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Guidance on Rail Vehicle Interior Structure and Secondary Structural Elements

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Rail Industry Guidance Note for GM/RT2100 issue four (Parts 5, 6 and 7)



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Guidance on Rail Vehicle Interior Structure and Secondary Structural Elements

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Guidance on Rail Vehicle Interior Structure and Secondary Structural Elements

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Guidance on Rail Vehicle Interior Structure and Secondary Structural Elements

Part 1 Introduction

1.1 Purpose and structure of this document

This document gives guidance on interpreting the requirements of Railway Group Standard GM/RT2100 Parts 5, 6 and 7. It does not constitute a recommended method of meeting any set of mandatory requirements.

Relevant requirements in GM/RT2100 are reproduced in the sections that follow. Guidance is provided as a series of sequentially numbered clauses prefixed 'GN'.

Specific responsibilities and compliance requirements are laid down in the Railway Group Standard itself.

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1.3 Approval and authorisation of this document

The content of this document was approved by:

Rolling Stock Standards Committee on 03 September 2010.

This document was authorised by RSSB on 06 October 2010.

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Part 2 Guidance for Secondary Structural Elements

2.1 Common design requirements

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Section 5.1 Common design requirements

5.1.1 All secondary structural elements, together with all mounting attachments, fixings and surrounding vehicle structure shall, in addition to the particular loads set out below, comply with the proof, ultimate and fatigue load requirements specified for vehicle body mounted equipment (see 3.2).

- GN01 For the purpose of this document, secondary structural elements are, as defined in GM/RT2100, those elements of a vehicle which interface directly with passengers or traincrew.
- GN02 Secondary structural elements, as defined in GM/RT2100, include:
- a) Windscreens (see Part 5 of GM/RT2100).
 - b) Windows (see Part 5 of GM/RT2100).
 - c) Doors (see Part 5 of GM/RT2100).
 - d) Gangways (see Part 5 of GM/RT2100).
 - e) Interiors, for example seats, tables, panelling, partitions etc. (see Part 6 of GM/RT2100).
- GN03 The intention of the mandatory requirements is to ensure that all structural elements of a rail vehicle, primary and secondary, are designed to a common standard. In particular it is intended that the secondary structural elements of vehicles are compatible with dynamic loadings that might be imposed due to a collision or derailment or sudden unexpected movement due to heavy braking or track irregularities.
- GN04 Assessment of the load requirements for vehicle mounted equipment may be made separately from loadings required for specific items. Where it can be shown that the combination of the generally applicable vehicle mounted equipment loadings and particular load requirements result in multiple loadings of essentially the same type but of different magnitudes, it should not be necessary to undertake a formal assessment of the lesser loadings.

2.2 Windscreens

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Section 5.2 Windscreens

5.2.1 Windscreen structural requirements

- 5.2.1.1 Any predominantly forward facing window which in normal service operation may be positioned at the leading end of a train behind which traincrew, personnel or passengers may be located shall satisfy the structural requirements for windscreens.
- 5.2.1.2 At intermediate ends of fixed formation units, any predominantly forward or rear facing window, behind which passengers, personnel or traincrew may be located in normal service, shall be considered to be a bodyside window.

- GN05 Windows in leading ends which are to shield equipment, indicators or which are fitted for aesthetic purposes should not be considered as windscreens provided that the applicable impact resistance requirements for vehicle leading ends are satisfied (see 3.3.3.1 in GM/RT2100).

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- GN06 Some types of rolling stock have for example windows fitted to the intermediate bodyends to improve security by giving passengers visibility throughout a unit. As these windows are not exposed to the same risk of missile impacts or aerodynamic forces as a cab windscreen, these are deemed to be equivalent to bodyside windows.

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Section 5.2 Windscreens

5.2.1 Windscreen structural requirements

- 5.2.1.3 The strength of windscreen fixings and the complete windscreen installation shall be consistent with the strength and impact requirements for the windscreen.

- GN07 It should be demonstrated that all windscreen loads can be satisfactorily transferred into the primary vehicle structure without significant permanent deformation or overloading of any system of fasteners or bonding used.

- GN08 In addition to loads acting on the windscreen being transferred into the vehicle primary structure, there should be careful consideration of the effect of other loadings on the vehicle structure affecting the windscreen and the security of its mountings. The intention is to ensure that as far as possible a windscreen cannot become detached due to flexure or breakage of cab canopy mouldings during a collision. This is out of consideration of maintaining the integrity of cab areas, preservation of survival space and the considerable mass of typical windscreen units (an individual screen can weigh between 30 kg and 140 kg) which, if detached, present a significant risk of serious injury or fatality to traincrew.

- GN09 The design of the windscreen installation should consider the combined effects of derailment and roll-over where there could be a risk of significant ballast and debris ingress in the event of the windscreen or surrounding structure failing or becoming detached. RSSB research project T190 has considered these issues in detail and it is recommended that where reasonably practicable the guidance contained in the report is followed.

- GN10 Where windscreens are structurally bonded into position, with the bond acting as an element of the load path between windscreen and structure, any rebate for mounting the glass should be protected from damage when bond material is cut during windscreen replacement.

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Section 5.2 Windscreens

5.2.2 Impact resistance for vehicle windscreens

- 5.2.2.1 The requirements for impact resistance and spalling set out in BS EN 15152:2007 shall apply for all vehicle windscreens.

- GN11 The High Speed Rolling Stock TSI mandates the same impact resistance requirements as set out in BS EN 15152:2007.

- GN12 BS EN 15152:2007 is intended for high speed trains but it is also applicable to the windscreens of other types of rolling stock if, as set out in the standard, the performance criteria are adjusted to suit the application.

- GN13 The impact requirements set out in BS EN 15152:2007 6.2.6.1 (Projectile form, mass and impact velocity) are identical to those set out in Appendix C of UIC leaflet 651 and are therefore suitable for all types of rolling stock.

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Section 5.2 Windscreens

5.2.3 Windscreen aerodynamic loadings

- 5.2.3.1 A windscreen together with all mounting attachments, fixings and surrounding vehicle structure shall withstand without failure the aerodynamic loads set out in Part 7.

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GN14 Please see guidance on aerodynamic vehicle loadings in Part 4 of this document.

2.3 Bodyside windows

GN15 A significant cause of fatality and serious injury in vehicle accidents has been the breakage of bodyside windows, which has allowed occupants to be ejected from moving vehicles (See RSS research project T310 phase 5).

GN16 The measures set out in GM/RT2100 relating to bodyside windows represent the result of extensive research involving accident and injury causation investigations, design development and laboratory testing. Please refer to RSSB research project T424 report 'Requirements for train windows in passenger rail vehicles' for full details of this work.

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Section 5.3 Bodyside windows

5.3.1 Window design requirements

5.3.1.1 All bodyside windows for vehicles carrying passengers, personnel or traincrew, in areas which are freely accessible during normal service, shall have at least one pane of laminated safety glass, or other material with equivalent or superior structural properties. The requirements for sleeper vehicles are set out in 5.3.1.3.

5.3.1.2 For refurbishment of existing vehicles where due to limitations imposed by the window frame design or the underlying vehicle structure it is not possible to achieve full compliance, the requirements of 5.3 shall be applied as far as it is reasonably practicable.

5.3.1.3 For dedicated sleeper vehicles the following requirements shall apply:

- a) Means shall be provided to allow compartment and corridor windows to be safely removed or opened in an emergency to allow passenger escape from the vehicle.
- b) For existing vehicles it is permissible, even if otherwise subject to the requirements of 10.2.1.3, for the windows to be breakable using a suitable hammer or other device to allow passenger escape in an emergency.

GN17 The definition of 'bodyside windows' includes windows in doors and cab side windows in addition to the windows in passenger saloons, catering areas and toilets. This requirement would not for example apply to bodyside windows to aid illumination of a locomotive engine compartment or a freight wagon interior. GM/RT2100 5.3.3.1 and 5.3.4.3 make a further distinction between cab side windows and other bodyside windows for vehicles carrying passengers, personnel or traincrew (see GN26 and GN30).

GN18 For on-track machines, where there are cabs or operator areas that are unoccupied outside of possessions, the requirement for laminated safety glass does not need to be applied.

GN19 For freight vehicles, where windows are required, toughened safety glass or some other suitable material may be used. In the case of hybrid vehicle types such as freight or parcels multiple units or driving van trailers the requirement for laminated safety glass does not need to be applied to areas which are normally unoccupied by traincrew or personnel.

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- GN20 The layout of existing sleeping car vehicles (Mark 3 design) consists of a side corridor with small windows and compartments each with a small window. In service, due to the internal layout, people are not usually adjacent to the windows (either moving along the side corridor or occupying a berth). In the event of a roll-over occupants of a berth would find themselves in a relatively confined space when compared to a conventional modern vehicle and as a result their only credible means of escape could then be via the berth window or out from the berth and through the nearest side corridor window. In consideration of these factors toughened glass is permitted to be retained for this type of vehicle whenever a change is proposed that affects windows in sleeping cars.

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Section 5.3 Bodyside windows

5.3.1 Window design requirements

- 5.3.1.4 Where double glazed units are fitted, it is permissible for one pane to be of toughened safety glass. When installed in the vehicle the laminated safety glass pane shall always be fitted on the side of the unit forming part of the vehicle interior.

- 5.3.1.5 Where double glazed units incorporate toughened glass either:

- a) A means of easily recognisable identification in English shall be provided on both the interior and exterior of the window to distinguish between laminated or toughened safety glass in order to show that windows are correctly fitted along the bodyside of the vehicle

Or

- b) The double glazed unit and its mounting to the vehicle shall be designed to prevent incorrect installation.

- GN21 For double glazed units, where one pane is of toughened safety glass, the requirement for installing the toughened safety glass pane on the vehicle exterior and the laminated safety glass pane on the interior has two purposes:

- a) To ensure that in the event of the outer toughened safety glass pane being broken due to impact or in the course of access in an emergency any passengers inside the vehicle are not showered by glass fragments.
- b) To ensure that the laminated safety glass interlayer is maintained within a temperature range at which its performance is optimal. With the laminated safety glass pane on the inside, the interlayer temperature will be close to the vehicle interior temperature and safely within the optimum range.

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Section 5.3 Bodyside windows

5.3.2 Window design requirements

- 5.3.2.1 Glass shall be manufactured in accordance with BS 857:1967 or an equivalent specification.
- 5.3.2.2 Bodyside window fixings and the complete bodyside window installation shall be consistent with the strength and impact requirements for the bodyside window set out in 5.3.3 to 5.3.5.
- 5.3.2.3 Bodyside window systems representative of production quality and construction shall be tested as required below (see 5.3.4 to 5.3.6). Where a vehicle or unit is fitted with a number of different sized windows to an otherwise common design, it is permissible for impact, containment and pressure pulse testing required in accordance with Appendices B, C and D to be undertaken on only the largest window unit.

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5.3.2.4 Impact, containment and pressure pulse testing required in accordance with Appendices B, C and D of this document is not required where either the height or width is less than 300 mm for window units or window unit subassemblies if the Bodyside window is subdivided.

- GN22 The detachment of a window or a window and its frame could result in injury, either because of the loss of containment or because of the effect on people outside the vehicle in question. Experience with Mark 3 coach windows has shown the necessity of providing a peripheral securing system which is:
- a) Flexible enough to cater for the expansion of the toughened safety glass panes when they are crazed as a result of impact loads.
- And
- b) Strong enough to keep the damaged panes in place when subsequently subjected to forces, including the aerodynamic forces, which may be expected in operation.
- GN23 Many vehicle designs currently in service use a variety of bodyside window types to suit the bodyshell design and interior layouts. The window units may be very similar in terms of their structural characteristics, in which case testing each and every variant would not be useful and should not be necessary. The determining factor for otherwise identical windows is the maximum pane deflection and induced bending stresses at the centre of a pane. Where the mounting of the glass is not identical, for example where hopper windows are fitted, additional testing should be undertaken.
- GN24 Where windows are fully or partially obscured by either surface coating or surface treatment or where full or partial blanking panels are used, it should be established by calculation or testing the degree of equivalence to the standard window unit in order to determine if additional tests are required.
- GN25 The limiting dimension of 300 mm relates to small or narrow windows or opening hopper window elements where, due to the size of the impactor, it is not possible to conduct the suite of tests required for standard windows. The glass and construction however should comply with all other requirements and the glass and construction specification should be consistent with other windows on a given vehicle. The relevant dimensions should relate to the aperture that would be created if the glass was absent.

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Section 5.3 Bodyside windows

5.3.2 Window design requirements

- 5.3.2.5 Where a window unit or window unit type has already been tested in accordance with Appendices B, C and D of this document, additional testing for a new installation shall not be required if it can be demonstrated that the following conditions are satisfied:
- a) The window unit design and mounting arrangements are mechanically equivalent to those for which test data has been obtained.
 - b) The window unit installation and corresponding vehicle structure can satisfactorily resist all structural loads from the series of tests for which data has been obtained.

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Section 5.3 Bodyside windows

5.3.3 Bodyside window structural requirements

5.3.3.1 Bodyside windows, when installed in a vehicle, shall remain fully serviceable after the application of the following loads, applied over the full surface area:

- a) The aerodynamic loads set out in Part 7.
- b) For all windows in areas accessible to passengers, personnel or traincrew with the exception of cabs, a sustained pressure of 6 kPa from inside the vehicle.
- c) For external door windows, the sustained pressure loads specified for the door assembly (see 5.4.2).
- d) For cab side windows, a sustained pressure of 3 kPa from inside the vehicle.

GN26 A pressure of 6 kPa represents the effect of a crush of people standing on or falling against the window with the vehicle on its side. A lower pressure of 3 kPa is specified for cab side windows for consistency with external door loadings and reflects the fact that areas exclusively for traincrew or personnel, such as cabs, are not likely to be as densely occupied as passenger areas.

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Section 5.3 Bodyside windows

5.3.3 Bodyside window structural requirements

5.3.3.2 If a bodyside window pane is damaged by impact, the risk of injury to vehicle occupants from any spalling of the inner surface shall be controlled. This objective shall be deemed to be satisfied by demonstrating that, when windows are tested in accordance with Appendices B and C:

- a) For the small missile tests (see Appendix B), the total amount of spall does not exceed 40 g.
- b) For the sequence of containment tests (see Appendix C), the total amount of spall for the steel ball impact test (see Appendix C.5) does not exceed 10 g.

5.3.3.3 If a bodyside window pane is damaged by impact, the risk of detachment from the outer surface of pieces, with the consequent risk of injury for people outside the vehicle, shall be controlled. For double glazed bodyside window units, this shall be demonstrated by satisfactory testing in accordance with the requirements of Appendix D.

GN27 Maximum values for spall have been developed from test data obtained during the RSSB research project T424 phase 4. Please refer to the T424 project reports for full details of this work.

GN28 When an outer toughened safety glass pane on a double glazed unit is damaged, the geometric characteristics of the semi-closed air space between the panes and the interaction with an external pressure wave generated by a passing train can cause the dice formed when the toughened glass is damaged to be pulled away resulting in a shower of potentially dangerous debris. After a number of incidents, a test method was developed by British Rail to control this risk. A revised version of former British Rail specification BR 573:1984 is set out in Appendix D of GM/RT2100.

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Section 5.3 Bodyside windows

5.3.4 Laminated glass bodyside window and window unit loads and impact resistance

- 5.3.4.1 To demonstrate resistance to small missiles, a laminated safety glass bodyside window pane or a double glazed window unit incorporating laminated safety glass shall resist without penetration into the vehicle, the impact of a solid steel ball weighing 0.25 kg travelling at a speed of 100 km/h when tested in accordance with the requirements of Appendix B.
- 5.3.4.2 When tested in accordance with Appendix C, a bodyside window or window unit, with the exception of cab bodyside and cab door windows, using laminated safety glass shall demonstrate acceptable containment performance by withstanding the following sequence of loads:
- a) The external impact of a solid steel ball weighing 5 kg travelling at a speed of 34 km/h.

This shall be followed by:
 - b) A 50 kg pendulum internal impact from a height of 1200 mm.

And then it shall be followed by:
 - c) A concentrated perpendicular internal load of 0.8 kN applied over an area of 0.1 m x 0.1 m on the surface at the window centre.
- 5.3.4.3 For cab bodyside and cab door windows acceptable performance shall be demonstrated only against the requirements of 5.3.4.2 a) when tested in accordance with the applicable parts of Appendix C.

- GN29 The small missile test requirement is to demonstrate satisfactory performance in the event of impacts due to small objects travelling at appreciably high speeds such as ballast or fixings being thrown up by the vehicle or other vehicles. The impact speed specified for this test was previously set out in GM/RT2456 as 62 mile/h. The speeds are equivalent for all practical purposes. It is not considered necessary to test separately the impact resistance of the toughened safety glass pane in the case of double glazed units which consist of both types of glass.
- GN30 The containment test sequence is the result of RSSB research project T424, in particular Phase 5. The solid steel ball tests were undertaken using a 12 lb ball at a speed of 20 mile/h. The conversion to metric units is intended to ensure that the impact energy is essentially maintained. (For a 12 lb ball at 20 mile/h the kinetic energy will be 218 J, for a 5 kg ball at 34 km/h the energy will be 223 J, an increase of 2.5%). Due to the relatively small size of cab side windows, the risk of loss of containment due to internal impact is considered to be very low if not negligible and therefore only the external impact test is specified for cab side windows.
- GN31 The detail design of laminated windows intended to be directly bonded into a frame or the vehicle bodyside should consider potential out of plane shear loading on the interlayer at the bond edge. This type of load induces tensile stresses acting perpendicular to the plane of the glass (between the inner glass surface and between the glass and the interlayer of the laminated safety glass pane). This type of loading could occur when the window is damaged by a severe impact (and the glass shattered but retained by the interlayer), with the risk of the pane then delaminating and a resulting loss of containment.

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Section 5.3 Bodyside windows

5.3.5 Toughened glass bodyside window impact resistance

5.3.5.1 Where these are permitted, toughened safety glass bodyside window units shall withstand without penetration the impact of a solid steel ball weighing 0.25 kg travelling at a speed of 50 km/h when tested in accordance with the requirements of Appendix B.

GN32 This requirement applies to window units which are constructed using only toughened safety glass panes. The impact speed specified for this test was previously set out in GM/RT2456 as 31 mile/h. The speeds are equivalent for all practical purposes.

GN33 The requirement for impact resistance is intended to protect against flying ballast or vandalism from outside the train. The weight of the missile and the impact speed selected are intended to represent the throwing of a large stone by a strong adult male. Allowance has been made, on the basis of the test requirements in BS 857:1967, for what can reasonably be resisted by toughened safety glass. The higher value specified for laminated safety glass reflects the higher impact strength and better protection given by this material.

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Section 5.3 Bodyside windows

5.3.6 Bodyside window emergency access

5.3.6.1 Testing shall be undertaken to demonstrate that the time to create an opening suitable for access shall not exceed 2 minutes, using tools typically available to rescue services.

5.3.6.2 Test samples shall be mounted at a height corresponding to the nominal relative height of the installed bodyside window from a standard station platform.

GN34 The specified access time has been established from tests conducted with the fire and rescue services. See RSSB research project T424 reports, in particular Phase 5 for guidance and description of tests undertaken.

2.4 External vehicle doors

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Section 5.4 External vehicle doors

5.4.1 External vehicle door design requirements

5.4.1.1 The strength of door frames, door locks and associated equipment shall be compatible with the strength of the doors.

GN35 In demonstrating how the specified door loadings are reacted through to the primary structure, any analysis should consider the final installation on a vehicle and the conditions of use in normal service, taking into account if necessary the effects of adjustment, tolerances and deflection of surrounding structure.

GN36 Where hinged external doors are used, typically for cabs, particular attention should be given to the design of the door frame and locks to ensure that in the event of a derailment resulting in a roll-over the structure cannot flex sufficiently to spring the door open with the subsequent risk of the ingress of ballast and debris.

GN37 The design of external cab doors and their installation should consider the combined effects of derailment and roll-over where there could be a risk of significant ballast and debris ingress in the event of the door or surrounding structure failing or becoming detached. RSSB research project T190 has considered these issues in detail and it is recommended that where reasonably practicable the guidance contained in the report is followed.

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Section 5.4 External vehicle doors

5.4.2 External vehicle door loads

- 5.4.2.1 External vehicle doors and their mountings shall withstand the following separate proof load cases without significant permanent deformation or loss of normal function:
- a) A concentrated perpendicular load of 2.5 kN applied over an area of 0.1 m x 0.1 m, acting from within the vehicle. The structure shall be capable of withstanding this load at any position on the surface of the door.
 - b) An external surface pressure load of 2.5 kPa.
 - c) The inner surface pressure load of 2.5 kPa, applied over the internal surface of the door plus a concentrated perpendicular load, acting from within the vehicle, of 0.8 kN applied over an area of 0.1 m x 0.1 m. The structure shall be capable of withstanding the concentrated load at any position on the surface of the door.
- 5.4.2.2 In the case of vehicles with a maximum speed in excess of 125 mile/h or pressure sealing, an appropriate quasi-static aerodynamic pressure load shall be determined according to the requirements set out in Part 7.
- 5.4.2.3 External doors shall withstand as an ultimate load case a sustained pressure of 6 kPa over its internal surface. It shall not be necessary for the door and associated components to remain operational after the application of this load.
- 5.4.2.4 Direct access external doors exclusively for use by traincrew or personnel for access and egress and only accessible by them in normal operation shall withstand as an ultimate load case a sustained pressure of 3 kPa over its internal surface. It shall not be necessary for the door and associated components to remain operational after the application of this load.
- 5.4.2.5 External doors shall withstand without significant permanent deformation or loss of normal function the transient aerodynamic load requirements set out in Part 7.

- GN38 The external vehicle door load cases represent respectively:
- a) The effect of somebody being projected against a door during a minor train collision.
 - b) The maximum differential air pressure which would normally be expected in service.
 - c) The maximum differential air pressure which would normally be expected in service acting on the inside surface of the door in combination with the effect of a person making contact with the door (the loading is roughly equivalent to a person of 80 kg mass with an acceleration of 1 g).
- GN39 The pressure loading of 6 kPa represents the effect of a crush of people falling against or standing on an external door with the vehicle on its side.
- GN40 Doors not intended for normal use by passengers (for example on driving van trailers) but which are intended for luggage, parcels or other goods should not be considered exclusively for the use by traincrew or personnel, and therefore the more onerous loading requirement should be applied.

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2.5 External steps, grab rails and grab handles

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Section 5.5 External steps, external grab rails and external handles

5.5.1 Structural requirements

- 5.5.1.1 A step shall withstand a concentrated downward vertical proof load of 2 kN, applied over an area of 100 mm x 200 mm. The structure shall be capable of withstanding the concentrated load at any position on the step surface.
- 5.5.1.2 A step shall withstand a uniformly distributed downward vertical proof load of 4 kN per metre over its length, without significant permanent deformation.
- 5.5.1.3 External grab rails or handles shall withstand a perpendicular proof load of 1.7 kN applied at any point along its length without significant permanent deformation.
- 5.5.1.4 External handles on external doors shall withstand a downward vertical proof load of 1.7 kN without significant permanent deformation. For external handles which rotate, the proof load shall be applied with the handle in the worst case position(s).
- 5.5.1.5 Step materials and surfaces shall be slip resistant.

- GN41 The concentrated load specified is intended to represent a person stepping into or out of a vehicle, with an allowance for the dynamic effect of a load being applied suddenly. The distributed load is intended to represent the possibility of more than one person being on a step at the same time.
- GN42 The strength requirements for external grab rails, grab handles and door handles are intended to ensure that a grab rail or handle does not bend significantly or break when a person is attempting to enter or exit a vehicle from a low level. In this situation it is possible for the full weight of the person, plus a dynamic increment, to be carried by the handle.
- GN43 It should be noted that external cab steps and grab rails, while normally exclusively intended for the use of traincrew or personnel, are sometimes required to be used by passengers for the purposes of evacuation.
- GN44 These load cases represent established design values and are consistent with the requirements of various European standards such as BS EN 14752:2005.

2.6 Inter-vehicle gangways

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Section 5.6 Inter-vehicle gangways

5.6.1 Structural requirements

- 5.6.1.1 A gangway, including all its flexible elements, shall remain stable and provide a safe passageway between vehicles. Compliance with the following requirements of 5.6.1 shall be deemed to satisfy these objectives for conventional gangways. Requirements for open wide gangways are an 'open point'.
- 5.6.1.2 In service, gangway movement shall not expose any gaps, crevices or openings where passengers or traincrew could be caught, trapped or become injured by crushing or pinching.
- 5.6.1.3 Gangway loads, and where appropriate combinations of loads, shall be identified taking full account of the following conditions:
 - a) Kinematic and dynamic movements due to operation in passenger service taking account of:
 - i) Vehicle speed.

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- ii) Vehicle loads.
 - iii) Relative displacement between vehicles, including where applicable variations due to inflated and deflated suspensions on adjacent vehicles.
 - iv) Combinations of horizontal and vertical curvature.
 - v) Cant deficiency and cant excess conditions, including where applicable effects due to tilt systems.
 - vi) Differences between vehicles due to wheel wear or vehicle set up or vehicle and suspension tolerances.
- b) Kinematic and dynamic movements due to low speed operation in sidings and depots.
- c) Aerodynamic forces due to pressure transients created by other trains, by lineside structures and by passage through tunnels.
- 5.6.1.4 A gangway shall withstand without significant permanent deformation the following proof loads:
- a) A pressure load of 6 kPa on the standing floor area.
 - b) A concentrated perpendicular load, acting from within the gangway, of 0.8 kN applied over an area of 0.1 m x 0.1 m acting on the surface of the side walls. The gangway structure shall be capable of withstanding the concentrated load at any position.
- 5.6.1.5 A gangway shall withstand without significant permanent deformation as a proof load a differential pressure between the inside and outside of the gangway of ± 2.5 kPa. In the case of vehicles with a maximum speed in excess of 125 mile/h, or pressure sealing, an appropriate quasi-static aerodynamic pressure load shall be determined according to the requirements set out in Part 7.

- GN45 To meet the objectives for a stable and safe passageway, the full range of potential inter-vehicle movements should be determined. Where friction face gangways are used, typically between multiple units, the amount of sliding movement between gangways should be determined and controlled to ensure that a safe passageway is maintained at all times when people could be present.
- GN46 The proof load cases represent respectively:
- a) The maximum number of people that could theoretically be accommodated on the gangway floor.
 - b) The effect of somebody falling or being projected against the gangway side.
- GN47 The differential pressure proof load represents the maximum differential air pressure which would normally be expected in unsealed vehicles.
- GN48 In addition, the method of gangway mounting and how the gangway behaves in the event of a collision requires careful consideration to ensure that the gangway elements do not interfere with coupler collapse, anti-climber engagement or structural crush zones. It is recommended that consideration of gangway collapse is therefore included in any overall collision energy management strategy.

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Part 3 Vehicle Elements Interfacing with Passengers and Traincrew

3.1 Overview of vehicle interior crashworthiness and design

- GN49 An objective of interior design and the specific objective of interior crashworthiness is, in the event of an accident, to protect passengers and traincrew from injury and where complete protection is not reasonably practicable, to minimise the level of injuries that might occur. In addition, the application of these measures assists in reducing the level of injury through trips, slips and falls that can result from unexpected vehicle movements caused by heavy braking or track irregularities.
- GN50 Part 6 of GM/RT2100 is concerned with structural and interior crashworthiness requirements for rail vehicles. In applying these measures, it should be taken into account that the risks to be controlled arising from collisions and derailments are relatively infrequent events and a proportionate and balanced view of the full range of vehicle design requirements is therefore required.
- GN51 Part 6 of GM/RT2100 is structured according to the following principles:
- a) General requirements are set out in 6.1. These include requirements relating to modifications to existing vehicles, common requirements for calculations, dynamic testing, acceptance of existing test results, structural integrity and secondary impact.
 - b) Specific requirements for critical features of a rail vehicle interior are set out in 6.2 to 6.9; seats (6.2), tables (6.3), seat back tables (6.4), interior doors and windows (6.5), grab handles, poles, rails and hand holds (6.6), interior fixtures and fittings (6.7), luggage stowage (6.8) and cabs (6.9).
 - c) Detailed requirements for dynamic testing are set out in Appendices E to H.
- GN52 Each sub-section of Part 6 of GM/RT2100 sets out:
- a) Relevant principles or objectives.
 - b) Particular functional requirements.
 - c) Static load requirements.
 - d) Dynamic test requirements (where applicable).

3.2 Vehicle interior crashworthiness design principles

- GN53 In a collision or derailment a vehicle can be expected to experience very rapid deceleration and a primary external impact or a series of impacts as the vehicle's kinetic energy is dissipated. Secondary impacts inside the vehicle can be expected to occur in these circumstances and will depend on the intensity and duration of the primary impact or deceleration.
- GN54 There are essentially two aspects to interior crashworthiness:
- a) Structural integrity, with the objectives of preserving occupant survival space and maximising containment.
 - b) Injury potential, with the objective of designing the rail vehicle interior to control the risk of injury to passengers and traincrew in the event of an accident.

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- GN55 The interior design of a rail vehicle should attempt to anticipate a wide range of accident scenarios. Individual vehicles will yaw, pitch and roll during accidents, effects which purely structural standards do not consider explicitly. Specific design scenarios have not been developed but it is clear from accident investigations that significant secondary impacts due to lateral and vertical accelerations feature in some vehicles in most accidents and thus the risk of secondary impacts from these directions should be considered.
- GN56 Many recent accidents cannot be easily related to the structural collision scenarios set out in BS EN 15227:2008 (for example Potters Bar, Ufton Nervet, Great Heck, Grayrigg). The crash scenarios set out in BS EN 15227:2008 are designed to test the vehicle primary structure and when taken with the static strength requirements (set out in BS EN 12663:2000), these can be seen to collectively represent an 'assault course', successful completion of which results in what is considered to be a satisfactory vehicle structure.
- GN57 Application of the interior crashworthiness requirements should maintain and complement the structural integrity of the complete vehicle by ensuring that the strength of the interior fixtures and fittings is consistent with the strength of the primary vehicle structure and to ensure that an unbroken chain of protection is maintained between an external accident and the people inside the vehicle.
- GN58 For assessing injury potential due to impacts within the vehicle, where dynamic testing is required the principal design scenario is based around a dynamic crash pulse (set out in Appendix E of GM/RT2100). This pulse is designed to generate impact velocities which will as far as reasonably practicable replicate the severity of injuries that are seen in accidents. This might entail some inconsistency with structural aspects but is consistent with the overall objectives of interior crashworthiness.
- GN59 A crashworthy interior design will not only complement structural standards in respect of major impacts but will also reduce the effect of slips, trips and falls arising from heavy braking and rough riding. It is recommended that the findings of RSSB research project T358 are taken into consideration.

3.2.1 Secondary impact

- GN60 As a vehicle decelerates all objects inside which are not attached or contained will retain their kinetic energy and continue to move at the velocity of the vehicle prior to the primary impact. This motion will continue until these objects are brought to rest by secondary impacts with fixed items. In a collision a passenger would therefore be projected in the direction of impact relative to the vehicle. On impacting an object or another person, some or all of the projected passenger's energy will be dissipated. Glancing impacts, which may still be sufficiently severe to cause injury, may leave the body with residual energy which will be dissipated in further impacts. It should not be assumed that all occupant movements will be parallel to the longitudinal axis of the vehicle and that all passengers and staff will be seated.
- GN61 In general the severity of a secondary impact injury is dependent upon the kinetic energy (proportional to the object's mass and the square of relative velocity) and its rate of dissipation on impact. The rate of kinetic energy dissipation (the relative deceleration at the point of contact) is related to the stiffness of the contact surface, the concentration of energy per unit contact area and the body region involved.
- GN62 The speed of an impacted vehicle and its interior components reduces very rapidly in a collision, whilst the velocity of an unrestrained passenger or object remains relatively constant (free flight). The risk of serious injury is lessened, therefore, by reducing the length of excursion occupants make along the vehicle. The shorter the excursion the less likelihood of severe secondary impact with interior features or other occupants, since the velocity of the passenger relative to the vehicle at impact will be less.

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GN63 The human body can be characterised as a group of linked segments, each with their individual masses, inertias and stiffness characteristics. If, for example in the case of a chest impact, where the chest is stopped directly but the head is not, the neck is stressed transferring forces and moments to the chest as the head is subsequently decelerated. It is therefore important to attempt to control the trajectory of the passenger in an accident, the passenger's orientation at impact, and to minimise the relative movement between body segments caused by rapid deceleration of one part but not the other.

GN64 To minimise the severity of injuries it is recommended that the interior crashworthiness design takes account of the following:

- a) The velocity at the point of contact.
- b) The area impacted in order to reduce the energy concentration.
- c) The potential for impact on the areas of the body containing vital organs.
- d) The relative movement between body segments.

3.2.2 Injury criteria

GN65 It is very rare that a passenger will sustain a fatal injury due to secondary impacts and it is therefore the intention that the levels and type of injury criteria should be set to ensure that potentially serious injuries are reduced to a lower category or eliminated altogether wherever possible.

GN66 The injury criteria have been developed over a number of years initially as part of the research programme launched by British Rail after the Clapham accident (1989). The criteria adopted have been developed from British Rail Safety Directorate Codes of Practice BR/BCT 608:1996 and BR/BCT 609:1996, which were merged and republished as ATOC Standard AV/ST9001 (2002).

GN67 The majority of the injury criteria selected were initially developed for the automotive industry. This has the advantage that standard measuring devices anthropomorphic test devices (ATDs) and instrumentation can be used. Where considered necessary the threshold or limiting values have been adjusted to reflect conditions in rail vehicles. The injury criteria were reassessed and revised by RSSB research project T066. These criteria have been and will be further refined as national, European and international research continues in this field.

3.2.3 Vehicle interior layouts

GN68 The vehicle layout, in particular the seating and the arrangement of screens, partitions and grab rails or poles will play a key role in determining potential trajectories for passengers in the event of a collision. The ability of vehicle interior components such as seats and tables to absorb energy and the detail design of seemingly minor items, such as luggage racks, coat hooks, magazine racks and table lights, can have a significant effect on the outcome of a collision for the passengers inside.

GN69 Analysis of passenger injury data has indicated that a high proportion of passenger injuries can be attributable to seat impacts. Unidirectional seating provided a higher degree of protection than open bay seating configurations or longitudinal seating arrangements by providing containment in the immediate seating area, preventing longer excursions in the vehicle and reducing the possibility of impacts or interaction with other passengers.

GN70 Bay seating with tables can give a high level of containment provided that the risk of chest or abdominal injury from impact against the table edge can be controlled. A number of strategies for achieving this have been investigated, for example deformable edges or flip up sections (see RSSB research project T201 report).

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- GN71 Open bay seating arrangements (bay seating arrangements without tables) can lead to an increase in injury severity due to the longer distance the passenger is thrown forward before impacting the seat opposite when compared with a unidirectional seating arrangement and the risk of increased injury numbers and severities due to impacts with passengers sitting opposite.
- GN72 For inner-suburban or metro applications where high densities of standing passengers are catered for and short station dwell times are essential, longitudinal seating can be an attractive solution. Longitudinal seating however does not necessarily provide a high level of containment for passengers in a collision.
- GN73 The potential disadvantages from an interior crashworthiness perspective of longitudinal seating layouts are generally mitigated by the lower operational speeds for inner-suburban or metro vehicles and can be further mitigated by careful consideration of draughtscreen size and positioning, the location of grab poles and the size and form of armrests where these are provided. For continuous rows of longitudinal seats, it is recommended that there should be no more than three adjacent longitudinal seating positions without separation from the adjoining seats by using grab poles, draughtscreens, or similar features.
- GN74 To minimise the risk of potentially long trajectories for seated occupants in a collision, exposed seats (a seat which does not have seats directly opposite as part of a seating bay) should not be used. An exposed seat can be considered to be a seat where the potential passenger trajectory significantly exceeds the dimensions of an open bay arrangement. It is recommended that where such seats would otherwise occur, the layout limits the potential occupant trajectory by the use of, for example, other seats, tables, partitions or, less beneficially, a longitudinal seat orientation.

3.3 Vehicle interior design requirements

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Section 6.1 Vehicle interior design requirements

6.1.1 General requirements

- 6.1.1.1 The requirements of Part 6 apply to all vehicle interior elements and aspects of passenger vehicles that interface with personnel or traincrew, subject to the following considerations set out in 6.1.1.2 to 6.1.1.5.
- 6.1.1.2 For new designs of vehicle the requirements shall apply in full. Where additional vehicles of an existing design are added to an existing fleet, or vehicles are built to replace damaged vehicles, it is permissible to comply with the original specifications and standards.
- 6.1.1.3 It is permissible to make changes or enhancements to a vehicle interior or to a distinct area of the interior using items to the same design standard as the existing vehicle interior where it can be demonstrated that the level of safety is at least maintained.
- 6.1.1.4 Where panelling, partitions, doors, grab rails, grab poles or other items are substituted or added, the substitute or additional items shall, as far as reasonably practicable, comply with the relevant requirements in Part 6.
- 6.1.1.5 For refurbishment of existing vehicles, and where a reasonable opportunity exists, the requirements shall apply in full to all areas where the vehicle interior is essentially removed and replaced with a new design. Where due to limitations imposed by the underlying primary vehicle structure, it is not possible to achieve full compliance, the requirements of Part 6 shall be applied as far as it is reasonably practicable.

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- GN75 Where additional vehicles are added into an existing fixed formation unit, for example lengthening an existing four car unit to five cars, it is intended that the original specifications and standards should be applicable provided that the design of the new vehicles is consistent with the existing vehicles (see 6.1.1.2 of GM/RT2100).
- GN76 An example of the type of change envisaged in 6.1.1.3 of GM/RT2100 would be, for example, a rearrangement of a vehicle saloon to change the mix of bay and unidirectional seating which could be achieved without any modification to the component parts.
- GN77 The structural integrity of adjacent items should be taken into account to ensure that overall the design of the vehicle interior remains coherent and consistent. Under no circumstances should the structural integrity of the vehicle interior be reduced.
- GN78 For some older vehicles it is recognised that the side wall or floor structures might not be sufficient to permit full compliance without substantial re-engineering in which case a compromise between the requirements in Part 6 of GM/RT2100 and the existing build standard could be justified on the grounds that a reasonable opportunity to achieve compliance with the requirements of GM/RT2100 did not exist.

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6.1.2 Dynamic testing, computer simulations and calculations

6.1.2.1 It is permissible to undertake computer simulations and calculations in place of dynamic testing where it can be demonstrated that the models used are validated against directly comparable test data for a rail vehicle interior. As a minimum, it shall be demonstrated that:

- a) Validated computer models of the anthropomorphic test devices (ATDs) are used.
- b) The models used for seats, tables or other fixtures are validated by testing or calculation.
- c) The results obtained exhibit good correlation with existing test data for equivalent conditions.

6.1.2.2 Reference to dynamic testing within Part 6 therefore includes the use of simulation or calculation methods set out in 6.1.2.1.

6.1.3 Applicability of existing component test results

6.1.3.1 Where an item has already been dynamically tested in accordance with this document or in accordance with AV/ST9001 which is superseded by this document, additional testing for a new installation shall not be required if it can be demonstrated that all of the following conditions are satisfied:

- a) The proposed layout in terms of occupant safety is equivalent or better than the arrangements previously tested.
- b) Dynamic load data has been obtained from the original test series to define the dynamic load requirements for the item's installation, attachment points and fixings.
- c) The item's fixings and corresponding vehicle structure can resist all loads resulting from static proof and dynamic collapse loads.
- d) The item's design and mounting arrangements are mechanically equivalent to those for which test data has been obtained.

- GN79 Dynamic testing is intended to validate a given seat or table design and when satisfactorily completed to then allow the seat or table to be used in a wide range of vehicle layouts provided that the limiting, worst case, conditions tested are not exceeded.

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- GN80 It is acceptable for a seat or table, having been successfully tested, to be used in seating layouts to suit a given vehicle interior without recourse to further testing provided that the effective design limits established are not exceeded and it can be demonstrated that the installation is mechanically equivalent. Typically the critical parameter for the risk of injury will be the relative seat pitches proposed and the potential free flight distance for a passenger in any given location.
- GN81 It should be demonstrated that the original test data is sufficient to fully define the dynamic seat mounting loads and that the new installation arrangement can satisfactorily withstand these loadings. For seats the squabs, cushions, headrests, frames, pedestal and fasteners should be mechanically equivalent to the design tested. For tables mechanical equivalence of the assembly and attachment points should be demonstrated.

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6.1.4 Security of furniture, equipment and features

- 6.1.4.1 Except for trolleys being used for the provision of an at-seat service (see 6.7.5), there shall be no loose items of furniture or equipment.
- 6.1.4.2 All interior panelling, furniture, equipment, access panels or other features shall comply with the requirements of 3.2 and Part 2.
- 6.1.4.3 Proof acceleration loads for seats, tables, body mounted interior panelling, fittings or equipment shall exclude loads due to passengers or luggage. Specific load requirements relating to passengers and luggage are set out in 6.2 and 6.8.

- GN82 The loadings on the interior due to passenger mass and luggage mass are considered separately. The objective is to ensure that passenger loads are not double-counted by imposing high and possibly unrealistic proof load requirements from vehicle structure acceleration loadings on interior furniture and then additionally requiring dynamic testing to simulate accident conditions. It should be considered that for most of the acceleration loadings specified, the added masses of passengers or luggage are only weakly coupled, if at all, to the masses of the interior furniture.

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6.1.5 Structural energy absorption and collapse

- 6.1.5.1 Seat assemblies, tables, and interior fixtures shall satisfy the following requirements under the proof, ultimate and, where applicable, dynamic load conditions specified in this document:
- a) Elements that form part of a primary load path shall include ductile materials to ensure that the complete structure exhibits post-yield plasticity and energy absorption, when loaded beyond the specified proof loads.
 - b) All attachments to the primary structure shall remain intact for all load conditions specified in this document.
 - c) A continuous load path shall be maintained under all load conditions specified in this document without abrupt changes in force levels due to for example buckling, snap-through or fracture.
 - d) No sharp objects or fracture surfaces are produced which are likely to cause injury.
- 6.1.5.2 For seats and tables, after application of a specified proof load, it is permissible for any permanent deformation to be of greater magnitude than would normally be considered to be acceptable, subject to the following conditions being satisfied:

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- a) The item is dynamically tested in accordance with 6.2.4 (seats) and 6.3.2 (tables) and satisfies all dynamic test requirements for structural strength and passenger injury.
- b) The permanent deformation is the result of post-yield plastic deformation.
- c) All structural attachments to primary structure and any joints or connections within the seat or table assembly, do not show any local deformation or strain that could affect the integrity of the attachments, connections or joints.

- GN83 Items such as seats and tables cannot generally be made entirely from ductile materials, however a complete seat or table assembly can be designed to behave in a ductile manner and absorb useful amounts of energy by using suitable materials for critical components where impact is most likely to occur and for the attachments to the primary vehicle structure.
- GN84 Items such as seats and tables should remain attached for the conditions specified due to their often appreciable mass which, if released, would have the potential to cause serious injury. Where items are loaded during an impact they should not break away or become partially detached to give a discontinuous load path with abrupt jumps in force levels or expose otherwise concealed parts with the potential for additional injury. In particular the fixings to the vehicle structure should be the last components to fail when the seat or table assembly is subject to overload.
- GN85 After testing seats and tables to the specified proof loads, it is possible to have deformations of a magnitude that would exceed what is usually considered to be 'significant permanent deformation'. To redesign these items to comply with more typical proof load acceptance criteria, could then put at risk satisfactory crashworthiness behavior, due to the increases in stiffness that might be required. For crashworthy seats and tables, it is considered that achieving the dynamic test requirements should take precedence over the proof loading conditions, since this is generally of the greater benefit to passengers. It is however essential to show that, if overloaded in an essentially quasi-static manner, the seat or table remains in a safe condition and that the dynamic test requirements for structural integrity and passenger injury are complied with in full.
- GN86 Materials should be carefully selected to ensure that sharp spikes or fragments are not formed or aggressive internal components of composite panels are not exposed when items are broken or ruptured due to severe impacts beyond the specified vehicle interior design requirements. The objective is to minimise the risk of injury due to severe abrasion, lacerations or stab wounds. It is acknowledged that other requirements, for example fire safety, will however restrict the options that are available and the extent to which the objective can be realised.

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6.1.6 Areas subject to secondary impact

- 6.1.6.1 Areas of a vehicle interior which are accessible to passengers, personnel or traincrew in normal service shall be assessed for potential injury due to secondary impact in the event of a collision or derailment. The secondary impact assessment shall include but not be limited to:
- a) Parts of seats, tables and drivers desks outside the scope of dynamic testing requirements (see 6.2, 6.3 and 6.9).
 - b) Panels and panel edges.
 - c) Controls, instruments, switches and indicators (for example driver's desks and guards panels).
 - d) Equipment cubicles or housings