

Calculation of Enhanced Permissible Speeds for Tilting Trains

Synopsis

This Railway Safety Approved Code of Practice sets out an approved method of calculating enhanced permissible speeds for tilting trains. It supports section 5.2.3 of Railway Group Standard GC/RT5021 and section 6.1.5 of Railway Group Standard GE/RT8012. It also provides a means of meeting the requirement for an assessment of the risk of roll-over in gales set out in Railway Group Standard GM/RT2142.

Signatures removed from electronic version

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Calculation of Enhanced Permissible Speeds for Tilting Trains

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Part A

Issue Record

This document will be updated when necessary by distribution of a complete replacement.

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One	June 2001	Original Document

Technical Content

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Railway Safety Approved Codes of Practice are non-mandatory documents detailing suitable and sufficient means of meeting the mandatory requirements of a Railway Group Standard.

* The railway group comprises Railtrack PLC, Railway Safety, and the train and station operators who hold railway safety cases for operation on or related to infrastructure controlled by Railtrack PLC.

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Supply

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Part B

1 Purpose

The purpose of this document is to set out an approved method of calculating **enhanced permissible** speeds for tilting trains. It supports section 5.2.3 of Railway Group Standard [GC/RT5021](#) and section 6.1.5 of Railway Group Standard [GE/RT8012](#). It also provides a means of meeting the requirement for an assessment of the risk of **roll-over** in gales set out in Railway Group Standard [GM/RT2142](#). (See section 4 for further details.)

2 Scope

This document contains recommendations that are applicable to the duty holders of the infrastructure controller category of Railway Safety Case.

The recommendations of this document apply to all curves in running lines on Railtrack controlled infrastructure, as defined in Appendix A of [GA/RT6001](#), over which tilting trains travel at **enhanced permissible** speeds.

Where necessary, additional guidance has been provided within this document to support the recommendations it contains.

3 Definitions

All technical terms used in this document, other than those given below, have the meanings defined in [GC/RC5603](#).

Critical Vehicle

*The critical vehicle of a tilting train is the vehicle having the lowest **overturning wind speed**. This will either be the vehicle having the lowest **roll-over** resistance or the vehicle having the highest aerodynamic **cant deficiency** coefficient calculated in accordance with Appendix F.*

Enhanced Permissible Speed

*The **speed** permitted over a section of line that applies to a specific type of train operating at **cant** deficiencies in excess of those permitted at the **permissible speed**. **Enhanced permissible** speeds are detailed in the sectional Appendix. There may be more than one **enhanced permissible speed** applicable to a given section of line.*

Maximum Design Service Cant Deficiency

*The maximum **cant deficiency** at which a train is designed to travel.*

Overspeed

*The amount by which the actual **speed** of a train could exceed the **enhanced permissible speed** for any reason.*

Overturning

*For the purposes of this document, '**overturning**' has the same meaning as '**roll-over**'. See '**roll-over**'.*

Permissible Speed

*The maximum **speed** permitted over a section of line that applies to trains when not operating at an **enhanced permissible speed**. **Permissible** speeds are detailed in the sectional Appendix.*

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. See also '**overturning**'.*

Route Section

*A section of a route over which a regular long distance commuter is assumed to travel (in one direction) for the purposes of calculating the risk to the commuter from **overturning** of the train in which he is travelling. The route section extends between stations or junctions at which the commuter joins and leaves the route. Route sections for long distance commuters are in the order of 100 miles long.*

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S&C

Abbreviation for 'switches and crossings'.

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.

Turnout Route and Through Route in S&C

A turnout route in S&C is one having a set in the stock rail at the switch toes. A through route has no set in the stock rail at the switch toes. Note that an equal split turnout has a set in both stock rails and that therefore both routes are turnout routes.

4 Documents Supported by this Document

4.1 Support to [GC/RT5021](#)

[GC/RT5021](#) sets out minimum requirements for the design, construction inspection and maintenance of the track system to ensure its safe performance. section 5 of [GC/RT5021](#) sets out particular requirements for track geometry design, and sub-section 5.2.3 sets out the requirements for calculation of **enhanced permissible** speeds.

This document quotes, verbatim and boxed, section 5.2.3 of [GC/RT5021](#) and gives recommendations which will enable the requirements of this section of the Railway Group Standard to be met.

This document also quotes other sections from [GC/RT5021](#) where they are relevant to the calculation of **enhanced permissible** speeds for tilting trains.

4.2 Support to [GE/RT8012](#)

[GE/RT8012](#) sets out requirements relating to the control of the **speed** of tilting trains travelling over curves where an **enhanced permissible speed** is permitted. These requirements are summarised in section 7 of this document.

Section 6.1.5 of [GE/RT8012](#) includes particular requirements where more than one **enhanced permissible speed** applies through a given curve. In this circumstance, only one **speed** value is to be shown on the **enhanced permissible speed** indicator. The value shown is to be the highest **enhanced permissible speed** at which all tilting trains authorised to operate on the route can safely traverse the curve without an unacceptable risk of **overturning**.

This document recommends a method of determining the **speed** to be displayed. This document therefore supports [GE/RT8012](#) in this respect.

4.3 Support to [GM/RT2142](#)

[GM/RT2142](#) sets out safety criteria for railway vehicles to ensure safe performance when operating under gale conditions on Railtrack controlled infrastructure. The objective is to minimise the risks of vehicle **roll-over**.

The **roll-over** probabilities for passenger carrying vehicles that operate at **cant** deficiencies greater than 6° [approximately 150mm] or freight vehicles operating at **cant** deficiencies greater than 4.25° [approximately 110mm], running at their operational speeds and **cant** deficiencies over their proposed routes of operation are to be determined. A risk assessment is then to be carried out to ensure that the probability of **roll-over** is broadly acceptable.

[GM/RT2142](#) permits this requirement to be satisfied by determination of the **enhanced permissible speed** as detailed in [GC/RT5021](#). This document therefore also supports [GM/RT2142](#) in this respect.

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5 Background to Calculation Methodology Presented in this Document

5.1 Cant Deficiency Margin Against Overturning

GM/RT2141 requires vehicles (other than freight vehicles designed to operate at speeds no greater than 75mph) to be able to run round smooth curves at constant speed, without overturning (roll-over), at not less than 21° cant deficiency.

GC/RT5021 sets a limit for design cant deficiency of 150mm (approximately 6°) for trains travelling at permissible speeds.

There is therefore, at worst, a margin of 15° cant deficiency between a train travelling at permissible speed and its roll-over resistance. Experience shows that this margin is sufficient to ensure that the risk of overturning is tolerable.

Tilting trains have 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 cant deficiencies (and therefore higher speeds) through curves than non-tilting trains.

A tilting train may have a maximum design service cant deficiency of up to 12°. In this case there is, at worst, a margin of only 9° cant deficiency between a train travelling at enhanced permissible speed and its roll-over resistance. This is a significant reduction in the margin against overturning compared to that offered at permissible speeds. Particular consideration therefore needs to be given to the adequacy of the margin and the additional controls against overturning required when trains travel at enhanced permissible speeds.

5.2 Factors Increasing Cant Deficiency

A train travelling at a nominal design cant deficiency may actually experience a significantly higher equivalent cant deficiency in practice, reducing the margin before overturning occurs. The additional equivalent cant deficiency arises from the following factors:

- a) track irregularities, in particular localised reduction in cant and curve radius below the nominal design values
- b) the effect of the wind on the train
- c) possible overspeeding of the train.

Errors in estimating the train's roll-over resistance and the effect of the factors listed above may also reduce the actual margin before overturning occurs.

These factors are considered in greater detail in section 10.

5.3 Probabilistic Combination of Factors Increasing Cant Deficiency

The enhanced permissible speed for each type of tilting train on each curve should be calculated in a way that takes the factors listed in section 5.2 into account. However, if all the effects which increase cant deficiency are considered to act simultaneously, a very conservative enhanced permissible speed would be produced. It is therefore necessary to consider the probabilities of those factors which are subject to random variation.

The interaction can be modelled by:

- a) assuming probability distributions for each variable
- b) determining which combinations of the variables give rise to overturning
- c) determining the probabilities with which these combinations will occur, and summing them to form a total probability of overturning.

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If the controls on track irregularity described in section 10.3 are put in place, the effect of track irregularities on **cant deficiency** is small. The conservative assumption has therefore been made that the maximum possible loss of **cant** and reduction in curve radius are present on every curve (that is, the maximum expected **cant deficiency** increase from track irregularities occurs with a probability of 1).

A fixed safety margin has been assumed to account for errors in estimating the train's **roll-over** resistance and the effect of the factors which increase **cant deficiency**.

These assumptions leave the effect of the **wind** on the train and overspeeding of the train as factors requiring probabilistic combination to determine the probability of the equivalent **cant deficiency** exceeding the train's **roll-over** resistance, causing the train to overturn.

5.4 Calculation of Enhanced Permissible Speed

The risk of **overturning** through curves where trains travel at **permissible** speeds is assumed to be adequately controlled by meeting the requirements of **GM/RT2141** and **GM/RT2142**. Therefore, for the purposes of calculating **enhanced permissible speed**, the risk of **overturning** only need be considered for those curves over which trains travel at **enhanced permissible** speeds.

This assumption defines the scope of application of the calculation methodology set out in this document. The principal stages of this calculation are:

- a) The route over which it is intended to run tilting trains at an **enhanced permissible speed** is divided into 'route sections', as defined in section 3.
- b) For each curve over which trains travel at **enhanced permissible** speeds within the route section, a target **enhanced permissible speed** is determined.
- c) The total probability of **overturning** for the route section contributed by all curves over which trains travel at **enhanced permissible** speeds is then determined.
- d) The total probability of **overturning** for the route section is compared with a pre-determined 'tolerable' probability of **overturning** (see section 5.5).
- e) If the total probability of **overturning** for the route section is less than or equal to the tolerable probability, the target **enhanced permissible** speeds can be adopted.
- f) If the total probability of **overturning** for the route section is greater than the tolerable probability, the probability of **overturning** for the route section should be reduced by applying risk reduction measures (which can include reducing the target **enhanced permissible** speeds on selected curves).

The method of calculating **enhanced permissible** speeds is considered in greater detail in section 11 and Appendix J.

5.5 Determination of the 'Tolerable' Probability of Overturning

There are two methods available to support a decision on the tolerability of risk from **overturning**.

The first method relies on comparing the calculated **overturning** probability with that of a reference vehicle travelling at **permissible** speeds through the curves over which trains are to travel at **enhanced permissible** speeds. This is the preferred method because it reduces the impact of the modelling uncertainties that affect both vehicles in a similar way.

It becomes difficult to apply the comparative method when the vehicle for which the **enhanced permissible speed** is being determined has a lower resistance to **overturning** than the reference vehicle or if no suitable reference vehicle can be identified. In such cases it is necessary to compare absolute values of the **overturning** probability with numerical tolerability criteria.

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The two methods of determining the tolerable probability of **overturning** are considered in greater detail in section 12.

Meeting the tolerability criteria will ensure that the risk of **overturning** contributes a small proportion of the overall risk to passengers and that there is a low likelihood of an **overturning** accident during the fleet lifetime. However, in order to demonstrate ALARP, it will still be necessary to consider whether the level of residual risk justifies the introduction of further control measures.

5.6 Diagrams illustrating issues discussed in section 5

Appendix A contains two diagrams illustrating the margin against **overturning** at **permissible** and **enhanced permissible** speeds (for a train with a roll-over resistance of 21 °) and the factors increasing **cant deficiency**.

The diagrams show the probabilistic combination of the effect of the **wind** on the train and overspeeding of the train to arrive at a residual risk of **overturning**.

The diagram illustrating an **enhanced permissible speed** also shows the effect of additional controls on track irregularities and the use of a **speed** supervision system. Additional measures to reduce the risk of **overturning** can be applied if necessary. These include increasing the train's resistance to **roll-over** and measures to reduce the allowance needed for the effect of **wind** (for example, by installing **wind** fences or by introducing systems to reduce the **speed** of trains when the **wind** exceeds a given limit).

The diagrams are purely illustrative and should not be used quantitatively.

6 Units and Conventions

6.1 Cant and Cant Deficiency

Cant and **cant deficiency** are angular measures which can be expressed in a number of ways.

Conventionally, when considering track, these parameters are expressed indirectly, as the height, measured in millimetres, of the opposite side of a right angle triangle with a hypotenuse equal to the distance between rail head centres (generally taken to be 1500mm). This is illustrated in Figure 1.

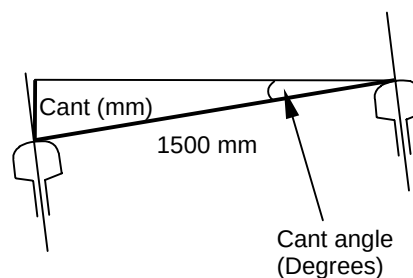


Figure 1: **Cant** expressed as a height

When considering vehicles, these parameters are conventionally expressed directly as an angle, in degrees.

For the purposes of the calculations set out in this document, measurement of **cant** and **cant deficiency** in degrees is used.

However, where values of **cant** and **cant deficiency** are quoted in millimetres in other documents, this usage has been retained in this document.

Cant and **cant** deficiencies quoted in millimetres should be converted to degrees using the following formula:

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$$E_{(\text{Degrees})} = \sin^{-1} \left(\frac{E_{(\text{mm})}}{1500} \right)$$

150mm of **cant** or **cant deficiency** is equivalent to 5.74°.

6.2 Speeds

For the purposes of the calculations set out in this document, measurement of **speed** in metres per second (m/s) is used.

However, where values of **speed** are quoted in miles per hour or kilometres per hour in other documents, this usage has been retained in this document.

Speeds quoted in miles per hour (mph) should be converted to m/s using the following formula:

$$V_{(\text{m/s})} = \frac{1609.3}{3600} V_{(\text{mph})}$$

Speeds quoted in kilometres per hour (km/h) should be converted to m/s using the following formula:

$$V_{(\text{m/s})} = \frac{1000}{3600} V_{(\text{km/h})}$$

6.3 Use of Small Angle Approximations

Small angle approximations ($\tan \theta \approx \theta$, where θ is in radians) should not be used when dealing with angles of the magnitude required for the purposes of this document.

To eliminate small angle approximations, the standard **speed** formula, relating **speed**, radius, **cant** and **cant deficiency**, takes the form:

$$V^2 = Rg \cdot \tan(E + D)$$

Where:

V = train **speed** (m/s)

R = curve radius (m)

g = acceleration due to gravity (9.81 m/s²)

E = **cant** (°)

D = **cant deficiency** (°)

6.4 Equations and Angular Measures

Throughout this document, equations have been written on the assumption that they will be evaluated using a calculator in 'degree mode'. Where a method of calculation which assumes that angles are expressed in radians is used (for example, an Excel spreadsheet), the appropriate conversion factor between radians and degrees must be incorporated.

For example, the equations quoted in sections 6.1 and 6.3 would become:

$$E_{(\text{Degrees})} = \left(\frac{180}{\pi} \right) \cdot \sin^{-1} \left(\frac{E_{(\text{mm})}}{1500} \right)$$

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$$V^2 = Rg \cdot \tan \left((E + D) \cdot \left(\frac{\pi}{180} \right) \right)$$

7 Conditions Under which Trains May Travel at an Enhanced Permissible Speed

GC/RT5021 section 5.2.3 (Part)

The conditions under which trains may travel at an **enhanced permissible speed** are set out in [GE/RT8012](#).

[GE/RT8012](#) sets out requirements relating to the control of the **speed** of tilting trains travelling over curves where an **enhanced permissible speed** is permitted. In summary, the most important requirements are that:

- additional lineside signs are to be used to indicate the **enhanced permissible speed**
- all changes in **permissible** speeds and **enhanced permissible** speeds on a route are to be signed
- only one **enhanced permissible speed** is to be displayed at any given location
- at locations where an **enhanced permissible speed** applies, a **speed** supervision and control system is to be used to control the **speed** of the train into the location.

The introduction to [GE/RT8012](#) notes that lineside signs serve as a reminder to drivers. A driver's actual authority to drive at a given **speed** comes from the **speed** limit information contained in the relevant sectional Appendix of the Rule Book.

[GE/RT8012](#) is supported by a Railway Safety Approved Code of Practice, [GE/RC8517](#). This code of practice is referred to further in section 10.6.

8 Where Enhanced Permissible Speeds are to be Calculated

GC/RT5021 section 5.2.3 (Part)

The **enhanced permissible speed** shall be calculated for each type of train on each curve. The **speed** on each track of a double or multiple line shall be considered separately. On bi-directional tracks, the **speed** in each direction shall be considered separately.

The **enhanced permissible speed** is to be calculated for each type of train because each type of train will differ in its characteristics. In particular, each type of train may have different:

- maximum design service **cant deficiency** (see section 10.1)
- dynamic **roll-over** resistance (see section 10.2)
- aerodynamic characteristics (see section 10.5)
- systems for controlling the **speed** of the train (see section 10.6).

The **enhanced permissible speed** is to be calculated for each curve, because each curve will differ in its characteristics, even if they have the same curvature and applied **cant**. In particular, each curve may have different:

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- a) maintenance tolerances on **cant** (see section 10.3)
- b) maintenance tolerances on curvature (see section 10.3)
- c) local **wind** conditions (see section 10.4).

The **speed** on each track of a double or multiple line is to be considered separately for the reasons given above.

On bi-directional tracks, the **speed** in each direction is to be considered separately because the effect of the **wind** on a train is dependent on the combined direction of the train and the direction of the **wind**.

9 Factors Common to Calculation of Permissible Speeds

9.1 Factors to be Taken into Account

GC/RT5021 section 5.2.3 (Part)

The calculation of **enhanced permissible speed** shall take account of the factors listed in section 5.2.2

The factors listed in section 5.2.2 of GC/RT5021 (**Permissible speed**) that are to be taken into account are:

- a) the radius of the curve
- b) the applied **cant**
- c) the permitted values of **cant deficiency**
- d) the permitted values of rates of change of **cant** and **cant deficiency** on the transitions either side of the circular curve.

9.2 Permitted Values of Curve Radius and Applied Cant

Permitted values of curve radius and applied **cant** are the same at both **permissible** and **enhanced permissible** speeds (see GC/RT5021).

9.3 Permitted Values of Cant Deficiency

Permitted values of **cant deficiency** are greater at **enhanced permissible** speeds than at **permissible** speeds. Permitted values are given in sections 5.3.9 and 5.3.10 of GC/RT5021. The sections are quoted below.

GC/RT5021 section 5.3.9

Cant deficiency on plain line at enhanced permissible speed

Cant deficiencies above those specified in section 5.3.7 shall be **permissible** on CWR plain line, provided no features likely to contribute to lateral misalignment are situated on the transition or circular curve. Features considered likely to contribute to lateral misalignment shall include catch points, adjustment switches, level crossings, longitudinal timbers and directly fastened track on bridges.

The term 'plain line' excludes the through route of S&C (see section 5.3.10).

The normal limiting design values for **cant deficiency** shall be:

- 185mm for curve radii less than 700m but greater than or equal to 400m;
- 265mm for curve radii greater than or equal to 700m.

The exceptional limiting design values for **cant deficiency** shall be:

- 225mm for curve radii less than 700m but greater than or equal to 400m;
- 300mm for curve radii greater than or equal to 700m.

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The maximum **cant** deficiencies for curve radii less than 400m shall be the same as those for **permissible** speeds specified in section 5.3.7.

The limiting design values quoted in this section shall be reduced where necessary to meet the requirements of section 5.2.3.

GC/RT5021 section 5.3.10

Cant deficiency on the through route of S&C at enhanced permissible speed

The normal limiting design values for **cant deficiency** on the through route of S&C shall be the same as those at **permissible speed** specified in section 5.3.7.

Exceptionally, a **cant deficiency** higher than the normal limiting value shall be **permissible** on strengthened S&C, up to a limit of 200mm, provided the radius is greater than or equal to 400m. Where a **cant deficiency** higher than the normal limiting value is proposed, its value shall be assessed, taking into account the following factors:

- any special features incorporated into the S&C that increase the fixity of the track alignment and crosslevel and eliminate potential sources of misalignment;
- the track geometry on the approach to the S&C, including the proximity of any designed change in **cant deficiency**;
- the proposed maintenance regime for the section of track concerned;
- any relevant local features or sources of risk to trains.

Detailed records of the assessment shall be retained with the design records required by section 5.8.

Where **cant** deficiencies above 110mm are proposed, the S&C shall be of a strengthened design with flat bottom rails, concrete bearers and high **speed** check rails with extended entry flares.

Where **cant** deficiencies above 150mm are proposed, additional special features shall be incorporated that:

- eliminate discontinuities at crossings (for example, by provision of swing nose crossings);
- eliminate potential sources of misalignment (for example, by provision of a fully welded layout);
- increase the fixity of the track alignment and crosslevel (for example, concrete slab track).

9.4 Permitted Values of Rates of Change of Cant and Cant Deficiency

*Permitted values of rates of change of **cant** and **cant deficiency** are greater at **enhanced permissible** speeds than at **permissible** speeds. Permitted values are given in sections 5.4.4 and 5.4.6 of GC/RT5021. The sections are quoted below.*

GC/RT5021 section 5.4.4

Rate of change of cant at enhanced permissible speed

The normal limiting design value for rate of change of **cant** shall be 75mm/s.

The exceptional limiting design value for rate of change of **cant** shall be 95mm/s.

GC/RT5021 section 5.4.6

Rate of change of cant deficiency at enhanced permissible speed

The normal limiting design value for rate of change of **cant deficiency** shall be 110mm/s on plain line.

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The exceptional limiting design value rate of change of **cant deficiency** shall be 150mm/s on plain line.

The limiting design values for rate of change of **cant deficiency** on S&C shall be the same as those at **permissible speed** specified in section 5.4.5.

10 Factors Particular to Calculation of **Enhanced Permissible** Speeds

10.1 Maximum **Cant Deficiency** at which Trains are Designed to Travel

GC/RT5021 section 5.2.3 (Part)

The calculation of **enhanced permissible speed** shall take account of ... the maximum **cant deficiency** at which the train is designed to travel.

*Different types of tilting trains are designed to operate up to particular maximum **cant deficiencies**. The maximum **cant deficiency** is set to limit the lateral acceleration experienced by passengers when travelling around curves. It will depend on the tilt capability and suspension characteristics of the train.*

*The maximum **cant deficiency** at which the train is designed to travel is referred to as the 'maximum design service **cant deficiency**' in this document.*

*Typical maximum design service **cant deficiencies** for tilting trains are 9° [approximately 225mm] and 12° [approximately 300mm].*

*GM/RT2141 requires train operators to make available to the infrastructure controller the maximum design service **cant deficiency** of all vehicles required to operate at **cant deficiencies** in excess of 6° [approximately 150mm].*

*GC/RT5021 sets out limiting design values for **cant deficiency** at **enhanced permissible** speeds (see section 9.3 of this document).*

*The service **cant deficiency** to be used in the selection of an initial target **enhanced permissible** speeds set out in section 11.2 should be the lower of the following two values:*

- a) *the maximum design service **cant deficiency** supplied by the train operator for the particular train considered*
- b) *the limiting design value for **cant deficiency**, appropriate to the design radius of the curve under consideration, set out in GC/RT5021 (see section 9.3 of this document).*

Examples:

1. *Consider a train designed for a maximum service **cant deficiency** of 12° running on plain line CWR track with a curve radius of 500m. GC/RT5021 sets an exceptional limiting design value of 225mm (= 8.627°). Therefore the service **cant deficiency** to be used is 8.627° (limited by GC/RT5021 requirement).*
2. *Consider a train designed for a maximum service **cant deficiency** of 9° running on plain line CWR track with a curve radius of 1000m. GC/RT5021 sets an exceptional limiting design value of 300mm (= 11.537°). Therefore service **cant deficiency** to be used is 9° (limited by train's maximum design service **cant deficiency**).*

Section 5.1 of GC/RT5021 sets out the requirements for using exceptional limiting design values rather than normal limiting design values.

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10.2 Dynamic **Roll-Over** Resistance of Trains

GC/RT5021 section 5.2.3 (Part)

The calculation of **enhanced permissible speed** shall take account of ... the dynamic **roll-over** resistance of the train (see [GM/RT2141](#)).

[GM/RT2141](#) sets out design requirements for traction and rolling stock to ensure acceptable resistance against flange climbing derailment and against **roll-over** induced by overspeeding.

Vehicles are to be designed with a 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° [approximately 425 mm] **cant deficiency** for freight vehicles designed to operate at speeds no greater than 75mph
- b) not less than 21° [approximately 540 mm] **cant deficiency** for all other vehicles.

For all vehicles that operate at a **cant deficiency** greater than 6° [approximately 150mm] particular attention is to be given to maximising, so far as is reasonably practicable, the margin between the operating **cant deficiency** and the **roll-over** resistance.

In practice, it is likely that tilting trains will have a **roll-over** resistance that is greater than the minimum specified in [GM/RT2141](#).

[GM/RT2141](#) requires train operators to make available to the infrastructure controller the resistance to **roll-over** of all vehicles required to operate at **cant** deficiencies in excess of 6° [approximately 150mm]. The **roll-over** resistance should be expressed as an equivalent **cant deficiency**, measured in degrees.

A vehicle acceptance body (VAB) is required to certify the **roll-over** resistance supplied to the infrastructure controller by train operators.

The **roll-over** resistance supplied by the train operator should be used in the calculation of the probability of **overturning** set out in Appendix J.

Note that the calculation should be made for the critical vehicle of the train, as defined in section 3. Where it is not certain which vehicle is critical, the **roll-over** resistance of the leading and second vehicles of the train, together with any other vehicles which could have a lower **roll-over** resistance or a higher aerodynamic **cant deficiency** coefficient (see Appendix F) than these vehicles, are required.

10.3 Track Irregularities

10.3.1 Track Parameters Influencing **Overturning**

The standard **speed** equation relating **cant**, **cant deficiency**, curve radius and **speed** indicates that the track parameters influencing **overturning** are **cant** and curve radius.

Other factors such as vertical alignment (top), twist and gauge are not significant when considering the risk of **overturning**, although they are important causes of derailment in general.

In order to cause **overturning**, irregularities in **cant** and curve radius must extend far enough to influence the entire vehicle. To do this, they must have wavelengths of the order of 100m. This is in contrast to flange climbing derailment, where the irregularities are measured over distances of metres rather than tens of metres.

The standard **speed** equation shows that the effect of loss of **cant** and reduction in curve radius can be expressed in terms of an equivalent **cant deficiency** increase.

Calculation of Enhanced Permissible Speeds for Tilting Trains

10.3.2 Maintenance Tolerances on Cant

GC/RT5021 section 5.2.3 (Part)

The calculation of **enhanced permissible speed** shall take account of ... the maintenance tolerances on **cant** (the amount by which, in practice, the applied **cant** could be less than its design value).

*A reduction in **cant** will, by definition, give rise to an equal increase in **cant deficiency**.*

*Measurements of **cant** on typical main line routes by track geometry recording vehicles, filtered to remove short wavelengths, suggest that in most cases the expected variation in **cant** from the design value will be less than 10mm (0.38°).*

GC/RT5021 section 5.2.3 (Part)

It shall be **permissible** to choose fixed maximum values for loss of **cant** ... when calculating **enhanced permissible** speeds provided:

- effective systems are in place for monitoring track geometry and maintaining it to a standard that ensures the chosen maximum values for loss of **cant** ... are never exceeded;
- the chosen maximum values for loss of **cant** ... are fully documented and made available to those responsible for the maintenance of the track.

*Measurement of cross level by a track geometry recording vehicles should be used to monitor loss of **cant**. Measurements should be made at the frequencies specified in section 8.6.4 of GC/RT5021 for track geometry measurement.*

*The infrastructure controller should decide on the value for loss of **cant** to be used in the calculation of the probability of **overturning** set out in Appendix J, taking the effectiveness of maintenance systems into account.*

*The value for loss of **cant** should not be less than 10mm (0.38°).*

10.3.3 Maintenance tolerances on curve radius

GC/RT5021 section 5.2.3 (Part)

The calculation of **enhanced permissible speed** shall take account of ... the maintenance tolerances on curvature (the amount by which, in practice, the curve radius could be less than its design value).

*Decreasing the radius of a curve from its design value will increase the actual **cant deficiency** experienced by a train.*

Measurements of curvature on typical main line routes by track geometry recording vehicles, filtered to remove short wavelengths, suggest that in most cases the expected minimum radius is:

- 80% of the design radius for curves with radii less than 3000m
- 70% of the design radius for curves with radii greater than or equal to 3000m.

GC/RT5021 section 5.2.3 (Part)

It shall be **permissible** to choose fixed maximum values for ... reduction in curve radius when calculating **enhanced permissible** speeds provided:

- effective systems are in place for monitoring track geometry and maintaining it to a standard that ensures the chosen maximum values for ... reduction in curve radius are never exceeded;
- the chosen maximum values for ... reduction in curve radius are fully documented and made available to those responsible for the maintenance of the track.