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

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Technical Content

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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.
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. Experience shows that this margin is sufficient to ensure that the risk of overturning is tolerable.

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.

5.2 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.
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.

```
1500 mm

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<tr>
<td>Cant angle (Degrees)</td>
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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:
Calculation of Enhanced Permissible Speeds for Tilting Trains

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

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 (\( \tan \theta \equiv \theta \), where \( \theta \) 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:

\[ V = \text{train speed (m/s)} \]
\[ R = \text{curve radius (m)} \]
\[ g = \text{acceleration due to gravity (9.81 m/s}^2\) \]
\[ E = \text{cant (°)} \]
\[ D = \text{cant deficiency (°)} \]

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:

\[ E_{\text{Degrees}} = \left( \frac{180}{\pi} \right) \cdot \sin^{-1}\left( \frac{E_{\text{mm}}}{1500} \right) \]
Calculation of Enhanced Permissible Speeds for Tilting Trains

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

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:

a) additional lineside signs are to be used to indicate the enhanced permissible speed

b) all changes in permissible speeds and enhanced permissible speeds on a route are to be signed

c) only one enhanced permissible speed is to be displayed at any given location

d) 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:

a) maximum design service cant deficiency (see section 10.1)

b) dynamic roll-over resistance (see section 10.2)

c) aerodynamic characteristics (see section 10.5)

d) 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:
9 Factors Common to Calculation of Permissible Speeds

9.1 Factors to be Taken into Account

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

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.

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

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.
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.
10.3.2 Maintenance Tolerances on Cant

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°).

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

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:

a) 80% of the design radius for curves with radii less than 3000m

b) 70% of the design radius for curves with radii greater than or equal to 3000m.

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.
Calculation of Enhanced Permissible Speeds for Tilting Trains

Two methods should be considered to monitor reduction in radius:

a) periodic measurement of curvature by track geometry recording vehicles

b) periodic measurement of the distance between fixed datum points at the trackside and the running edge of the nearest rail.

The two methods are equivalent in action.

In the case of measurement of curvature by track geometry recording vehicles, the percentage curve radius reduction can be found directly by comparing the measured radius with the design radius.

In the case of measurements from fixed datum points, the measured distance to the track can be compared with a calculated maximum allowed value. The method of converting distances measured from fixed datum points to a radius reduction is set out in Appendix B.

For either method, 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 reduction in radius to be used in the calculation of the probability of overturning set out in Appendix J, taking the effectiveness of maintenance systems into account.

Unless special controls are put in place, the value taken for the reduced radius should not be larger than:

a) 80% of the design radius for curves with radii less than 3000m

b) 70% of the design radius for curves with radii greater than or equal to 3000m.

10.4 Local Wind Conditions

GC/RT5021 section 5.2.3 (Part)
The calculation of enhanced permissible speed shall take account of the expected local wind conditions.

10.4.1 Reference Wind Speed
Appendix C gives a map showing the extreme mean hourly wind speeds for the UK with a 50 year return period assuming uniformly open country terrain. The extreme mean hourly wind speed for the particular curve under consideration should be determined from this map. This value is the ‘reference wind speed’ for the site.

10.4.2 Local Wind Speed
The reference wind speed should then be adjusted for altitude, wind direction, ground roughness, topography, gust duration and shelter effects to arrive at the speed of a 3 second duration gust with a 50 year return period.

This value is the local wind speed, \( V_{WL} \), which should be used in the calculation of the probability of overturning set out in Appendix J. The recommended methodology for making the necessary adjustments to the reference wind speed is set out in Appendix D.

The 3 second gust duration is chosen for convenience. The method of calculating enhanced permissible speeds set out in this document assumes that peak overturning effects can be determined from the 3 second gust without requiring any allowances for dynamic and aerodynamic admittance effects.

10.4.3 Probability of High Wind Speeds Coming From Particular Directions
The effect of the wind on a train depends on two directional factors:

a) high winds are most likely to blow from the south-west
b) winds only affect trains significantly when acting at between 45° and 105° to the track (that is, when the angle $\phi$ shown on Figure J2 in section J5.1 of Appendix J is between 45° and 105°).

The probability of the wind approaching in the significant range of angles depends on the orientation of the track (relative to north) and whether the train is travelling clockwise or anticlockwise around the curve. A table of wind direction probability factors is given in Appendix E.

The values quoted in Appendix E are for winds blowing towards the outside of the curve. The case where the winds blow inwards may be ignored, because the risk of overturning is negligible compared with the other case.

The wind direction probability factor appropriate to the curve under consideration should be selected from the table in Appendix E and used in the calculation of the probability of overturning set out in Appendix J.

10.4.4 Reducing the Speed of Trains when the Wind Speed Exceeds a Given Limit

A wind alert system or strategy is required to allow the speed of trains to be reduced when the wind speed exceeds, or is predicted to exceed, the chosen maximum wind speed on the curve.

The issues associated with the design of effective wind alert systems and strategies are complex. A full treatment of these issues is beyond the scope of this document. However, the design of any proposed wind alert system or strategy should address the following issues:

a) the accuracy of forecasts; the resolution of forecasts, which cover large areas, and their applicability to any particular site with its own topographical and, possibly, local climatic conditions; the effectiveness and reliability of communication of forecasts; the time lag between receipt of a forecast of high winds and the implementation of a reduction in train speeds

b) the uncertainty in relying on wind measurements at a limited number of locations to monitor and predict conditions along a stretch of line

c) the directionality of the site and wind climate

d) the possibility of sudden gusts due to convective conditions (such as squalls and thunderstorms) that can be much greater than the mean wind and preceding gusts, and could arrive from a different direction

e) the balance between a strategy depending on forecasts or on-site wind measurements

f) the balance between a strategy based on mean winds (which are more readily predictable) or on gusts (which are of more relevance)

g) the balance between a fully automated "black box" solution or a procedural solution requiring greater knowledge and judgement by the operators
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h) human factors in the assessment of the wind hazard and in the reaction to this perceived hazard

i) the setting of appropriate risk criteria on which to base operational wind thresholds and the uncertainties in the assessment of limiting winds for stability

j) the ability to maintain the system to an acceptable level of dependability.

If it is considered necessary to introduce a wind alert system or strategy, the advice of persons or organisations having recognised expertise in aerodynamics, meteorology and wind engineering should be sought. The design of any wind alert system or strategy should take account of the experiences of existing transport operations which use such systems.

10.4.5 Provision of Wind Barriers or Fences to limit the Wind Speed

Section D9 in Appendix D gives details of a ‘fence factor’ to be applied to the reference wind speed when adjusting it to arrive at the local wind speed.

Section D9 includes a reference to the relevant Engineering Science Data Unit (ESDU) data items that should be used to calculate appropriate fence shelter effects where fence parameters differ from those assumed in Section D9.

Should it be considered necessary to provide wind fences or barriers, the advice of persons or organisations having recognised expertise in aerodynamics, meteorology and wind engineering should be sought.

10.5 Effect of Wind on Trains

GM/RT2142 requires train operators to determine the following vehicle characteristics for vehicles that are required to operate at cant deficiencies in excess of a nominal 6° [approximately 150mm]:

a) maximum train speed (as determined by its design)

b) total projected side area of vehicle or side area used to determine its aerodynamic rolling moment coefficient about the lee rail from tests

c) vehicle mean roof height above axle centrel ine or height used to determine its aerodynamic rolling moment coefficient about the lee rail from tests (the lee rail is the rail away from the direction from which the wind is blowing)

d) vehicle aerodynamic rolling moment coefficient about the lee rail at 50° yaw, taking account of the position of the vehicle in the train (the yaw angle is the angle \( \psi \) shown on Figure J2 in section J5.1 of Appendix J).

e) vehicle mass

f) height of vehicle centre of mass above rail level.

The vehicle characteristics listed above are those that determine the behaviour of vehicles under wind loading. The train operator is to make these vehicle characteristics available to the infrastructure controller.
A vehicle acceptance body (VAB) is required to certify the vehicle characteristics supplied to the infrastructure controller by train operators.

The vehicle characteristics 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 characteristics of the leading and second vehicles of the train, together with any other vehicles which could have a lower roll-over resistance (see section 10.2) or a higher aerodynamic cant deficiency coefficient (see Appendix F) than these vehicles, are required.

10.6 Systems Adopted for Controlling the Speed of Trains

The calculation of enhanced permissible speed shall take account of... the system adopted for controlling the speed of the train and the extent to which overspeed can occur (see GE/RT8012).

GE/RC8517 supports GE/RT8012. It sets out recommendations, amongst other things, for the speed supervision and control system required by GE/RT8012. This speed supervision system limits overspeeding by the automatic application of the train’s brakes. The recommendations of GE/RC8517 include guidance on determining intervention criteria for the speed supervision.

A speed supervision system needs to allow a driver, when driving correctly, to achieve the enhanced permissible speed, as indicated on the speedometer display seen from a normal driving position. Therefore, the speed supervision system intervenes at a speed above the prevailing enhanced permissible speed. The intervention level is set at a level that avoids unwarrented intervention, taking into account:

a) the accuracy of the speed measuring system
b) the type of speedometer display and how it is read
c) the dynamics of controlling the train’s speed (the time taken for intervention to take effect).

Typically, the intervention limit will be set at 10km/h (2.778 m/s) above the prevailing enhanced permissible speed.

Depending on the intervention limit set and the characteristics of the supervision system, there will be a given probability of exceeding the enhanced permissible speed by a given amount. A function can be derived describing the relationship between overspeed and the probability of its occurrence.

The function describing the probability distribution of overspeed can be presented, to simplify matters, as a table giving the probability of occurrence for a given overspeed condition. The method of calculating the probability of overturning set out in Appendix J includes a loop requiring each overspeed condition in the table to be numbered sequentially from 1.

A typical probability distribution of overspeed, assuming a balise based speed supervision system, is given in the table below. It is provided for illustrative purposes only.

The third column gives the probability that the overspeed will be in the range indicated. For the purpose of calculating the probability of overturning set out in Appendix J, it should be assumed conservatively that the probability relates to the upper speed in the range. The degree of conservatism can be reduced by applying a finer resolution than the 1.389 m/s (5 km/h) steps used in this example.
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<table>
<thead>
<tr>
<th>Condition, n</th>
<th>Overspeed (m/s)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≤ 0</td>
<td>0.900</td>
</tr>
<tr>
<td>2</td>
<td>0 - 1.389</td>
<td>0.082</td>
</tr>
<tr>
<td>3</td>
<td>1.389 - 2.778</td>
<td>0.018</td>
</tr>
<tr>
<td>4</td>
<td>2.778 - 4.167</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

Table 1: Illustrative probability distribution of overspeed

The train operator is to make the probability distribution of overspeed available to the infrastructure controller.

The probability distribution of overspeed supplied by the train operator should be used in the calculation of the probability of overturning set out in Appendix J.

It should be noted that a probability distribution of overspeed can be derived for the case where there is no speed supervision system (as permitted for trains travelling at permissible speeds). This distribution is required when determining the tolerable probability of a train overturning when travelling at an enhanced permissible speed using the ‘comparative method’ (see section 12 and Appendix G).

10.7 Safety Margin

GC/RT5021 section 5.2.3 (Part)
The calculation of enhanced permissible speed shall take account of ... a safety margin equivalent to no less than 50mm of cant deficiency.

A safety margin is required to account for imprecision in determining values for the factors described in sections 10.1 to 10.6. The safety margin is defined by a fixed amount of cant deficiency for all curves.

A safety margin of 2° (= 52mm) should be used in the calculation of the probability of overturning set out in Appendix J.

11 Method of Calculating Enhanced Permissible Speeds

11.1 Calculation Methodology
The following method should be used for calculating enhanced permissible speeds.

The calculation should be made for the critical vehicle of the train, as defined in section 3. Appendix J includes the recommended approach to be taken if it is not known which vehicle is critical.

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.

For each curve over which trains travel at enhanced permissible speeds within the route section, a target enhanced permissible speed is determined (see section 11.2).

The probability of overturning for a single train pass through each curve is then calculated using the algorithm set out in Appendix J, taking the factors described in section 10 into account.

The total probability of overturning for the route section contributed by all curves over which trains travel at enhanced permissible speeds is then determined by adding the individual probabilities for each curve.

The total probability of overturning for the route section is compared with a pre-determined tolerable probability of overturning. The tolerable probability of overturning is determined by the ‘comparative method’ as described in section 12.
Calculation of Enhanced Permissible Speeds for Tilting Trains

overturning should be determined using either the comparative or absolute method described in section 12.

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.

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. This can be achieved in a number of ways:

a) by reducing the target enhanced permissible speeds on selected curves
b) by providing wind barriers or fences to limit the wind speed on selected curves (see section 10.4.5)
c) by introducing a wind alert system or strategy to allow the speed of trains to be reduced when the wind speed exceeds, or is predicted to exceed a chosen maximum wind speed on selected curves (see section 10.4.4).

The risk reduction measures are listed in order of preference, based on the robustness with which they will achieve the required risk reduction.

The risk reduction measures should be applied preferentially to those curves in the route section having the highest calculated probability of overturning for a single train pass through the curve.

Once risk reduction measures have been selected, the total probability of overturning for the route section contributed by all curves over which trains travel at enhanced permissible speeds should be recalculated to confirm that it is less than or equal to the tolerable probability. If it remains greater than the tolerable probability, further risk reduction measures should be applied and the total probability of overturning for the route section should be recalculated. This process should be repeated until the total probability of overturning for the route section is less than or equal to the tolerable probability.

To prevent any single curve from dominating the risk profile, the calculated probability of overturning for a single train pass through any particular curve should be limited to some suitable fraction (F_{curve}), not exceeding 25%, of the total probability of overturning for the route section.

A flow chart, summarising the recommended method of calculating enhanced permissible speeds is given in Appendix H.

11.2 Selection of Initial Target Enhanced Permissible Speed for Each Curve

The initial target enhanced permissible speed should be selected to meet operational aspirations. Usually, this will be the maximum attainable speed using the limiting service cant deficiency set out in section 10.1. In this case, the target speed should be calculated using the standard speed equation given in section 6.3:

\[ V_T = \sqrt{Rg \cdot \tan(E + D)} \]

Where:

\[ V_T = \text{target enhanced permissible speed (m/s)} \]

\[ R = \text{design curve radius (m)} \]

\[ E = \text{design cant (°)} \]

\[ D = \text{service cant deficiency set out in section 10.1 (°)} \]

\[ g = \text{acceleration due to gravity (9.81 m/s}^2) \]
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12 Tolerable Probability of Overturning

<table>
<thead>
<tr>
<th>Section</th>
<th>Factor</th>
<th>Value to be used</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1</td>
<td>Service cant deficiency</td>
<td>Maximum cant deficiency at permissible speed applicable to the curve and reference vehicle</td>
</tr>
<tr>
<td>10.2</td>
<td>Roll-over resistance of the train</td>
<td>Roll-over resistance of the reference vehicle</td>
</tr>
<tr>
<td>10.3.2</td>
<td>Loss of cant</td>
<td>To suit current (not proposed) maintenance systems</td>
</tr>
<tr>
<td>10.3.3</td>
<td>Reduction in radius</td>
<td>To suit current (not proposed) maintenance systems</td>
</tr>
<tr>
<td>10.4.2</td>
<td>Local wind speed</td>
<td>As for enhanced permissible speed (see Note 1)</td>
</tr>
<tr>
<td>10.4.3</td>
<td>Wind direction probability factor</td>
<td>As for enhanced permissible speed</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Section</th>
<th>Factor</th>
<th>Value to be used</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.5</td>
<td>Vehicle characteristics (determining the behaviour of vehicles under wind loading)</td>
<td>Characteristics of reference vehicle (see Note 2)</td>
</tr>
<tr>
<td>10.6</td>
<td>Probability distribution of overspeed</td>
<td>Probability distribution with no speed supervision system, given in Appendix G</td>
</tr>
<tr>
<td>10.7</td>
<td>Safety margin</td>
<td>As for enhanced permissible speed</td>
</tr>
</tbody>
</table>

Table 2: Recommendations on the values to be used in calculation of tolerable probability

Note 1
Local wind speed should exclude the effect of any wind alert system or strategy (section 10.4.4) and any wind barriers or fences (section 10.4.5) not in place during the majority of the reference vehicle’s history of running.

Note 2
To ensure comparability, characteristics of the reference vehicle should be determined in the same way as the characteristics of the tilting vehicles whose enhanced permissible speed is being calculated. The characteristics of both vehicles should be determined in accordance with GM/RT2142.

12.3 Comparative Method - New Routes
This document does not contain recommendations applicable to new routes, where a comparison with existing reference vehicles travelling at permissible speeds over the route being considered is not possible. However, in principle, the tolerable probability of overturning can be determined by comparison with an existing reference vehicle travelling at permissible or enhanced permissible speeds over a reference route passing though an area having similar characteristics to the new route under consideration.

12.4 Absolute Method - Tolerability Criteria
The ALARP framework is constructed around the risk to individuals. The specification of the tolerability criteria should therefore be performed with reference to an individual belonging to an at-risk group. A regular long distance commuter travelling on the tilting train for which the enhanced permissible speed is being calculated appropriately represents such an individual.

Railtrack’s Railway Safety Case (1998) has a short-term target, or benchmark, of $10^{-5}$/year for the risk of a fatality to a passenger. This benchmark has been selected to apply to the commuter. The value of $10^{-5}$/year is the limit on the risk to the commuter from all sources.

The risk to the commuter from overturning should be a suitably small proportion of the total risk, to allow for the other hazards present. A suitable proportion is of the order 1%. In this case the corresponding risk of fatality to the commuter due to overturning on curves over which trains travel at enhanced permissible speeds would be $10^{-7}$ per year.

It is possible, using the following equation, to derive a tolerable probability of overturning for a route section, $P_{tol}$:

$$R_{tgt} = P_{tot} \cdot N_{pj} \cdot P_{fat}$$

Re-arranging:

$$P_{tot} = \frac{R_{tgt}}{N_{pj} \cdot P_{fat}}$$

Where:
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\[ P_{\text{tol}} = \text{the tolerable probability of an overturning accident per route section (taken to be the average probability from the commuter's outbound and return journeys)} \]

\[ R_{\text{tgt}} = \text{target risk of fatality to commuter due to overturning} \ (10^{-7} \text{ per year based on 1\% of Railtrack's Railway Safety Case (1998) short term target)} \]

\[ N_{\text{pj}} = \text{the number of commuter journeys per year (typically, 250 return journeys per year, giving } N_{\text{pj}} = 500) \]

\[ P_{\text{tot}} = \text{the probability that the commuter will be killed if in an overturning accident} \ (\text{Railway Safety's Safety Risk Model gives an estimated average figure of 5\% for derailments)} \]

For values of \( R_{\text{tgt}}, N_{\text{pj}}, \) and \( P_{\text{tot}} \) equal to \( 10^{-7} \) per year, 500, and 5\% respectively, the value of \( P_{\text{tol}} \) is \( 4 \times 10^{-9} \) per section.

If the length of the route section is \( L_{\text{rs}} \) and the number of curves per mile over which trains travel at enhanced permissible speeds within this section is \( \rho_{\text{rs}} \), it follows that the average tolerable probability of overturning per curve is:

\[
P_{\text{tol(C)}} = \frac{P_{\text{tol}}}{(L_{\text{rs}} \cdot \rho_{\text{rs}})}
\]

For values of \( P_{\text{tol}}, L_{\text{rs}}, \) and \( \rho_{\text{rs}} \) equal to \( 4 \times 10^{-9} \) per section, 100 miles, and 1 per mile respectively, the average tolerable probability per curve is \( 4 \times 10^{-11} \).

It is not essential to achieve this value of overturning per curve, as long as the aggregate probability over all curves within the section is less than or equal to \( P_{\text{tol}} \). However, as noted in section 11.1, to prevent any single curve from dominating the risk profile, the probability per curve should be limited to a suitable fraction \( F_{\text{curve}} \) of the total. For values of \( F_{\text{curve}} \) equal to 25\%, and equal to \( 4 \times 10^{-9} \) per commuter section, the maximum tolerable probability of overturning per curve is \( 10^{-9} \).

In summary, using numerical example above, the tolerability criteria would be:

a) tolerable probability of overturning per 100 mile route section \( (P_{\text{tol}}) = 4 \times 10^{-9} \)

b) average tolerable probability of overturning per curve \( (P_{\text{tol(C)}}) = 4 \times 10^{-11} \)

c) maximum tolerable probability per curve = \( 10^{-9} \)

The figures quoted in this section are illustrative. Particular values should be calculated for each route section.

12.5 Demonstrating ALARP
Meeting the tolerability criteria specified above 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.

13 Enhanced Permissible Speed to be Displayed

13.1 Requirements of GE/RT8012
As noted in section 4.2 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
Calculation of Enhanced Permissible Speeds for Tilting Trains

to operate on the route can safely traverse the curve without an unacceptable risk of overturning.

13.2 Calculation of Enhanced Permissible Speed to be Displayed
Where trains with different characteristics travel over the same section of route, they may have differing enhanced permissible speeds. The principal characteristic that will cause trains to have differing enhanced permissible speeds is likely to be their differing maximum design service cant deficiencies (see section 10.1).

The maximum design service cant deficiency is dependent on the tilt capability of the train. Should this cant deficiency be exceeded, the consequence will only be increased passenger discomfort, provided the train’s speed is such that it can still safely traverse the curve without an unacceptable risk of overturning.

Therefore the speed to be displayed on the enhanced permissible speed indicator may be determined as follows:

Calculate a ‘display speed’ for each train using the methodology set out in section 11, but using the appropriate limiting design value for cant deficiency set out in GC/RT5021, rather than the maximum design service cant deficiency, when selecting the initial target speed. If the limiting design value for cant deficiency set out in GC/RT5021 is the required service cant deficiency, the value of the display speed = enhanced permissible speed.

The speed to be displayed is the lowest display speed of all the tilting trains using the section of route under consideration.

It should be noted that if trains have significantly differing resistances to overturning or aerodynamic characteristics, the enhanced permissible speed to be displayed would be determined by the train with the poorest characteristics. This may penalise the performance of the trains with better characteristics.

14 Enhanced Permissible Speeds Through S&C

GC/RT5021 section 5.2.3 (Part)
Enhanced permissible speeds shall not be permitted on the turnout route of S&C.

Enhanced permissible speeds are permitted on the through route of S&C. However, special conditions apply to the use of higher than normal limiting cant deficiencies on the through route of S&C. These are set out in section 5.3.10 of GC/RT5021 and are quoted in section 9.3 of this document.

15 Procedure for Calculating Enhanced Permissible Speeds

GC/RT5021 section 5.2.3 (Part)
The Infrastructure Controller shall have a procedure for calculating enhanced permissible speeds meeting the requirements of this section. The procedure shall also set out the method of gaining technical approval for the calculated enhanced permissible speed.

15.1 Basis of Procedure for Calculating Enhanced Permissible Speeds
The methodology set out in this document should form the core of the procedure for calculating enhanced permissible speeds required by GC/RT5021.
Calculation of Enhanced Permissible Speeds for Tilting Trains

The calculations required to determine enhanced permissible speeds are complex. Appropriate software should therefore be developed and validated which automates the calculation processes. The software should allow the data required for the calculations to be entered in a standard format. It should also provide output that documents the calculated enhanced permissible speed, the inputs used and important intermediate calculated parameters.

15.2 Method of Gaining Technical Approval
The infrastructure controller should in addition set out the method of gaining technical approval for the calculated enhanced permissible speed. Technical approval should require:

a) validation of any software used to calculate the enhanced permissible speed
b) verification of site data
c) verification of track maintenance systems
d) documentation of any assumptions made
e) documentation of the tolerable probability of overturning used, including the basis on which it has been derived
f) a check on the correctness of the calculations made.

15.3 Other Factors to be Considered
It should be noted that there are factors other than those set out in this document that should be considered when determining the enhanced permissible speed. These are outlined in GK/RT0007 and set out in greater detail in other Railway Group Standards. They include:

a) the condition of the track
b) the condition and load carrying capacity of structures
c) the safety of people on platforms
d) safety at level crossings
e) safety of people working on or near the line
f) availability of sufficient access to the infrastructure to permit it to be properly inspected and maintained
g) the suitability of the signalling system
h) the suitability of the electrification system
i) maintenance of clearances.

16 Records of Calculation of Enhanced Permissible Speeds

GC/RT5021 section 5.2.3 (Part)
Detailed records of the calculation of the enhanced permissible speeds shall be retained with the design records required by section 5.8.
Calculation of Enhanced Permissible Speeds for Tilting Trains

Section 5.8.1 of GC/RT5021 is quoted below:

GC/RT5021 section 5.8.1
Horizontal alignment design records
Records of all horizontal curves on running lines in track categories 1A, 1, 2, 3, and 4 shall be maintained. Records of horizontal curves in track categories 5 and 6 where the radius is less than 200m shall also be maintained. Details to be recorded shall include:

- location of all tangent points;
- radius;
- cant;
- transition lengths;
- cant gradients;
- permissible speed;
- enhanced permissible speeds (where appropriate);
- the maintenance tolerances on cant and radius used to calculate enhanced permissible speeds (where appropriate).

Section 15 of this document sets out recommended requirements for technical approval for the calculated enhanced permissible speed. The details of the technical approval listed in section 15 should also be retained with the design records.

The requirements for the management of safety related records of elements of the infrastructure are set out in GI/RT7001.

17 Review of Enhanced Permissible Speeds

GC/RT5021 section 5.2.3 (Part)
The value of the factors used in the calculation of enhanced permissible speeds shall be reviewed at five yearly intervals to determine their continuing validity.

The value of the factors used in the calculation of enhanced permissible speeds should also be reviewed if any reason to doubt their continuing validity arises within the five year review interval.
Appendix A
Diagrams Illustrating Issues Discussed in Section 5

The following diagrams illustrate 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.

They should be read in conjunction with section 5. The diagrams are purely illustrative and should not be used quantitatively.
Calculation of Enhanced Permissible Speeds for Tilting Trains

Figure A1: Permissible speed
Calculation of Enhanced Permissible Speeds for Tilting Trains

Figure A2: Enhanced permissible speed
Control of Radius Using Fixed Datum Points

If radius control using measurements to fixed datum points is introduced, it is necessary to determine the degree of radius reduction that can occur for a given level of measured lateral misalignment.

Any misalignment can be expressed as a sum of sine waves. The radius reduction depends on the wavelength of the misalignment. It can be shown that the minimum wavelength of interest is 120m.

To control misalignments of this wavelength effectively, the minimum datum point spacing should be no more than 60m. In practice, a minimum datum spacing of no more than 30m should be adopted.

The maximum expected radius reduction can be calculated for a given maximum allowable deviation from the design lateral offset between track and datum point by:

\[ R_R = \frac{RS_D^2}{S_D^2 + 2.818Ry} \]

Where:
\( R_R \) = reduced radius (m)
\( R \) = design curve radius (m)
\( S_D \) = datum point spacing (m)
\( y \) = deviation from the design lateral offset (m)
Appendix C

Reference Wind Speed

The reference wind speed, $V_{\text{REF}}$, depends on the location of the site.

A map of the UK showing the extreme mean hourly wind speeds in m/s with a 50 year return period can be found in ESDU Engineering Data Item 82026. It is reproduced here as Figure C1.

The map assumes the following reference conditions:

a) wind speed measured 10m above a site datum with a height, $H = 0$ m above sea level
   (see section D3 in Appendix D for details of how this is adjusted for the location of the particular curve under consideration)

b) uniformly open country terrain with a roughness parameter, $z_0 = 0.03$ m
   (see section D5 in Appendix D for details of how this is adjusted for the characteristics of the terrain for the particular curve under consideration).

The extreme mean hourly wind speed shown on the map at the location of the particular curve under consideration is used as the reference wind speed, $V_{\text{REF}}$. 

---

Superseded by RIS-7704-INS Iss 1 with effect from 03/03/2018
Calculation of Enhanced Permissible Speeds for Tilting Trains

Figure C1: Extreme mean hourly wind speeds in m/s with a 50 year return period
Calculation of Enhanced Permissible Speeds for Tilting Trains

Appendix D
Local Wind Speed

D1 Data Used to Develop Wind Speed Model

The wind speed model used here has been developed using the ESDU Engineering Data Items 82026, 83045 and 91043.

D2 Local 3 Second Gust Wind Speed

The local 3 second gust wind speed depends on several factors. It can be found by multiplying the reference wind speed by several speed-up factors in the following way:

\[ V_{WL} = V_{REF} \cdot K_A \cdot K_\theta \cdot K_S \cdot K_Z \cdot K_L \cdot K_\tau \cdot K_F \]

Where:

- \( V_{REF} \) = reference wind speed (once in 50 year hourly mean) – regional reference wind speed, defined at 10m above level ground at sea level (see Appendix C)
- \( K_A \) = altitude factor – allows for higher wind speeds at higher altitudes
- \( K_\theta \) = wind direction factor – allows for higher extreme wind speeds from particular directions
- \( K_S \) = ground surface roughness factor – corrects for effects of surface vegetation etc
- \( K_Z \) = factor depending on the height of the track above surrounding ground level – allows for higher wind speeds further from the ground surface
- \( K_L \) = topographical factor – allows for wind acceleration over embankments and escarpments or reduction in cuttings
- \( K_\tau \) = time averaging factor – adjusts the averaging time from 1 hour to a 3 second gust. This factor makes allowances for changes in turbulence and varies with ground roughness
- \( K_F \) = shelter factor for fences – allows for acceleration or deceleration behind fences

Methods of determining each speed-up factor follow in this Appendix. The following input parameters have been used:

- \( z_0 \) = roughness parameter (m)
- \( H \) = height of local ground level above sea level (m)
- \( H_V \) = height of viaduct above ground level (m)
- \( H_E \) = height of embankment above ground level (m)
- \( H_F \) = height of fence above ground level (m)
- \( \theta \) = wind direction, measured from North (°)

All of these parameters are variable and should be input for the site under consideration.

D3 Altitude Factor, \( K_A \)

This factor allows for the general increase in the speed of the wind with the altitude above sea level. The altitude factor is given by:

\[ K_A = \text{function of altitude} \]
Calculation of Enhanced Permissible Speeds for Tilting Trains

\[ K_A = 1 + 0.001H \]

**D4 Wind Direction Factor, \( K_\theta \)**

The reference wind speed map gives the mean 50 year wind speed irrespective of direction. To obtain the same risk for individual 30° sectors, the factors to be applied are as indicated in Table D1.

<table>
<thead>
<tr>
<th>Relevant wind direction, ( \theta )</th>
<th>( K_\theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clockwise</td>
</tr>
<tr>
<td>0</td>
<td>0.82</td>
</tr>
<tr>
<td>30</td>
<td>0.78</td>
</tr>
<tr>
<td>60</td>
<td>0.73</td>
</tr>
<tr>
<td>90</td>
<td>0.74</td>
</tr>
<tr>
<td>120</td>
<td>0.74</td>
</tr>
<tr>
<td>150</td>
<td>0.80</td>
</tr>
<tr>
<td>180</td>
<td>0.85</td>
</tr>
<tr>
<td>210</td>
<td>0.93</td>
</tr>
<tr>
<td>240</td>
<td>1.00</td>
</tr>
<tr>
<td>270</td>
<td>1.00</td>
</tr>
<tr>
<td>300</td>
<td>0.99</td>
</tr>
<tr>
<td>330</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Table D1: Wind direction factor, \( K_\theta \)

The relevant wind direction is that from which the wind would blow at right angles to the mid-point of the curve. This is illustrated in Figure D1, from which it can be seen, by comparing with Appendix E, that the relevant wind direction will coincide with the curve direction.

It should be noted that, since the worst wind direction for overturning may not be at right angles to the track, the relevant wind direction is actually a 60° sector. For a clockwise train movement, this covers the sectors with mid-points \( \theta \) and \( \theta - 30° \), whereas for an anti-clockwise movement, it covers the \( \theta \) and \( \theta + 30° \) sectors. The values given in Table D1 take this into account, and represent the maximum \( K_\theta \) factors for the two relevant sectors in each case.
Calculation of Enhanced Permissible Speeds for Tilting Trains

Figure D1: Relevant wind direction

Schematic defining the bearing, \( \theta \), of the 'relevant wind direction' and explaining the meaning of 'clockwise curve' and 'anti-clockwise curve'. The relevant wind direction is given by the angle (\( \theta \)) from North, measured clockwise, to the vector joining the mid-point of the curve to the compass point from which the wind originates. In the scenario depicted in Figure D1, the relevant wind direction is shown as approximately 225° for the purpose of illustration.

D5 Ground Surface Roughness Factor, \( K_S \)

This factor is dependent on the ground roughness at the site in question and also on the reference ground roughness, which is 0.03m for the map reproduced in Appendix C. The factor is then:

\[
K_S = 2.59 \frac{\ln(10/z_0)}{\ln(10^5/z_0)}
\]
Calculation of Enhanced Permissible Speeds for Tilting Trains

The roughness length, \( z_0 \), is obtained by matching the terrain description in Table D2 with the terrain in the first 200m upwind of the track, in the direction as defined in section D4 above.

<table>
<thead>
<tr>
<th>Category</th>
<th>Terrain Description</th>
<th>Approx. value of ( z_0 ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Flat areas with short grass and no obstructions; Runway area of airports; Rough sea in annual extreme storms</td>
<td>0.003</td>
</tr>
<tr>
<td>1</td>
<td>Fairly level grass plains with isolated trees; Very rough sea in extreme storms (once in 50yr extreme)</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>Open level country with few trees and hedges and isolated buildings; typical farmland</td>
<td>0.03</td>
</tr>
<tr>
<td>3</td>
<td>Outskirts of small towns; Villages; Countryside with many hedges, some trees and some buildings. Also small towns; suburbs and woods.</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table D2: Terrain roughness length, \( z_0 \), for each category.

If the site is assessed as Category 2 or 3, the upwind terrain should be reviewed over a distance of 200 to 1000m from the track. The category should be upgraded if necessary as indicated in Table D3. In applying this table, judgement should be used to ascertain an average roughness over the distances indicated.

<table>
<thead>
<tr>
<th>Site Category</th>
<th>Average Category: 200-1000m</th>
<th>Revised Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Table D3: Review of surface roughness categories, where a change in the surface roughness occurs within 1km of the track.

If there is any doubt, it is advisable to use the next lowest category to ensure that the results are conservative.

For the standard roughness categories, the \( K_S \) parameters to be used are as presented in Table D4.

<table>
<thead>
<tr>
<th>Category</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( z_0 )</td>
<td>0.003</td>
<td>0.01</td>
<td>0.03</td>
<td>0.1</td>
</tr>
<tr>
<td>( K_S )</td>
<td>1.21</td>
<td>1.11</td>
<td>1.00</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Table D4: Standard \( K_S \) factors.

### D6 Height Factor, \( K_z \)

The wind speed increases as the height above the ground surface increases. This increase of wind speed follows a boundary layer profile, and is given by the factor \( K_z \). It should be noted that, where a viaduct is involved, the height above ground level should include the height of the viaduct. Using a reference height of 3m gives the height factor as:

\[
K_z = \frac{\ln((H_v + 3)/z_0)}{\ln(10/z_0)}
\]

Where \( H_v \) is the height of the viaduct and \( z_0 \) is obtained from the terrain category table (Table D2).
Calculation of Enhanced Permissible Speeds for Tilting Trains

If there is no viaduct, then $H_V = 0$.

For the standard roughness categories, with no viaduct ($H_V = 0$), $K_Z$ takes the values shown in Table D5.

| Category | 0  | 1  | 2  | 3  |
|----------|----|--|--|--|--|
| $z_0$    | 0.003 | 0.01 | 0.03 | 0.1 |
| $K_Z$    | 0.85 | 0.83 | 0.79 | 0.74 |

Table D5: Standard $K_Z$ factors.

D7 Topographical Factor, $K_L$

The topographical factor is applied if the track is on an embankment, escarpment, or on the side of a hill. If the track is in a cutting, there may be some shelter ($K_L < 1$), and this is also taken into account.

Assuming that the horizontal distance along the top of the embankment from its leading edge to the edge of the train is 1.5m and the height above ground at which the wind is assumed to act is 3m, then the topographical factors for each of these cases can be calculated, and are summarised in Table D6. This table gives factors for embankments and cuttings, which are symmetrical, and for escarpments, for which the ground level remains at its elevated level beyond the track for a distance of at least $5H_E$ m.

<table>
<thead>
<tr>
<th>$H_E$</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_L$ (embankment)</td>
<td>1.22</td>
<td>1.33</td>
<td>1.42</td>
<td>1.49</td>
<td>1.55</td>
</tr>
<tr>
<td>$K_L$ (escarpment)</td>
<td>1.20</td>
<td>1.27</td>
<td>1.36</td>
<td>1.41</td>
<td>1.43</td>
</tr>
<tr>
<td>$K_{LC}$ (cutting)</td>
<td>0.82</td>
<td>0.72</td>
<td>0.66</td>
<td>0.61</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Table D6: The topographical factor, $K_L$, varying with the height of the embankment, escarpment or cutting.

If the track is in the lee of a hill, there is likely to be some shelter. However, it is recommended that a $K_L$ factor of 1 should be used unless the track is close to the top of the slope. In this case, use of the embankment factors given in Table D6 would be conservative. If greater accuracy is required, $K_L$ should be re-calculated on a case-by-case basis.

D8 Time Averaging Factor, $K_T$

The gust speed is affected by the atmospheric turbulence. The equation for the time averaging factor for a 3 second gust can be simplified to:

$$K_T = 1 + \frac{4.84 + 0.81 \ln((H_V + 3)/z_0)}{(2.63 - 0.11 \ln(z_0))\ln((H_V + 3)/z_0)}$$

where $H_V$ is the height of the viaduct ($H_V = 0$ when there is no viaduct), and $z_0$ is obtained from the terrain category table.

For the standard terrain categories, with no viaduct, the time averaging factors are as indicated in Table D7.

| Category | 0  | 1  | 2  | 3  |
|----------|----|--|--|--|--|
| $z_0$    | 0.003 | 0.01 | 0.03 | 0.1 |
| $K_T$    | 1.45 | 1.53 | 1.61 | 1.77 |

Table D7: Standard $K_T$ factors with no viaduct.
Calculation of Enhanced Permissible Speeds for Tilting Trains

**D9  Fence factor, \(K_F\)**

**D9.1 Wind Barriers or Fences**

In areas where there is a likelihood of very strong winds, a fence may be used to reduce the effect of the wind. The optimum for this particular application is likely to be a 4m fence located between 8 and 12m from the track, in which case the factors given in Table D8 should be used to multiply the reference wind speed.

<table>
<thead>
<tr>
<th>Porosity, (\Phi)</th>
<th>0</th>
<th>0.25</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(K_F)</td>
<td>0.45</td>
<td>0.55</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Table D8: Fence shelter factors for porosities, \(\Phi = 0, 0.25\) or 0.5, at \(H=4\) m, \(x = 8 - 12\) m

Where the fence parameters differ from the assumptions given above, then the ESDU data item 97031 or ESDUpac E9731 should be used to calculate the appropriate fence shelter effects.

It should also be noted that the fence methodology described is not strictly applicable if the track is on an embankment. If it is deemed necessary to consider shelter fences at embankment sites, more detailed assessment, for example expert application of the ESDU data items, should be undertaken.

**D9.2 Noise Barriers or Fences**

An alternative use of fences is to attenuate the noise which emanates from the wheel/track interface. Such fences are solid (porosity \(\Phi = 0\)) and are typically either 1, 2 or 3m high at specified distances from the track. The fence factors that should be applied in this case are given in Table D9.

<table>
<thead>
<tr>
<th>Height ARL (m)</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from the train (m)</td>
<td>0.8</td>
<td>2.35</td>
<td>2.35</td>
</tr>
<tr>
<td>(K_F)</td>
<td>1.2</td>
<td>1.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table D9: Typical shelter factors, \(K_F\) for noise fences

It should also be noted that the fence methodology described is not strictly applicable if the track is on an embankment. However, it is considered appropriate and approximately correct to use both the fence factor and the embankment factor for solid noise reduction fences.

**Appendix E**

**Wind Direction Probability Factor, \(P_D\)**

<table>
<thead>
<tr>
<th>Curve Direction, (\theta) (degrees)</th>
<th>Proportion of Wind</th>
<th>Proportion of Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clockwise</td>
<td>Anti-Clockwise</td>
</tr>
<tr>
<td>0</td>
<td>0.050</td>
<td>0.023</td>
</tr>
<tr>
<td>30</td>
<td>0.023</td>
<td>0.013</td>
</tr>
<tr>
<td>60</td>
<td>0.013</td>
<td>0.015</td>
</tr>
<tr>
<td>90</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>120</td>
<td>0.015</td>
<td>0.030</td>
</tr>
<tr>
<td>150</td>
<td>0.030</td>
<td>0.076</td>
</tr>
<tr>
<td>180</td>
<td>0.076</td>
<td>0.200</td>
</tr>
<tr>
<td>210</td>
<td>0.200</td>
<td>0.452</td>
</tr>
<tr>
<td>240</td>
<td>0.452</td>
<td>0.582</td>
</tr>
<tr>
<td>270</td>
<td>0.582</td>
<td>0.394</td>
</tr>
<tr>
<td>300</td>
<td>0.394</td>
<td>0.150</td>
</tr>
</tbody>
</table>
Calculation of Enhanced Permissible Speeds for Tilting Trains

<table>
<thead>
<tr>
<th>Wind direction probability factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>330 0.150 0.050</td>
</tr>
</tbody>
</table>

The curve direction is illustrated in Figure E1.

It should be noted that, since the worst wind direction for overturning may not be at right angles to the track, the curve direction is actually a 60° sector. For a clockwise train movement, this covers the sectors with mid-points \( \theta \) and \( \theta - 30° \), whereas for an anti-clockwise movement, it covers the \( \theta \) and \( \theta + 30° \) sectors. The values given in Table E1 take this into account.

**Figure E1: Curve direction**

Schematic defining the bearing, \( \theta \), of the curve direction and explaining the meaning of 'clockwise curve' and 'anti-clockwise curve'. The curve direction is given by the angle \( \theta \), measured clockwise from North, to the vector joining the mid-point of the curve to the curve centre. The direction of the curve illustrated is approximately 225°.
Appendix F

Aerodynamic Cant Deficiency Coefficient

The aerodynamic cant deficiency coefficient, $f_2$, for a vehicle can be calculated from:

$$f_2 = \frac{0.5dAhC_{R(50)}}{Mgh_M}$$

Where:

$d = \text{density of air (1.225 kg/m}^3\text{)}$

$A = \text{total projected side area of vehicle or side area used to determine its aerodynamic rolling moment coefficient about the lee rail from tests}$

$h = \text{vehicle mean roof height above axle centreline or height used to determine its aerodynamic rolling moment coefficient about the lee rail from tests}$

$C_{R(50)} = \text{vehicle aerodynamic rolling moment coefficient about the lee rail at 50° yaw, taking account of the position of the vehicle in the train}$

$M = \text{vehicle mass}$

$g = \text{acceleration due to gravity (9.81 m/s}^2\text{)}$

$h_M = \text{height of vehicle centre of mass above rail level}$

The vehicle having the highest coefficient is the critical vehicle (see section 10.5).
Appendix G

Overspeed Probability Distribution With No Speed Supervision System

The table below gives a probability distribution of overspeed (in 5km/h steps) for the case where there is no speed supervision system (as permitted for trains travelling at permissible speeds). This distribution is required when determining the tolerable likelihood of a train overturning when travelling at an enhanced permissible speed (see section 12).

<table>
<thead>
<tr>
<th>Condition, n</th>
<th>Overspeed (m/s)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≤ 0</td>
<td>0.900</td>
</tr>
<tr>
<td>2</td>
<td>0 - 1.389</td>
<td>0.082</td>
</tr>
<tr>
<td>3</td>
<td>1.389 - 2.778</td>
<td>0.015</td>
</tr>
<tr>
<td>4</td>
<td>2.778 - 4.167</td>
<td>0.003</td>
</tr>
<tr>
<td>5</td>
<td>4.167 - 5.556</td>
<td>4.6E-04</td>
</tr>
<tr>
<td>6</td>
<td>5.556 - 6.944</td>
<td>8.2E-05</td>
</tr>
<tr>
<td>7</td>
<td>6.944 - 8.333</td>
<td>1.5E-05</td>
</tr>
<tr>
<td>8</td>
<td>8.333 - 9.722</td>
<td>2.6E-06</td>
</tr>
<tr>
<td>9</td>
<td>9.722 - 11.111</td>
<td>4.6E-07</td>
</tr>
<tr>
<td>10</td>
<td>11.111 - 12.500</td>
<td>8.2E-08</td>
</tr>
<tr>
<td>11</td>
<td>12.500 - 13.889</td>
<td>1.5E-08</td>
</tr>
</tbody>
</table>

Table G1: Probability distribution of overspeed where there is no speed supervision system

The third column gives the probability that the overspeed will be in the range indicated. For the purposes of calculation, it should be assumed conservatively that the probability relates to the upper speed in the range.

The table is based on the best available data at the time of writing. The table should be reviewed and, if necessary, revised if other appropriate measured data becomes available.
Appendix H
Summary of Recommended Method of Calculating Enhanced Permissible Speeds

The following flow chart summarises the recommended method of calculating enhanced permissible speeds set out in section 11.

1. Identify route section, as defined in section 3
2. Curve number within route section
   - \( n = 1 \)
3. Select target enhanced permissible speed for curve
4. Calculate probability of overturning for a single train pass through a curve
   (Appendix J)
5. Compare with predetermined tolerable overturning probability for the route section
   (Section 12)
6. If total probability of overturning > tolerable probability of overturning
   - \( n \leq N \)
   - Apply risk reduction measures to reduce probability of overturning
   - \( n > N \)
   - Calculate total probability of overturning for the route section
   - Compare with predetermined tolerable overturning probability for the route section
   (Section 12)
7. Target enhanced permissible speeds can be adopted

Figure H1: Flowchart summarising recommended method of calculating enhanced permissible speeds
Appendix J
Calculating the Probability of Overturning for a Single Train Pass Through a Curve

J1 Outline of Calculation Methodology

The recommended method of calculating the probability of overturning for a single train pass through a curve is summarised in the flowchart below.

The inputs to the calculation shown on the flowchart include references back to the relevant sub-sections in section 10 of this document, which give details about the inputs or sources for the inputs.

The inputs for the roll-over resistance and the aerodynamic characteristics should relate to the critical vehicle. If it is not known which vehicle is critical, calculation steps 3 and 4 should be repeated for each candidate vehicle. The critical vehicle will be the vehicle having the lowest overturning wind speed.

The calculation steps are described in detail in sections J2 to J8. Again, references back to these sections are shown on the flowchart.
Calculation of Enhanced Permissible Speeds for Tilting Trains

**Step 1:** Calculate train speed for overspeed condition considered (Section J2)

**Step 2:** Calculate cant deficiency from curving (Section J3)

**Step 3:** Calculate remaining allowable wind induced cant deficiency (Section J4)

**Step 4:** Calculate overturning wind speed (Section J5)

**Step 5:** Calculate passage time of train through the curve (section J6)

**Step 6:** Calculate probability of reaching critical overturning wind speed (Section J7)

**Step 7:** Calculate total probability of overturning (Section J8)

**Inputs:**
- Overspeed conditions (Section 10.6)
- Design cant
- Design radius
- Loss of cant (Section 10.3.2)
- Reduction in radius (Section 10.3.3)
- Roll-over resistance of critical vehicle
- Safety margin (Section 10.7)
- Aerodynamic characteristics of critical vehicle (Section 10.5)
- Length of curve
- Local wind speed (Section 10.4.2 and Appendix D)
- Probabilities of overspeed conditions (Section 10.6)
- Wind direction probability (Section 10.4.3)

**Figure J1:** Flowchart summarising recommended method of calculating the probability of overturning for a single train pass through a curve.
Calculation of Enhanced Permissible Speeds for Tilting Trains

**J2 Calculation step 1: Calculate train speed for overspeed condition considered**

For the first cycle of the calculation process, the train speed is the target enhanced permissible speed selected for the curve under consideration (see section 11). In this case, the overspeed condition is zero overspeed. In subsequent cycles, the speed is increased by the value of overspeed for the condition (n) considered (see section 10.6):

\[
V_n = V_T + s_n
\]

Where

- \( V_n \) = speed at overspeed condition n (m/s)
- \( V_T \) = target enhanced permissible speed (m/s)
- \( s_n \) = value of overspeed for condition n (m/s) \([s_n = 0 \text{ when } n = 1]\)

**J3 Calculation Step 2: Calculate Cant Deficiency From Curving**

For each overspeed condition, n, calculate the cant deficiency from curving (using the standard speed equation given in section 6.3), making allowance for loss of cant (see section 10.3.2) and reduction in radius (see section 10.3.3):

\[
D_n = \tan^{-1} \left( \frac{V_n^2}{(R - r)g} \right) - (E - e)
\]

Where:

- \( D_n \) = cant deficiency at overspeed condition n (°)
- \( V_n \) = speed at overspeed condition n (m/s)
- \( R \) = design curve radius (m)
- \( r \) = reduction in radius (m)
- \( E \) = design cant (°)
- \( e \) = loss of cant (°)
- \( g \) = acceleration due to gravity (9.81 m/s²)

**J4 Calculation Step 3: Calculate Remaining Allowable Wind Induced Cant Deficiency**

For each overspeed condition, n, add the safety margin set out in section 10.7 (2°) to the cant deficiency at overspeed condition n calculated in step 2.

The cant deficiency plus safety margin is then subtracted from the roll-over resistance of the critical vehicle of the train under consideration (see section 10.2) to give the ‘allowable wind induced cant deficiency’, \( D_{WA} \) at overspeed condition n. The allowable wind induced cant deficiency is the remaining roll-over resistance available to resist the effects of wind.

\[
D_{WA} = D_{RR} - (D_n + D_{SM})
\]
Calculation of Enhanced Permissible Speeds for Tilting Trains

Where:

\[ D_{WA} = \text{allowable wind induced cant deficiency at overspeed condition } n \ (°) \]

\[ D_{RR} = \text{Roll-over resistance of the train } (°) \]

\[ D_n = \text{cant deficiency at overspeed condition } n, \text{ calculated in step 2 } (°) \]

\[ D_{SM} = \text{safety margin } (°) \]

**J5 Calculation Step 4: Calculate Overturning Wind Speed**

**J5.1 Equations to be Solved**

Determine the characteristics of the critical vehicle as set out in section 10.5 and Appendix F.

For each overspeed condition, \( n \), solve the following equations for \( V_{WO} \) for the critical vehicle:

\[
D_{WA} = \tan^{-1}\left(f_2 \frac{C_R(\psi)}{C_R(50)} V_R^2 \right) \tag{1}
\]

\[
V_R^2 = V_n^2 + V_{WO}^2 + 0.68V_n V_{WO} \tag{2}
\]

Note that this is an approximation based upon a wind angle (\( \phi \)) of 70° to the track, and can be generalised for any value of \( \phi \) (by replacing 0.68 by 2 \( \cos \phi \)). It can be shown to be conservative for the case where the rolling moment coefficient, \( C_R(\psi) \), varies linearly with \( \psi \). However, if the variation of \( C_R(\psi) \) is concave (i.e. \( \psi^n \), where \( n > 1 \)), then the method could become very conservative. In such cases, the critical value of \( \phi \) will be closer to 90°, and the appropriate concave data should be used for \( C_R(\psi) \).

\[
C_R(\psi) = C_R(50) \frac{\psi}{50} \quad \text{if } \psi < 50°
\]

\[
C_R(\psi) = C_R(50) \quad \text{if } \psi \geq 50° \tag{3}
\]

This formulation is based upon the fitting of typical wind tunnel data to an idealised 'ramp' equation (that is, \( C_R(\psi) \) varies linearly with \( \psi \)). If actual data or an improved formulation are available, then these should be used in preference.

\[
\psi = \sin^{-1}\left(0.94 \frac{V_{WO}}{V_R} \right) \tag{4}
\]

If the equation for \( V_R^2 \) is generalised for any angle then it is necessary to account for this in the equations for \( C_R(\psi) \) and \( \psi \), by replacing 0.94 by \( \sin \phi \) in the equation for \( \psi \). It would then be possible to obtain greater accuracy by integrating the wind effects over all angles.

Where:

\[ D_{WA} = \text{allowable wind induced cant deficiency calculated in step 4 } (°) \]

\[ f_2 = \text{aerodynamic cant deficiency coefficient for the critical vehicle, calculated as set outs in Appendix F.} \]

\[ C_R(\psi) = \text{vehicle aerodynamic rolling moment coefficient about the lee rail at } \psi^° \text{ yaw, taking account of the position of the vehicle in the train } (°) \]
Calculation of Enhanced Permissible Speeds for Tilting Trains

\[ CR(50) = \text{vehicle aerodynamic rolling moment coefficient about the lee rail at 50° yaw, taking account of the position of the vehicle in the train} \]

\[ VR = \text{resultant wind speed relative to the train (m/s)} \]

\[ VWO = \text{overturning wind speed (m/s)} \]

\[ V_n = \text{train speed at overspeed condition n calculated in step 1 (m/s)} \]

\[ \psi = \text{angle of resultant wind speed relative to the train (°)} \]

\[ \phi = \text{wind angle relative to the track (°)} \]

**Figure J2: Relationship between VWO, VR, Vn, \( \psi \) and \( \phi \)**

An iterative procedure is required to obtain a solution to this set of equations. Their solution is non-trivial, and convergence could be difficult if their formulation is not optimised. A suggested method of solution is given in section J5.2.

**J5.2 Method of solution for equations given in section J5.1**

Section J5.1 requires iteration for the solution of four equations, using \( D_{WA} \) as input in order to calculate the value of \( VWO \). Note that the two lines of the equation \( CR(\psi) = \ldots \) (equation (3)) are considered to be one equation.

These can be re-cast to give the following equations:

\[
\frac{CR(\psi)}{CR(50)} = \frac{\tan(D_{WA})}{f_2 V_R^2} \tag{5}
\]

\[
V_R^2 = V_n^2 + V_{WO}^2 + 0.68V_nV_{WO} \tag{6}
\]

\[
\psi = 50 \left( \frac{CR(\psi)}{CR(50)} \right) \]

\[
\psi = 50 \quad \text{if} \quad CR(\psi) \geq CR(50) \tag{7}
\]

\[
V_{WO} = \frac{V_R}{0.94} \sin(\psi) \tag{8}
\]

Solution of such a set of coupled equations is non-trivial, and convergence is not guaranteed. One possible method of solution is suggested below.

It should be noted that this set of equations is derived using the assumptions noted in section J5.1 regarding the linearity of the rolling moment coefficient, and the consequent use of a worst case yaw angle (\( \phi \)) of 70°. Any divergence from these assumptions should be considered carefully before adopting the suggested method of solution.

(a) Guess an initial value of \( V_{WO} \) (maybe use \( V_{WL} \))
Calculation of Enhanced Permissible Speeds for Tilting Trains

(b) Calculate $V_R$ (equation (6))

(c) Calculate $C_n(\psi) / C_n(50)$ (equation (5))

(d) Calculate $\psi$ (equation (7))

(e) Calculate $V_{WO}$ (equation (8))

Then compare with the previous value of $V_{WO}$, and repeat (b) - (e) until convergence is achieved.

It should be noted that the method should be modified if $\psi > 50^\circ$. In this case, $C_n(\psi) = C_n(50)$, and $V_R$ is calculated from equation (5)

$$V_R^2 = \frac{\tan(D_{WA})}{f_2}$$

Equation (6) can then be solved for $V_{WO}$:

$$V_{WO} = \sqrt{\left(V_R^2 - 0.8844V_n^2\right) - 0.34V_n}$$

No iteration is required in this case, but equation (4) should be checked to ensure that $\psi \geq 50$.

**J6 Calculation Step 5:**
Calculate Passage Time of Train Within the Curve

For each train overspeed condition, $n$, calculate the passage time of the train through the curve:

$$T_n = L/V_n$$

Where:

- $T_n =$ passage time of train at overspeed condition $n$ (s)
- $L =$ length of curve (m)
- $V_n =$ train speed at overspeed condition $n$ calculated in step 1 (m/s)

**J7 Calculation Step 6:**
Calculate Probability of Reaching Critical Overturning Wind Speed

Calculate the local wind speed, $V_{WL}$ as set out in section 10.4 and Appendices C and D.

For each train overspeed condition, $n$, calculate the probability that a critical overturning gust will occur (from any wind direction) during the passage time of a train:
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\[ P_{Cn} = \exp \left( \ln(T_n) - 21.2 \right) \frac{V_{WO}}{V_{WL}} \]

Where:

- \( P_{Cn} \) = probability of occurrence of the critical overturning gust during the passage of the train (-)
- \( T_n \) = passage time of train at overspeed condition n calculated in step 6 (s)
- \( V_{WO} \) = overturning wind speed calculated in step 4 (m/s)
- \( V_{WL} \) = local wind speed (m/s)

J8 Calculation Step 7:
Calculate Total Probability of Overturning

Calculate the total probability of overturning, considering the probability of overspeed occurring and the probability of the wind reaching the critical overturning wind speed in the relevant direction while the train is traversing the curve:

\[ P_{T(curve)} = P_D \sum_{n=1}^{N} P_{On} P_{Cn} \]

where:

- \( P_{T(curve)} \) = total probability of overturning for a single train pass through the curve (-)
- \( P_D \) = wind direction probability factor, as set out in section 10.4.3 and Appendix E (-)
- \( P_{On} \) = probability of the overspeed condition occurring, given by the probability distribution of overspeed described in section 10.6 (-)
- \( P_{Cn} \) = probability of occurrence of the critical overturning gust calculated in step 6 (-)
- \( N \) = number of overspeed conditions (-).
Calculation of Enhanced Permissible Speeds for Tilting Trains

References

Railway Group Standards

GA/RT6001  Railway Group Standards Change Procedures
GC/RC5603  Standard Definitions of Civil Engineering Terms
GC/RT5021  Track System Requirements
GE/RC8517  Recommendations for Systems for the Supervision of Enhanced Permissible Speeds and Tilt Enable
GE/RT8012  Controlling the Speed of Tilting Trains through Curves
GI/RT7001  Management of Safety Related Records of Elements of the Infrastructure
GK/RT0007  Alterations to Permissible Speeds
GM/RT2141  Resistance of Railway Vehicles to Derailment and Roll-Over
GM/RT2142  Resistance of Railway Vehicles to Roll-Over in Gales

Other References

Engineering Science Data Unit (ESDU) Data Items
ESDU Engineering Data Item 97031. Estimation of shelter provided by solid and porous fences, ESDU vol 1b [E9731v1.0, Vol 1b disk], 1998.