Appendix and method 3 of 2.1.5 shall be used in order to determine whether derailment resistance is acceptable.

D.5 Required performance

D.5.1 Except as set out in D.5.2 the vertical acceleration performance of the vehicle shall be such that the measured exceedence values lie below the limit curve given in Figures D.1a for all significant representative conditions.

D.5.2 To assess the vertical performance of bogie freight vehicles when tested over jointed track it is permissible to use the Figure D.1b (instead of Figure D.1a) and the vertical acceleration performance shall be such that the measured exceedence values lie below the limit curve given in Figure D.1b.

D.5.3 The lateral acceleration performance of the vehicle shall be such that the measured exceedence values lie below the limit curves given in Figure D.2 for all significant representative conditions.

D.6 Records of test conditions

D.6.1 Records of the cumulative acceleration values and the geometric quality of the track used for the test shall be retained such that the effect of subsequent changes in track quality, or of running on other routes with different track quality, can be assessed. The track geometry quality shall be characterised by standard deviations in stated wavelength ranges, or appropriate time histories, chord offsets, etc.
Figure D.1a  Cumulative vertical peak acceleration curve, for all vehicles except bogie freight vehicles when tested on jointed track

<table>
<thead>
<tr>
<th>Vertical acceleration (g)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>100</td>
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<td>89</td>
</tr>
<tr>
<td>0.15</td>
<td>70</td>
</tr>
<tr>
<td>0.2</td>
<td>47</td>
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<tr>
<td>0.25</td>
<td>25</td>
</tr>
<tr>
<td>0.3</td>
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<td>2</td>
</tr>
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<tr>
<td>&gt; 0.65</td>
<td>0.1</td>
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</table>

Table D.1a  Values for the cumulative vertical peak acceleration curve, for all vehicles except bogie freight vehicles when tested on jointed track
Figure D.1b  Cumulative vertical peak acceleration curve for bogie freight vehicles tested on jointed track

<table>
<thead>
<tr>
<th>Vertical acceleration (g)</th>
<th>Percentage</th>
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<td>100</td>
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<tr>
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<td>89</td>
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<td>70</td>
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<td>47</td>
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</tr>
<tr>
<td>&gt; 0.8</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table D.1b  Values for the cumulative vertical peak acceleration curve values for bogie freight vehicles tested on jointed track
Figure D.2  Cumulative lateral peak acceleration curve, for all vehicles

<table>
<thead>
<tr>
<th>Lateral acceleration (g)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
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<td>0.025</td>
<td>100</td>
</tr>
<tr>
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<td>100</td>
</tr>
<tr>
<td>0.075</td>
<td>100</td>
</tr>
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<td>0.1</td>
</tr>
<tr>
<td>&gt; 0.35</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table D.2  Values for the cumulative lateral peak acceleration curve, for all vehicles
Appendix E  On-track Dynamic Measurement of Y/Q Ratio and Analysis of the Results

The content of this appendix is mandatory when it is a requirement of the compliance method used.

E.1 General requirements
E.1.1 The test shall be such that it permits a derivation of the ratio of lateral to vertical forces measured at the wheels of a moving vehicle in an on-track test.

E.2 Test conditions
E.2.1 The vehicle configurations covered by the test programme shall be sufficient to allow all significant representative conditions to be assessed. The test shall be conducted at least over the routes which will be used in service. The test shall be carried out on dry rail conditions. Representative parts of the route shall be covered at a range of speeds up to and including the intended maximum operating speed and sufficient to identify any resonance effects which might cause the behaviour to be worse at intermediate speeds than at the intended maximum operating speed.

E.2.2 Particular care shall be taken to ensure a representative assessment of the behaviour in conditions where high curvature, cant and track twist can occur simultaneously.

E.2.3 In considering whether the test programme allows an assessment of all significant representative conditions, particular care shall also be taken to take appropriate account of the effect of wheel profile wear on the effective conicity. The results from theoretical prediction methods and practical experience of the behaviour of similar vehicles shall be used, as necessary, in deciding the extent to which tests need to be carried out with fully or partially worn wheel profiles. Where the likely worn profile cannot be predicted with sufficient confidence, whether tests need to be undertaken after the accumulation of service mileage in order to check that the vehicle remains acceptable.

E.3 Test measurements
E.3.1 The measurements shall include one of the following, as a minimum:

a) Direct vertical and lateral wheel / rail force measurement using load measuring wheels

b) Indirect measurement of these forces, these being deduced from suspension forces, accelerations, suspension displacements, etc.

E.3.2 When making indirect measurements where there is direct transfer of lateral force from left hand wheel to right hand wheel and vice-versa, the lateral force at any wheel shall be computed by assuming that the other wheel on the same axle is in full lateral slip in the direction which promotes flange climbing of the wheel in question.
E.4 Analysis of results

E.4.1 The ratio of Y/Q shall be computed over a 2 m length of track, using a sliding mean with a sample interval of 0.5 m after filtering with a 20 Hz low pass filter, rejection rate 24 dB/octave.

E.5 Performance requirements

E.5.1 The maximum permissible value of Y/Q shall be computed using Nadal’s formula (below), taking into account:

a) The flange angle, in both new and worn conditions

b) The range of coefficients of wheel / rail friction which will be met in service conditions.

E.5.2 Nadal’s formula indicates that the limiting value of Y/Q above which derailment will occur is given by:

\[
\frac{Y}{Q} = \frac{\tan \alpha - \mu}{1 + \mu \tan \alpha}
\]

where \( \alpha \) is the flange angle and \( \mu \) is the coefficient of wheel / rail friction.

E.5.3 In assessing the test results, the following consideration shall be taken into account (the list is not exhaustive):

a) An isolated exceedence of the permitted Y/Q ratio shall not be a bar to acceptance provided that the location of the track fault which has induced the exceedence can be established, the feature can be identified as being beyond the limits and that arrangements can be made to ensure that it does not recur.

b) Caution shall be exercised when assessing vehicles where there are frequent excursions up to a Y/Q value which approaches the limit discussed above, given the variability of track conditions which will occur on any given route.

E.6 Records of test conditions

E.6.1 Records of the Y/Q values and of the geometric quality of the track used for the test shall be retained such that the effect of subsequent changes in track quality, or of running on other routes with different track quality, can be assessed. The track geometry quality shall be characterised by standard deviations in stated wavelength ranges, or appropriate time histories, chord offsets etc.
Appendix F  Guidance on Alternative Routes to Compliance with this document

The content of this appendix is not mandatory and is provided for guidance only.

F.1  Precautionary measures

F.1.1  In cases where the chosen route to compliance does not involve a formal check against the requirements of Appendices A and B, it is nevertheless strongly recommended that wheel unloading and bogie rotation performance is assessed by means of controlled tests, which may be those described in Appendices A and B or equivalent methods. This permits:

a)  A direct verification of the behaviour from which the output data can be used to refine the vehicle model to the computer simulation, if the latter is being used, as required by Appendix C.

b)  A check that there are no abnormalities in the vertical suspension behaviour nor any fouls or body / bogie interconnection restraints (such as short traction motor cables or brake hoses) which might inhibit bogie rotation and thus present a risk to the safety of the vehicle during on-track tests.

F.1.2  It is strongly recommended that a computer simulation be performed prior to Y/Q tests on vehicles with novel suspension or running gear, so as to maximise the possibility of understanding any aspects of the behaviour which might present a risk to the safety of the vehicle during on-track tests.

F.2  Test sequence

F.2.1  For vehicles with neither a novel suspension nor running gear nor a multi-bogie / axle configuration, the normal route to compliance will be by method 1. However, if the vehicle fails to satisfy either the wheel unloading or bogie rotation criteria, method 2 can be used. If either of the two criteria from method 2 (predicted Y/Q ratio and ride quality) are not satisfied, method 3 is available. There may, of course, be circumstances where method 3 is chosen from the outset, but in view of the complexity of implementation of method 3, it is suggested that the sequence described above will generally be the most economic. It is shown in the flow diagram of Figure F.1 a).

F.2.2  For vehicles which have a multi-bogie / axle configuration but not a novel suspension or running gear, the suggested flow diagram is shown in Figure F.1 b).

F.2.3  For vehicles with a novel suspension or running gear the suggested flow diagram is shown in Figure F.1 c).
Resistance of Railway Vehicles to Derailment and Roll-Over

a) Vehicles with neither a multi-bogie / axle configuration nor a novel suspension or running gear

Wheel unloading and bogie rotation test

Fail either

Computer simulation

On-track Y/Q test

Pass both

Fail

On-track ride test

Vehicle not accepted

Pass

Vehicle acceptance

Pass

b) Vehicles with a multi-bogie / axle configuration but not a novel suspension or running gear

Wheel unloading and bogie rotation test

Pass or fail

Computer simulation

On-track Y/Q test

Vehicle not accepted

Pass

Vehicle acceptance

Pass or fail

On-track ride test

Fail

Vehicle not accepted

Pass

Vehicle acceptance

Fail

On-track Y/Q test

Pass

Vehicle acceptance

Pass

c) Vehicles with a novel suspension or running gear

Wheel unloading and bogie rotation test

Pass or fail

Computer simulation

On-track Y/Q test

Vehicle not accepted

Pass

Vehicle acceptance

Pass

On-track ride test

Fail

Vehicle not accepted

Pass

Vehicle acceptance

Pass

Figure F.1  Flow diagram

Amendments to this document are published on RSSB Standards Catalogue http://www.rssb.co.uk/railway-group-standards
Definitions

Bogie freight vehicle
A freight vehicle fitted with bogies that is used exclusively for the transportation of freight commodities / loads, excluding on-track machines (as defined in GM/RT2400).

Cant deficiency
The difference between the angle to which track would have to be canted on a curve to just counterbalance the centrifugal forces acting on a vehicle, and the actual cant angle of the track.

Certificate of Engineering Acceptance
The declaration by a railway undertaking, or by a notified body or a competent person employed or contracted by a railway undertaking, that a rail vehicle(s) conforms to all of the relevant mandatory standards (including authorised deviations).

Multi-bogie / axle configuration
An axle arrangement such that body / bogie rotational freedom alone is not sufficient to allow all axles to lie in the centre of the flangeway when a vehicle is on a smooth horizontal curve. Examples are three independent axles, three independent two axle bogies and bogies with more than two axles, all of which require lateral suspension flexibility or free lateral movement in order to cater for the geometric chord offset effect which arises in negotiating curves.

Notified national technical rule
As defined by the Railways (Interoperability) Regulations 2006.

Novel suspension or running gear
A system which has features of a type such that combinations of the wheel unloading, bogie rotational resistance, ride or computer simulation criteria in this document cannot be relied upon to demonstrate adequate resistance to derailment. This may either be because the behaviour is not sufficiently well understood or because one or more of the criteria is known to be inappropriate.

Permissible or enhanced permissible speed
The maximum speed published in the Sectional Appendix at which traffic is allowed to run on a line.

Roll-over
The situation reached when all the wheels on one side of a vehicle reach 100% unloading with their running rail and the whole weight of the vehicle is supported by the wheels on the other running rail.

Tilting train
A train having a system which tilts the train body to reduce the lateral acceleration experienced by passengers when operating around curves, allowing the train to run at higher speeds through curves than non-tilting trains.
Resistance of Railway Vehicles to Derailment and Roll-Over

Railway Group Standard
GM/RT2141
Issue Three
Date June 2009

References

The Catalogue of Railway Group Standards and the Railway Group Standards CD-ROM give the current issue number and status of documents published by RSSB. This information is also available from www.rgsonline.co.uk.

Documents referenced in the text

RGSC 01 The Railway Group Standards Code

Railway Group Standards
GC/RT5021 Track System Requirements
GE/RT8012 Controlling the Speed of Tilting Trains through Curves
GE/RT8270 Assessment of Compatibility of Rolling Stock and Infrastructure
GM/RT2142 Resistance of Railway Vehicles to Roll-over in Gales
GM/RT2400 Engineering Acceptance and Design of On-Track Machines

RSSB documents
GM/RC2641 Recommendations for Vehicle Static Testing

Other references
SI 2006/397 The Railways (Interoperability) Regulations 2006 (as amended)