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# GN

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### Guidance on Loading Requirements for the Design of Railway Structures

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Rail Industry Guidance Note



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# Guidance on Loading Requirements for the Design of Railway Structures

## Issue record

| Issue | Date          | Comments                                                                                                                                                                                                                                                                 |
|-------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| One   | December 2014 | Original document<br><br>Gives guidance on the loading requirements for the design of railway structures, it also provides guidance on the structures requirements within the latest draft of the Infrastructure Technical Specification for Interoperability (INF TSI). |

## Superseded documents

The following Railway Group documents are superseded, either in whole or in part as indicated:

| Superseded documents                                                                        | Sections superseded | Date when sections are superseded |
|---------------------------------------------------------------------------------------------|---------------------|-----------------------------------|
| GC/RT5112 issue two, Rail Traffic Loading Requirements for the Design of Railway Structures | All                 | March 2015                        |

GC/RT5112 issue two ceases to be in force and is withdrawn as of 07 March 2015.

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# Guidance on Loading Requirements for the Design of Railway Structures

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# Guidance on Loading Requirements for the Design of Railway Structures

## Part 1 Introduction

### G 1.1 Purpose of this document

- G 1.1.1 This document gives guidance on loading requirements for the design of railway structures. It does not constitute a recommended method of meeting any set of mandatory requirements.
- G 1.1.2 The coverage of the document is addressed within section G 1.2, which explains the subject areas for which guidance has been provided, for example 'aerodynamics' and 'derailment actions'.

### G 1.2 Scope

- G 1.2.1 In the context of this document railway structures includes:
- a) Under-line bridges.
  - b) Over-line bridges.
  - c) Lineside structures.
  - d) Tunnel inverters.
  - e) Culverts.
  - f) Buried structures.
  - g) Retaining walls and embankments.
- G 1.2.2 This document:
- a) Lists, by means of a matrix, key documents which set out loading requirements for railway structures, together with other relevant documents.
  - b) Provides guidance on the application of the dynamic factor in BS EN 1990:2002+A1:2005 and for dynamically sensitive structures.
  - c) Provides guidance on aerodynamic actions and the requirements of BS EN 1991-2:2003 incorporating corrigenda December 2004 and February 2010, Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges - 6.6 Aerodynamic actions: the guidance may be used with confidence for train speeds up to 225 mph (360 km/h).
  - d) Provides guidance on accidental actions and the requirements of BS EN 1991-1-7:2006 incorporating corrigendum February 2010, Eurocode 1: Actions on structures - Part 1-7: General actions - Accidental actions - 4.5 Accidental actions caused by derailed rail traffic under or adjacent to structures, the guidance is appropriate for train speeds up to 225 mph (360 km/h).
- G 1.2.3 A revised Infrastructure Technical Specification for Interoperability (INF TSI), is planned to replace the current High Speed (HS) INF TSI (Commission Decision 2008/217/EC) and the Conventional Rail (CR) INF TSI (Commission Decision 2011/275/EU), in January 2015. The scope of the revised INF TSI will extend to the whole of the mainline railway system.

# Guidance on Loading Requirements for the Design of Railway Structures

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- G 1.2.4 Guidance is provided in Appendix A of this document on the requirements for structures set out in the revised INF TSI, based on the latest available draft at the time of writing (version 4.5, 23/04/2013). (The requirements for structures set out in the draft of the revised INF TSI are considered unlikely to change significantly before publication of the revised INF TSI.) The guidance is provided as a series of sequentially numbered clauses prefixed 'G' immediately below greyed extracts from the draft INF TSI to which it relates. Provision of guidance in this document is an interim measure prior to issue of the revised INF TSI and prior to future amendment of GI/GN7608. This guidance will be transferred to GI/GN7608 when there is an opportunity to do so.

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## **G 1.4 Approval and authorisation of this document**

- G 1.4.1 The content of this document was approved by Infrastructure Standards Committee on 10 September 2014.
- G 1.4.2 This document was authorised by RSSB on 01 October 2014.

# Guidance on Loading Requirements for the Design of Railway Structures

## Part 2 Source of Design Requirements for Loading of Railway Structures

### G 2.1 Document matrix

G 2.1.1 The key documents which set out the loading requirements for the design of railway structures are listed below:

- a) INF TSI.
- b) BS EN 1990:2002+A1:2005 incorporating corrigenda December 2008 and April 2010, Eurocode 1 - Basis of structural design and its UK National Annex.
- c) BS EN 1991-2:2003 incorporating corrigenda December 2004 and February 2010, Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges and its UK National Annex.
- d) BS EN 1991-1-7:2006 incorporating corrigendum February 2010, Eurocode 1: Actions on structures - Part 1-7: General actions - Accidental actions and its UK National Annex.

G 2.1.2 Implementation of the European Directive covering procurement procedures for public bodies in the transport sector (Directive 2004/17/EC) will require publicly funded works to be designed to the Structural Eurocodes once the national standards are withdrawn. Directive 2004/17/EC is implemented in the GB through the Utilities Contracts Regulations 2006 and the Utilities Contracts (Scotland) Regulations 2006.

G 2.1.3 Indication of the particular clauses within the listed key documents is given in the form of a matrix (see Table G 1), with design requirements listed along the vertical-axis and relevant documents listed on the horizontal-axis. Cells either indicate the precise clauses in a document that are relevant, or include 'x' to indicate that the document should be referred to in its entirety.

G 2.1.4 RGSs which capture vehicle / bridge compatibility requirements related to design of railway structures, and UIC Leaflet 777-2R, 2nd Edition, September 2002, 'Structures built over railway lines - Construction requirements in the track zone', which provides guidance on design and risk assessment for accidental actions resulting in impact with railway structures, are also included.

# Guidance on Loading Requirements for the Design of Railway Structures

| Design Requirements                                                                                          | Documents<br>INF TSI | GC/RT5021 | GE/RT8006 | BS EN 1990:2005<br>(A1) | BS EN 1991-2:2003 | BS EN 1991-1-7:2006 | UIC Leaflet 777-2R |
|--------------------------------------------------------------------------------------------------------------|----------------------|-----------|-----------|-------------------------|-------------------|---------------------|--------------------|
| <b>Vertical loads</b>                                                                                        |                      |           |           |                         |                   |                     |                    |
| Load model 71                                                                                                | 4.2.7.1.1 (1)<br>(a) |           |           |                         | 6.3.2             |                     |                    |
| Load model SW/0                                                                                              | 4.2.7.1.1 (1)<br>(b) |           |           |                         | 6.3.3             |                     |                    |
| Eccentricity of vertical loads                                                                               |                      |           |           |                         | 6.3.5             |                     |                    |
| Earthworks                                                                                                   | 4.2.7.2              |           |           |                         | 6.3.6.4           |                     |                    |
| Load classification factor ( $\alpha$ )                                                                      | 4.2.7.1.1 (2)<br>(3) |           |           |                         | 6.3.2 (3)         |                     |                    |
| Existing bridges and earthworks                                                                              | 4.2.7.4              |           | x         |                         |                   |                     |                    |
| <b>Dynamic effects</b>                                                                                       |                      |           |           |                         |                   |                     |                    |
| Requirement for a static or dynamic analysis                                                                 | 4.2.7.1.2 (2)        |           |           |                         | 6.4.4             |                     |                    |
| Dynamic factor ( $\Phi$ )                                                                                    | 4.2.7.1.2 (1)        |           |           |                         | 6.4.5             |                     |                    |
| Requirements for a dynamic analysis (HSLM)                                                                   | 4.2.7.1.2 (2)<br>(3) |           |           |                         | 6.4.6             |                     |                    |
| <b>Horizontal forces</b>                                                                                     |                      |           |           |                         |                   |                     |                    |
| Centrifugal forces                                                                                           | 4.2.7.1.3            |           |           |                         | 6.5.1             |                     |                    |
| Nosing force                                                                                                 | 4.2.7.1.4            |           |           |                         | 6.5.2             |                     |                    |
| Actions due to traction and braking                                                                          | 4.2.7.1.5            |           |           |                         | 6.5.3             |                     |                    |
| Combined response of structure and track                                                                     |                      |           |           |                         | 6.5.4             |                     |                    |
| <b>Aerodynamic actions from passing trains</b>                                                               | 4.2.7.3              |           |           |                         | 6.6               |                     |                    |
| <b>Derailment and other actions for railway bridges</b>                                                      |                      |           |           |                         |                   |                     |                    |
| Derailment actions from rail traffic on a railway bridge                                                     |                      |           |           |                         | 6.7.1             |                     |                    |
| Derailment actions under or adjacent to a structure and other actions for Accidental Design Situations       |                      |           |           |                         | 6.7.2             | 4.5, Annex B        | x                  |
| Other actions                                                                                                |                      |           |           |                         | 6.7.3             |                     |                    |
| <b>Application of traffic loads on railway bridges</b>                                                       |                      |           |           |                         | 6.8               |                     |                    |
| <b>Traffic loads for fatigue</b>                                                                             |                      |           |           |                         |                   |                     |                    |
| <b>Combinations rules for railway</b>                                                                        |                      |           |           | A2.2.4                  | 6.9               |                     |                    |
| <b>Combination of actions for accidental (non-seismic) design situations</b>                                 |                      |           |           | A2.2.5                  |                   |                     |                    |
| <b>Values of <math>\psi</math> factors</b>                                                                   |                      |           |           | A2.2.6                  |                   |                     |                    |
| <b>Ultimate limit states</b>                                                                                 |                      |           |           | A2.3                    |                   |                     |                    |
| <b>Verifications regarding deformations and vibrations for railway bridges - Criteria for traffic safety</b> |                      |           |           | A2.4.4.2                |                   |                     |                    |
| Vertical acceleration of the deck                                                                            |                      |           |           | A2.4.4.2.1              |                   |                     |                    |
| Deck twist                                                                                                   | 4.2.8.3              | 2.11.2    |           | A2.4.4.2.2              |                   |                     |                    |
| Vertical deformation of the deck                                                                             |                      |           |           | A2.4.4.2.3              |                   |                     |                    |
| Transverse deformation and vibration of the deck                                                             |                      |           |           | A2.4.4.2.4              |                   |                     |                    |
| Longitudinal displacement of the deck                                                                        |                      |           |           | A2.4.4.2.5              |                   |                     |                    |

**Table G 1** Documents for loading requirements for the design of railway structures

# Guidance on Loading Requirements for the Design of Railway Structures

G 2.1.5 The design requirements and guidance within the listed documents are primarily intended for the design of bridges, although they are also applicable to all railway structures which are subjected to railway traffic.

## **G 2.2 Application of the dynamic factor for verification of vertical deformation requirements in BS EN 1990:2002 + A1:2005 Annex A2**

G 2.2.1 BS EN 1990:2002 + A1:2005 clause A2.4.4.2.3 requires vertical deformation due to railway traffic actions to be checked with the 'classified characteristic vertical loading', for example, including the load classification factor  $\alpha$ , but makes no mention of the dynamic factor  $\Phi$ . This is an oversight in the standard and will in due course require an amendment to EN 1990:2002 + A1:2005. For calculation of vertical deformation, the effects from railway traffic should be multiplied by  $\alpha$  and  $\Phi$ .

## **G 2.3 Dynamically sensitive railway structures**

G 2.3.1 For novel and dynamically sensitive railway structures, the European Committee for Standardisation (CEN), has carried out studies in response to a request from the European Railway Agency (ERA), on the compatibility of vehicles and railway bridges across the European Union. This work has identified that supplementary vehicle / bridge compatibility checks are required and that there is a potential problem across all countries for vehicles that operate in the 100 – 125 mph (160 – 200 km/h) range.

G 2.3.2 BS EN 1991-2:2003 Figure 6.9 sets out a flow chart for determining whether a dynamic analysis is required. A dynamic analysis is required where train speeds are greater than 125 mph (200 km/h), and / or the limits of bridge natural frequency ( $\eta_0$ ) fall outside the specified limits, but it does not distinguish between 'simple' and 'complex' railway structures. Figures NA.2.12 and NA.2.13 in the UK National Annex to BS EN 1991-2:2003 provide alternative flow charts for simple and simple / complex structures respectively, but also require a dynamic analysis for simple structures where train speeds are greater than 125 mph (200 km/h), or for simple / complex structures where train speeds are greater than 110 mph (180 km/h).

G 2.3.3 Loading from vehicles operating outside of the 100 – 125 mph (160 – 200 km/h) speed range, and in some cases between 90 – 100 mph (140 – 160 km/h), has caused increased 'dynamic effects', including higher accelerations within the ballast which has the potential to reduce the effectiveness of the ballast in providing support to the track.

G 2.3.4 The higher speeds and increased axle loads attributable to the emerging generation of European multiple units, will result in the occurrence of dynamic effects (acceleration and deformation), which may exceed the design limits in BS EN 1990:2002 + A1:2005 Annex A2. It may therefore be necessary to modify the design requirements for structures which are subject to traffic loading, in particular bridges, by increasing the magnitude of the dynamic factor applied to the static traffic loading and / or examining the suitability of the design limits within BS EN 1990:2002 + A1:2005 Annex A2.

G 2.3.5 Research is being undertaken on behalf of the Vehicle / Structures System Interface Committee (V/S SIC), to investigate this issue for Great Britain (GB) conditions. The project will examine the aspirations of the operators, train manufacturers, and train service specifiers, for current and future GB vehicles and to establish appropriate Reference Load Models (RLMs) to represent them. Additionally, an investigation will be undertaken into the compatibility of the RLMs with GB bridges for speeds in excess of 90 mph (140 km/h), provide guidance on compatibility assessment, and examine the acceptance criteria for ballast acceleration in BS EN 1990:2002 + A1:2005 Annex A2.

# Guidance on Loading Requirements for the Design of Railway Structures

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## **G 2.4 Trackside and overhead structures subjected to transient aerodynamic loads**

- G 2.4.1 RSSB research project T750 'Review of Euronorm design requirements for trackside and overhead structures subjected to transient aerodynamic loads', has concluded that the application of the aerodynamic design requirements for structures in BS EN 1991-2:2003 would result in overestimation of the loads for GB structures, as the design pressures are based on larger continental gauge rolling stock.
- G 2.4.2 Alternative design pressures for GB structures have been developed on the basis of train model testing. These alternative design requirements have been included within Part 3 of this document in advance of their publication within a future revision of the UK National Annex for BS EN 1991-2:2003.

## **G 2.5 Design of railway structures to resist derailment loads**

- G 2.5.1 Design requirements for railway structures to resist derailment loads are set out in BS EN 1991-1-7:2006 and its UK National Annex. Guidance on undertaking a risk assessment to support a decision to design structures for a reduced loading is set out in Part 4 of this document, for use in circumstances where an alternative design strategy, other than design for the recommended impact values for Class A and B structures, is considered to be appropriate.

# Guidance on Loading Requirements for the Design of Railway Structures

## Part 3 Guidance on GB Requirements for Design of Structures Subject to Aerodynamic Actions

### G 3.1 Introduction

- G 3.1.1 In the absence of 'alternative values' in the UK National Annex for BS EN 1991-2:2003, RSSB has undertaken research (see research project T750 for further details), which provides the basis for providing the alternative GB specific design requirements to replace the existing clause NA.2.74 of UK National Annex for BS EN 1991-2:2003.
- G 3.1.2 Until the UK National Annex for BS EN 1991-2:2003 is updated, the following guidance has been provided to help the industry when considering the design of structures that are subject to aerodynamic actions.

### G 3.2 Aerodynamic actions

- G 3.2.1 A moving train generates an aerodynamic pressure field, which it imposes on structures alongside and over the track. The pressure field is largest at the front and rear of the train and at the nose-to-nose coupling between separate rakes of multiple units. The resultant pressure field exerts load on trackside structures, which is taken into account in design to ensure that they can withstand the aerodynamic actions (loads) and do not sustain fatigue damage.
- G 3.2.2 When calculating the mechanical and fatigue strength of a structure, the aerodynamic actions are assumed to be of an equivalent amplitude at the head and tail and, in the case of nose-to-nose coupled trains, also at the coupler. This amplitude is taken to be the largest of the actions generated during the complete time of passing of the train.
- G 3.2.3 In reality, a train passing generates a maximum pressure (aerodynamic action). The maximum load that the structure experiences will depend upon the dynamic sensitivity of the structure and its response to the aerodynamic action. It is recommended that a characteristic pressure value is taken to represent the maximum static action. BS EN 1991-2:2003, clause 6.6.1 (5) recommends a dynamic amplification factor of 2.0. The adequacy of this factor may need to be determined from a structure-specific study taking into account the dynamic response of the structure.
- G 3.2.4 Whether a dynamic amplification factor of 2.0 is too high or insufficient, will depend upon whether the structure is able to respond to the pressure wave from a passing train. This is not a judgement that is possible without prior knowledge of the sensitivity of a structure to passing pressure waves or by undertaking a structure-specific dynamic analysis.
- G 3.2.5 Guidance on determination of the dynamic amplification for noise barriers is set out in UIC-779-1R, 2nd Edition 'Effect of the slipstream of passing trains on structures adjacent to the track'.
- G 3.2.6 These aerodynamic actions are applied perpendicular to the surface of the structure in each case (see Figures G 1 to G 3 of this document). They are termed characteristic pressure values and it should be noted that in most cases the given characteristic pressure values (or equivalent pressures in non-dimensionalised form), represent the maximum area-averaged pressures on a structure. The design characteristic pressure distributions in Figures G 1 to G 3 of this document are relevant for application to the surfaces indicated for each structure type. Pressure distributions have not been derived for vertical surfaces above the track such as bridge parapet fences.
- G 3.2.7 Guidance on the susceptibility of bridge structures to aerodynamic excitation, including the provision of approximate formulae for estimation of the fundamental frequencies of bending and torsion for bridge structures is set out in the Highways Agency standard BD 49/01 'Design rules for aerodynamic effects on bridges'. However, its application for consideration of railway bridge structures subject to the aerodynamic effects from passing trains, is expected to be restricted to 'limited amplitude response', due to the smaller magnitude and frequency of aerodynamic actions compared to ambient wind.

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- G 3.2.8 Guidance on the assessment of fatigue sensitive details for noise barriers is set out in UIC 779-1R, 2nd Edition 'Effect of the slipstream of passing trains on structures adjacent to the track'. No specific guidance is available for fatigue-sensitive details associated with other structure types.
- G 3.2.9 For structures that are dynamically sensitive, fatigue calculations require an assessment of the additional number of pressure cycles generated by the dynamic response of the structure arising from the train-induced pressure pulse. The magnitude of the pressure pulse increases with reduction of the length of structure over which the pressure pulse is assumed to act. The design pressures for local fatigue sensitive details may be critical in some cases.
- G 3.2.10 The resulting equivalent pressures that are calculated from the characteristic pressure values are mainly dependent on:
- a) The square of the speed of the train.
  - b) The aerodynamic shape of the front of the train.
  - c) The shape and type of the structure.
  - d) The position of the structure, in particular the clearance between the vehicle and the structure.
- G 3.2.11 Train aerodynamic nose shapes are classified here as bluff, intermediate or streamlined corresponding to freight locomotives, standard GB multiple units and streamlined high speed trains.

## G 3.3 Relationship with BS EN 1991-2:2003

- G 3.3.1 In BS EN 1991-2:2003, section 6.6 'Aerodynamic actions from passing trains', methods are provided for calculating equivalent pressure loads on a variety of trackside structures. These can be used, but will generally over-estimate the equivalent loads, as the data on which the code is based used continental gauge trains, which lead to reduced clearances between the vehicles and the structures. However, the method for simple horizontal structures adjacent to track in BS EN 1991-2:2003, clause 6.6.4 is not recommended, as GB platforms are higher than European platforms and under-estimates of the pressure loads may result.
- G 3.3.2 The data on which the following GB specific guidance for alternative design pressures is based forms a consistent and extensive database and was derived from moving model tests using GB gauge trains. It is therefore considered to be more appropriate for calculating equivalent pressures on relevant GB trackside structures.

## G 3.4 Flat vertical structures parallel to the tracks

- G 3.4.1 The following structures belong to this category:
- a) Trackside acoustic and wind protection barriers.
  - b) Walls and fences.
  - c) Facades of buildings near the track.
  - d) Trackside and platform hoardings.
- G 3.4.2 The true pressure field around the train is considered to be represented by the equivalent distributed pressures  $+p_{1k}$  and  $-p_{1k}$ , each of which is taken to be 5 m long and proportional to the speed of the train as shown in Figure G 1 of this document. The calculated pressure applies from the foot of the structure on the track formation, up to a maximum height of 5 m above rail level. The pressure distributions apply at the train nose and tail, as well as to intermediate nose-to-nose couplings if present.