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Railway applications — Rolling stock — Interior passive safety

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ISO/TR 5914

Railway applications — Rolling stock — Interior passive safety

Applications ferroviaires — Matériel roulant — Sécurité passive des aménagements intérieurs

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Contents

Page

Foreword ... **iv**
Introduction ... **v**
1 Scope ... **1**
2 Normative references ... **1**
3 Terms and definitions ... **1**
4 Strategic objectives ... **4**
4.1 Road transport comparison ... 4
4.2 Rail context ... 5
4.3 Structural passive safety ... 5
4.4 Minimization of injury ... 6
4.5 Interior passive safety principles ... 6
4.5.1 General design considerations ... 6
4.5.2 Component design ... 7
5 Benefits of interior passive safety in train collisions ... **7**
6 Examples of rail vehicle interior structural design criteria ... **7**
6.1 Global standards for vehicle structural integrity ... 7
6.2 Standards for interior equipment ... 8
6.3 Material selection for rail vehicle interiors ... 9
6.4 Structural energy absorption and collapse: UK practice from GMRT2100 ... 10
6.5 Secondary impact assessment ... 10
6.5.1 Considerations for persons with reduced mobility ... 10
6.5.2 Secondary impact principles ... 11
6.5.3 Secondary impact review ... 11
6.5.4 Secondary impact design scenarios ... 12
6.5.5 Containment and compartmentalization ... 12
6.5.6 Minor impacts with interior features ... 13
6.6 Geometric criteria ... 13
6.6.1 Standards with geometric requirements ... 13
6.6.2 Geometric principles ... 13
6.7 Computer simulations, calculations and testing ... 14
6.8 Possible re-use of existing component test results ... 15
6.9 Open bay seating ... 16
Annex A (informative) **Interior passive safety experience from UK and US** ... **17**
Annex B (informative) **Accident statistics** ... **33**
Annex C (informative) **Costs and potential benefits of interior passive safety, based on UK practices** ... **47**
Annex D (informative) **Considerations for persons with reduced mobility** ... **54**
Annex E (informative) **Example abbreviated injury scale** ... **57**
Bibliography ... **58**

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Full document details: PD ISO/TR 5914:2024

Foreword

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This document was prepared by Technical Committee ISO/TC 269, *Railway applications*, Subcommittee SC 2, *Rolling stock*.

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Introduction

It is generally accepted that avoiding collisions is a key operating principle of railway systems. This can be achieved, for example, by dedicated lines, eliminating level crossings and providing sophisticated control (signalling) systems.

The safety performance of railways has improved significantly in recent years, to the extent that train crashes, derailments and overturning are now very rare events. However, this document includes evidence which suggests that, despite advancements in train control and other active safety measures, these incidents will continue to occur, albeit at a much-reduced rate of incidence. Collisions and derailments can still occur due to incidents such as infrastructure failures, landslides or incursions from road traffic.

Railway administrations in different countries have conducted extensive accident investigations and research into collision events. These and other countries have reached consensus that there is benefit in managing collision energy and vehicle dynamics in collision conditions. This is achieved by designing rail vehicle structures to have better collision performance in certain prescribed conditions; such vehicles are said to have a “crashworthy structural design”.

Many countries have static structural standards; these are complemented (e.g. in Europe and North America) with structural crashworthiness standards. The aims of crashworthy structural designs are generally to:

— reduce the risk of vehicles overriding;

— absorb collision energy in a controlled manner;

— maintain survival space and structural integrity of the occupied areas;

— limit the car body deceleration;

— reduce the risk of derailment;

— limit the consequences of hitting an obstruction on the track.

Some countries have investigated the effect of train crashes on passengers in rail vehicles, aiming to establish a causal link between occupant fatalities or injuries and the design and layout of train interior fixtures, such as seats, tables, luggage racks, stanchions and interior glazing. These investigations culminated in the modelling and testing of deceleration events, as prescribed for the crashworthy structural design, to apply measures to the design of rail vehicle interiors which provide a favourable environment for passengers and staff in these conditions. These measures are collectively considered as interior passive safety and will aid:

— containment;

— compartmentalization;

— reducing and controlling the risk of injuries in secondary impacts that occupants can experience in train crashes and derailments, by incorporating energy absorption in seats and tables and non-aggressive shapes for interior equipment (tables, grab poles, seats, luggage racks).

Specifically, the aim of interior passive safety is to reduce injuries and injury severity to limits which are not life threatening, nor a threat to mobility or cognitive function. However, it is recognized that in the catastrophic and chaotic events associated with vehicle collisions, derailments and overturning, passenger injuries will still occur.

Interior passive safety principles are based on extensive research (e.g. the European Union (EU)-funded SafeInteriors research project (2006–2010), and work conducted by the US Department of Transportation (DoT) Federal Railroad Administration (FRA) and the Volpe National Transportation Systems Center). This research has concluded that the aims of preventing occupant fatalities, and reducing the number and severity of injuries, are best achieved through combining vehicle structural crashworthiness with interior passive safety.

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Application of the principles of interior passive safety can also be expected to reduce the consequences of minor incidents, such as slips, trips and falls, that can result from unexpected vehicle movements caused by, for example, emergency braking or track irregularities.

This document describes the worldwide state of the art regarding interior passive safety on passenger rail vehicles.

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Railway applications — Rolling stock — Interior passive safety

1 Scope

This document reports worldwide best practice to minimize the risk of death and injury to occupants of rail vehicles in the event of a collision or derailment.

This document investigates recent interior designs for passenger areas in heavy rail vehicles (e.g. coaches, fixed units, trainsets), including refurbished interiors.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 17343:2023, *Railway applications – General terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 17343:2023 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
structural passive safety
crash energy management
CEM
design to preserve the structural integrity of a rail vehicle during a collision or derailment

Note 1 to entry: It usually includes the objectives of reducing the *risk* (3.19) of derailment and overriding, providing *survival space* (3.2) for occupants, and minimizing the risk of detached or loose objects or debris.

3.2
survival space
residual space
portion of the vehicle interior designed to have limited or no structural deformation

Note 1 to entry: This can apply both to the general vehicle structure and to smaller subdivisions such as the space between seats or between a seat and a table.

Note 2 to entry: In terms of occupant interior passive safety, this is regarded as the space required for an occupant to survive and to avoid crush-type injury and entrapment.

3.3
containment
keeping occupants within vehicles

Note 1 to entry: Containment predominantly prevents occupant excursion via windows and doors.

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3.4
compartmentalization
control of occupant trajectory length within a vehicle

Note 1 to entry: This generally refers to an interior design strategy with the goal of limiting occupants' travel within a small, defined space during a collision, i.e. between rows of seats, or a seat and table, to prevent occupants from travelling large distances and impacting other more hostile objects with larger velocities.

3.5
primary impact
collision of a rail vehicle with another rail vehicle or an obstacle on the track

3.6
secondary impact
contact of an occupant with a fixed interior feature, or another occupant or occupants, following a *primary impact* (3.5) or other accident

3.7
proof load
load which represents, or is intended to be equivalent to, an exceptional maximum load that can be encountered when in normal service and which, when applied and removed, results in no damage, loosening of fixings or deformation that would require repair or replacement

Note 1 to entry: Normally, a proof load is a static or quasi-static load which has been derived from more complex dynamic conditions.

[SOURCE: UNIFE REF 001[1], 3.17]

3.8
ultimate load
load which represents, or is intended to be equivalent to, an exceptional load outside of normal service conditions due to overloading or accident which can result in significant damage or permanent deformation that will require repair or replacement

Note 1 to entry: An ultimate load may be a static, quasi-static or dynamic load.

3.9
slips, trips and falls
accidental or involuntary movement of a person arising from and/or resulting in contact with an object or surface

Note 1 to entry: A person can slip when they lose their footing, trip when they catch a foot on or in something, and fall when they come down suddenly.

Note 2 to entry: Slipping is defined to be a fall because of sliding due to a sudden loss of all or part of the support base (the area spread by the feet and any other support) in a way that the gravity line moves beyond the support area. Tripping is most often caused by an obstruction, followed by uneven surfaces, preventing normal foot movements and leading to a loss of balance. The size and location of any defects affects the severity of the trip. Finally, falling is usually defined to be a fall from a height.[2][3]

3.10
handhold
handrail
any device on board a transport vehicle that is designed to allow passengers to use their hand grip to manoeuvre through the vehicle or provide passengers with a more stable ride while on board the vehicle

[SOURCE: ISO 10865-1:2012[4], 3.4, modified — Admitted term "grab bar" deleted.]

3.11
grab rail
handhold (3.10) designed to support and to permit transfer of body weight, usually found in locations adjacent to showers, bathtubs, WC suites, and wash basins in a bathroom or toilet

[SOURCE: ISO 6707-1:2020[5], 3.3.2.76, modified — Admitted term "grab bar" deleted.]

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3.12
light injury
moderate injury
person who is hospitalized for one day to three days or requires one day to three weeks off work

Note 1 to entry: See also *minor injury* (3.13), *serious injury* (3.14) and *life threatening* (3.15). These definitions vary between countries. ISO/TS 17755-2[6] relates predominantly to fires in buildings.

Note 2 to entry: For the technical evaluation of occupant injury, the abbreviated injury scale (AIS, see Annex E) is used by researchers and accident investigators to evaluate levels of attributed injury. The AIS system is an anatomically based injury severity scoring system. It is linked to injury acceptance reference values (IARVs) or injury criteria used by some countries to limit the injury potential of train furniture.

[SOURCE: ISO/TS 17755-2:2020[6], 3.57, modified — Cross-reference to "fire injury" deleted and additional sentences added in Note 1 to entry. Note 2 to entry added.]

3.13
minor injury
person who is hospitalized or off work for less than one day

Note 1 to entry: See also *light injury* (3.12), *serious injury* (3.14) and *life threatening* (3.15). These definitions vary between countries. ISO/TS 17755-2[6] relates predominantly to fires in buildings.

Note 2 to entry: See also Note 2 to entry in 3.12.

[SOURCE: ISO/TS 17755-2:2020[6], 3.61, modified — Cross-reference to "fire injury" deleted and additional sentences added in Note 1 to entry. Note 2 to entry added.]

3.14
serious injury
person who is hospitalized for four days or more or has more than three weeks off work

Note 1 to entry: See also *minor injury* (3.13), *light injury* (3.12) and *life threatening* (3.15). These definitions vary between countries. ISO/TS 17755-2[6] relates predominantly to fires in buildings.

Note 2 to entry: See also Note 2 to entry in 3.12.

[SOURCE: ISO/TS 17755-2:2020[6], 3.73, modified — Cross-reference to "fire injury" deleted and additional sentences added in Note 1 to entry. Note 2 to entry added.]

3.15
life threatening
injured person who must immediately receive emergency rescue and medical treatment to prevent a certain and impending death

Note 1 to entry: See also *minor injury* (3.13), *light injury* (3.12) and *serious injury* (3.14). These definitions vary between countries. ISO/TS 17755-2[6] relates predominantly to fires in buildings.

[SOURCE: ISO/TS 17755-2:2020[6], 3.56, modified — Cross-reference to "fire injury" deleted and additional sentences added in Note 1 to entry.]

3.16
fatality
death
person who has died as a result of injuries sustained during an accident

Note 1 to entry: In this context, there is no limitation of time after the accident. Fatalities also include death from natural or accidental causes sustained while involved in the activities of attempting rescue or escaping from the dangers of the accident.

Note 2 to entry: Fatalities are composed of all persons discovered or declared dead at the location of the accident, during their transportation to the hospital or after their admission to the hospital.

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Note 3 to entry: These definitions vary between countries; ISO/TS 17755-2[6] relates predominantly to fires in buildings.

[SOURCE: ISO/TS 17755-2:2020[6], 3.37, modified — Terms "fatal casualty" and "fatal injury" deleted. References to fire either replaced by "accident" or deleted in the terms, definition and notes to entry. "including blast and defenestration, except when a death occurred in sites with the right of extraterritoriality" deleted from Note 1 to entry. Note 3 to entry added.]

3.17
value of preventing a fatality
VPF
sum of money used in *cost benefit analysis* (3.18) for the valuation of safety benefits and disbenefits in decision-making processes

3.18
cost benefit analysis
CBA
means used to assess the relative cost and benefit of a number of *risk reduction* (3.20) alternatives

[SOURCE: ISO/TS 16901:2022[7], 3.7, modified — Note 1 to entry deleted.]

3.19
risk
combination of the probability of occurrence of harm and the severity of that harm

[SOURCE: ISO/IEC Guide 51:2014[8], 3.9, modified — Note 1 to entry deleted.]

3.20
risk reduction
actions or means to eliminate hazards or reduce *risks* (3.19)

[SOURCE: ISO 10377:2013[9], 2.22]

3.21
fatalities and weighted injuries
FWI
composite measure of *risk* (3.19) or harm that combines *fatalities* (3.16) with physical injuries and cases of shock/trauma, which are weighted according to their relative severity

Note 1 to entry: The measurement is the number of fatalities, *serious injuries* (3.14) and *minor injuries* (3.13) from the consequences of accidents, where 1 serious injury is considered equivalent to 0,1 fatalities, and 1 minor injury is considered equivalent to 0,01 fatalities.

[SOURCE: RSSB[10], modified — Note 1 to entry added.]

4 Strategic objectives

4.1 Road transport comparison

Although travel by rail is generally safer than by car or bus, many of the safety measures adopted in the United Kingdom (UK) and the United States of America (US) are derived from the automotive industry, as described in the following paragraphs.

European automotive regulations (UN/ECE 80[11]) require impact testing using a sled to achieve a change of velocity (Δv) of between 30 km/h and 32 km/h (8,3 m/s to 8,9 m/s); this gives acceleration levels between 8*g* and 12*g*.

It is worth noting that the reduced levels of acceleration (and the increased time period of the pulse) set out in GMRT2100[14] are based on trains being significantly heavier than road vehicles, and that there is potentially more space in the front of a rail vehicle to provide a "crumple zone" than in a road vehicle. Clause A.2 describes the derivation of the pulse.

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US automotive regulations 49 CFR 571_208 (FMVSS208)[15]: The platform is decelerated from 48 km/h to 0 km/h (30 mph to 0 mph) in a distance of not more than 0,914 m (3 feet), without change of direction and without transverse or rotational movement during the deceleration of the platform and the departure of the vehicle. The deceleration rate is at least 20*g* for a minimum of 0,04 s. This therefore gives a change of velocity (Δv) of at least 0,04 × 20 × 10 = 8 m/s; which is similar to UN/ECE 80[11].

In 2023, the US DoT FRA developed an "Engineers' Protection System" (comprising an airbag and knee bolster fitted in the driver's cab).[16] The analysis and testing thereof used a test pulse derived from the acceleration measured in the engineer's cab during a single multilevel rail car impact with a rigid wall at 58,9 km/h (36,6 mph).

The APTA standard for seats (APTA PR-CS-S-016-99, Rev. 3.1, 2023[17]) uses a scaled version of the aerospace crash test pulse in SA AS8049[18]. This is a triangular pulse, maximum 8*g* over 250 ms, giving a minimum Δv of 35,3 km/h (21,95 mph or 9,81 m/s).

Some recent work conducted by Transport Research Laboratory (TRL) for Transport for London in the UK assessed the potential reduction in injuries on buses simply by implementing geometric criteria (e.g. eliminating or relocating sharp edges).

4.2 Rail context

Rail systems aim to transport passengers and goods from place to place safely, comfortably and economically. Active train control systems play a major part in this, notably in reducing the number of train collisions; however, unforeseen circumstances still occur which can lead to collisions or derailments. Such circumstances are often outside the immediate control of the railway system, such as weather-related events or incursions of obstacles (such as debris, landslips and road vehicles) into the railway.

Further, operational events such as emergency braking, coupling trains in operation, and traversing switches and crossings lead to accelerations affecting occupants.

Annex A gives further details of the application of interior passive safety on rail vehicles in the UK and the US.

4.3 Structural passive safety

There exist many examples worldwide of static structural standards, and these are complemented by rail vehicle design standards for dynamic structural crashworthiness in North America and Europe. These aim to preserve the structural integrity of the interior during a collision or derailment, with the objectives of preserving occupant survival space and minimizing the risk from detached or loose objects or debris.

For example, EN 15227:2020[19] states:

> "The objective of the passive safety requirements described in this European Standard is to reduce the consequences of collision accidents. The measures considered in this European Standard provide the means of protection when all possibilities of preventing an accident have failed. It provides a framework for determining the crash conditions that rail vehicle bodies can be designed to withstand, based on the most common collisions and associated risks.
>
> This European Standard adds to the basic strength requirement defined in EN 12663-1:2010+A1:2014[20] by setting additional requirements for structural passive safety in order to increase occupant safety in case of collisions.
>
> In the event of a collision, application of this European standard provides protection for the occupants of new designs of crashworthy vehicles through the preservation of structural integrity, reducing the risk of overriding and limiting decelerations. This protection does not extend to interactions between the occupants and the vehicle interior …" © CEN, reproduced with permission

Interior passive safety is therefore generally considered in the context of the first principle of vehicle structural design and structural passive safety, i.e. the use of structural passive safety components to preserve space and limit longitudinal decelerations up to specific collision speeds. Structural passive safety also helps to prevent override and lateral buckling. Experience of crash tests varies between countries, with some reporting reductions in fatalities and injuries from structural passive safety alone in relatively

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high-speed collisions, while in other cases, the use of structural passive safety without considering interior passive safety has led to increases in injuries from secondary impacts.[21] Therefore, in general, it is concluded that designing the interior to control secondary impacts is necessary to reduce the risk and/or the severity of injuries.

4.4 Minimization of injury

The second principle of interior passive safety is to minimize the risk of injury to train occupants in the event of a collision or derailment. Even if the possibility of injury cannot be eliminated, the seriousness of potential injuries can at least be reduced; this improves the chances of injured persons being able to evacuate themselves.

A further outcome is a likely reduction in the injuries to occupants arising from slips, trips and falls, by minimizing or eliminating sharp contours and edges.

If there remains sufficient occupant survival space, and interior components such as seats, tables, fire extinguishers, etc. have not detached from the structure, minimization of occupant injuries is achieved by the following three main control measures:

a) Containment of occupants:

— to prevent occupants from being ejected from the vehicle by careful design of doorways (e.g. EN 14752[22]) and glazing (e.g. ISO 22752[23]).

b) Compartmentalization:

— in the event of a collision or derailment, occupants are contained within a small area of the vehicle (e.g. between rows of seats, between a seat and table) and, equally, that heavy items such as luggage or on-board equipment are contained in their respective areas.

c) Reduction of the consequences of secondary impacts:

— minimizing the trajectory length of an occupant before collision with interior fitments or another occupant by careful design of seats, tables, partitions and luggage racks;

— careful design of interior components, including glazing (see EN 17530[24]) to reduce point loads on the human body, and avoiding trapping risks by good geometric design and selection of materials (see JIS E 7103[25], JIS E 7104[26] and JRIS R 1010[27]);

— consideration of the potential impact surface, e.g. impact surface mechanical performance and its ability to absorb impact energy, and the shape of features and components.

Careful design of the interior of a rail vehicle can also reduce the risk of injuries from other mechanisms such as:

— electric shocks from damaged electrical fittings or exposed wiring;

— injuries from broken glass in windows, partitions and draught screens.

4.5 Interior passive safety principles

4.5.1 General design considerations

Experience from research and accident investigations in the UK (see RSSB Report T910[28]) and the US (see Clause B.2) has shown that the vehicle layout, in particular the seating and the arrangement of screens, partitions and grab rails or poles, plays a key role in determining potential trajectories for occupants in the event of a collision.

NOTE Annex B contains examples of accident statistics from various countries.

Inside the vehicle, compartmentalization measures have the objective of managing the risk of uncontrolled movement of occupants in the vehicle interior space. Vehicle interior layouts that offer good levels of

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compartmentalization limit the length and number of potential trajectories from a given occupant location (seated or standing) and therefore reduce the risk of injury.

Interior layouts are subject to a wider range of, sometimes contradictory, considerations, for example:

— operational needs and aspirations, including passenger density, boarding and alighting times;

— the type of service (distance, speed, duration);

— vehicle ambience and security.

4.5.2 Component design

It is intended that, once a component design is successfully validated (e.g. for a seat or table), it can be used in another vehicle design without the need for further validation, when the vehicle category is similar, and the installation is mechanically equivalent. Validation can consist of calculations, static or dynamic testing, or a combination thereof.

When satisfactorily completed, the component can then be used in a wide range of vehicle layouts provided that the limiting, worst case, conditions tested are not exceeded. It is therefore acceptable for a component, having been successfully tested, to be used in a given vehicle interior without recourse to further testing, provided that the effective design limits established are not exceeded.

5 Benefits of interior passive safety in train collisions

As indicated in the introduction of this document, train crashes, derailments and overturning are very rare events. Because of this, there is very little data upon which to base a realistic analysis of the direct benefits of interior passive safety measures.

However, it is considered that these measures are likely to lead to reductions in the number and severity of injuries in collisions and derailments, which in turn lead to a better chance of escape. For example, a vehicle interior designed with these principles can reduce the risk of an occupant sustaining a head injury or a broken limb, which is likely to mean that the occupant is able to self-evacuate in the event that the train was involved in an accident.

Other perceived benefits would include reduced injuries and their severities in “other incidents” (see LOC&PAS TSI[29] clause 7.5.2 and Powell & Fletcher[30]. There is also the potential for improvements to reputation and the public perception of the safety of travelling by rail, even extending to reductions in lawsuits.

The RSSB Business Case for GMRT2100 issue 4 (Annex F of Reference [31]) gave a benefit to cost ratio of 1,9 based on reductions in injuries from slips, trips and falls alone (thus ignoring the benefits of improved signalling systems in preventing collisions).

Further details of potential benefits and costs are given in Annex C.

6 Examples of rail vehicle interior structural design criteria

6.1 Global standards for vehicle structural integrity

In Europe, high-level legislation for mainline passenger rail vehicle structural integrity is set out in the LOC&PAS TSI[29] (the equivalent being the NTSN[32] in the UK). The TSI requires compliance to parts of the European standards EN 12663-1[20] and EN 15227[19], which would otherwise be voluntary standards.

In the US, Passenger Equipment Safety Standards 49 CFR 238[33] are federal regulations required by law. These are supported by (voluntary) APTA standards shown in Table 1.

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Table 1 — Selection of APTA standards for passenger rail vehicles

Reference	Title
APTA PR-CS-RP-001-98[34]	Passenger Equipment Roof Emergency Access
APTA PR-CS-RP-003-98[35]	Developing a Clearance Diagram for Passenger Equipment
APTA PR-CS-RP-019-12[36]	Pushback Coupler in Passenger Rail Equipment
APTA PR-CS-S-020-03[37]	Passenger Rail Vehicle Structural Repair
APTA PR-CS-S-034-99[38]	Design and Construction of Passenger Railroad Rolling Stock

Other rail vehicle structural standards and codes are listed in Table 2.

Table 2 — Other rail vehicle structural standards and codes

Reference	Title
PRIIA 305 (US)[39]	Requirements Document For PRIIA Diesel-Electric Passenger Locomotives
UIC 566 (worldwide)[40]	Loadings of coach bodies and their components
TB/T 3548 (China)[41]	Strength design and test accreditation specification for rolling stock — General
TB/T 3500 (China)[42]	Crashworthiness requirements and verification specification for car body of EMU/DMU
TB/T 3501 (China)[43]	Test method for crash test of rolling stock
JIS E 7103 (Japan)[25]	Rolling Stock – General requirements of car body for passenger car
JIS E 7105 (Japan)[44]	Rolling stock – Test methods of static load for body structures
JIS E 7106 (Japan)[45]	Rolling Stock – Car body structure for passenger cars – General rules for design

6.2 Standards for interior equipment

ISO 22752[23] (bodyside windows) contains static loading requirements which are relevant to the safety of rail vehicle occupants.

The same can be said of the European Standards EN 14752[22] (doors) and EN 17530[24] (interior glazing). EN 14752[22] is called up in the LOC&PAS TSI[29]. UIC 566[40] includes proof loading requirements for interior equipment such as luggage racks, coat hooks, seats, tables and doors.

GMRT2100[14] is the Railway Group Standard in the UK for rail vehicle structures. GMRT2100 issue four[13] and later issues include aspects of interior passive safety based on the outcomes of the European SafeInteriors research programme and research required to satisfy various recommendations made by various public inquiries into UK rail disasters.

It was originally intended that UIC and UNIFE would publish a joint Technical Recommendation document (TecRec), but this never came to be. There exists a draft UNIFE Technical Report[1], and a UIC International Railway Solution (IRS 50564-3)[46], both of which have very similar content to GMRT2100[14] in respect of interior passive safety. GMRT2100[14] is mandatory in the UK. UIC 566[40] and the IRS[46] are voluntary standards.

The US APTA standards for passenger vehicle interior equipment are listed in Table 3.

Table 3 — US APTA standards for passenger vehicle interior equipment

Reference	Title
APTA PR-CS-S-006-98[47]	Attachment Strength of Interior Fittings for Passenger Railroad Equipment
APTA PR-CS-S-011-99[48]	Cab Crew Seating Design and Performance
APTA PR-CS-S-012-02[49]	Door Systems for New and Rebuilt Passenger Cars
APTA PR-CS-S-016-99[17]	Passenger Seats in Passenger Railcars
APTA PR-CS-S-018-13[50]	Fixed Workstation Tables in Passenger Rail Cars

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Japanese standards for passenger vehicle interior equipment include JRIS R 1010[27] (luggage racks) and JIS E 7104[26] (passenger seats). Further, Japanese standard JIS E 7103[25] requires that:

> "the facility shall be designed to have sufficient strength taking such factors into consideration such as the vibrations and impacts in running, the pushing force of hands or bodies of a passenger and possibility that two or more passengers may use the same facility at the same time".

Chinese standards include TB/T 3263[51] (passenger seats) and TB/T 3286[52] (luggage racks and hat hooks).

Standards in the UK (GMRT2100[14] and RIS-2780-RST[53]) and the US (49 CFR 238[33]) generally require equipment fitted inside rail vehicles to be designed to meet the same load cases as set out for exterior-mounted equipment. The European Technical Specification for Interoperability (TSI)[29] also requires the attachments of "fixed devices including those inside the passenger area" to be designed in accordance with EN 12663-1[20].

US Standard APTA PR-CS-S-006-98, Rev. 2, 2021[47] requires body mounted equipment generally to withstand ultimate inertial accelerations of 8*g* longitudinal, 4*g* lateral and 4*g* vertical, applied separately. Given that in EN 12663-1:2010+A1:2014[20], there is a recommended ultimate factor of 1,5, the APTA accelerations are slightly greater than the European requirements of 3*g* or 5*g*, 1*g* and (−1 ± 2)*g*, respectively.

Where there are specific static proof and ultimate loading requirements for interior mounted items (such as seats, tables, grab handles, grab poles, grab rails and luggage stowage), and when the acceleration loads set out in EN 12663-1:2010+A1:2014[20] applied on the corresponding mass are less severe than the specific requirements, separate assessments against the acceleration loads set out in EN 12663-1:2010+A1:2014[20] are not always necessary because the specific requirements are derived from service and accident conditions, are therefore more onerous and any requirements relating to EN 12663-1:2010+A1:2014[20] are therefore satisfied.

To maintain a continuous load path for all load conditions and to absorb energy requires ductile behaviour. Many interior elements will, however, use some non-ductile components (e.g. a table), where the tabletop is often made from a non-ductile composite or wood-based material, but the legs and mountings are made from ductile materials such as steel or aluminium. As a result, the overall assembly or sub-structure can exhibit the desired behaviour when overloaded through plastic deformation of the ductile parts when subject to the loadings set out in this document.

It is accepted practice for what can be considered minor items, where an installation has been used for an extended period in service in a similar or more arduous environment and has performed satisfactorily with no records of consistent unscheduled maintenance, this can be taken as evidence of acceptable performance. Where adopted, this approach is generally documented.

In some cases, quasi-static inertia proof loads (mass × specified acceleration) have been applied dynamically using a dynamic test pulse, scaled to the acceleration level required where necessary. The required acceleration level is sustained for at least 80 ms for consistency with the dynamic test pulse.

6.3 Material selection for rail vehicle interiors

Materials can play a part in achieving the aim of reducing the number and severity of occupant injuries (e.g. from abrasion, lacerations or stab wounds) in the event that parts of a vehicle interior are fractured, deformed or dislodged under impact conditions. This fact is recognized in GMRT2100[14].

Therefore, the suitability of materials used in vehicle interiors, in addition to fulfilling structural and impact requirements, usually takes into account other foreseeable material requirements, for example:

— fire performance;

— durability, including behaviour under fatigue loading;

— safety in manufacture;

— repair and disposal;

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— the potential for degradation due to ageing or environmental factors such as temperature, humidity, sunlight, etc.

Compromises are therefore always required when selecting materials.

The principles of reducing injury from vehicle interior components include ensuring the following:

— When items are broken or ruptured, sharp spikes, splinters or fragments are not formed where an occupant could come into contact with them, and, for composite panels or substructures, aggressive internal components (e.g. metallic inserts) are not exposed to occupants.

— When loaded beyond the specified proof loads (i.e. the ultimate load, which is generally around 1,5 times the quasi-static load, see EN 12663-1:2010+A1:2014[20], 5.4.3), vehicle interior structures or sub-structures are designed to collapse in a controlled and predictable manner and have good post-yield plasticity and/or energy absorption properties.

— Non-ductile or brittle materials are therefore designed to withstand the ultimate load, or are only used where the consequences of their failure are mitigated, for example by alternative load paths.

6.4 Structural energy absorption and collapse: UK practice from GMRT2100

GMRT2100[14], A.4, states:

> "All interior fixtures, including seats and tables, shall meet the following requirements when the specified proof, ultimate and dynamic loads are applied:
>
> a) Elements that form part of a primary load path shall include ductile materials.
>
> b) All attachments to the primary structure shall remain intact.
>
> c) A continuous load path shall be maintained, without abrupt changes in force levels due, for example, to buckling, snap-through or fracture.
>
> d) Sharp objects or fracture surfaces that are likely to cause injury shall not be produced."

NOTE The term "snap-through" relates to a sudden movement of a structure with a relatively large deflection, often without structural failure. It can also relate to a mechanical fuse where the modification of the shape or performance an item or device is beneficial to the safety of a vehicle occupant.

This ensures that the complete structure exhibits post-yield plasticity and energy absorption, when loaded beyond the specified proof loads. It controls the risks of injury to vehicle occupants in the event of an accident and represents UK practice.

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.

Large items such as seats and tables have the potential to cause serious injury if they become detached. It is therefore good practice to ensure that all items remain attached for the conditions specified.

Discontinuous load paths, abrupt jumps in force levels and the exposure of otherwise concealed parts also have the potential for additional injury. Where items are loaded during an impact, it is good practice to ensure that they do not break away or become partially detached, and that the fixings to the vehicle structure are the last components to fail when the seat or table assembly is subject to overload.

6.5 Secondary impact assessment

6.5.1 Considerations for persons with reduced mobility

See Annex D.

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6.5.2 Secondary impact principles

In a collision or derailment, a vehicle typically experiences a primary impact or a series of impacts, and a very rapid deceleration. Some of the vehicle's kinetic energy is retained by the occupants and objects, which is then dissipated by secondary impacts inside the vehicle.

The severity of a secondary impact injury is dependent upon the occupant's kinetic energy and the rate of energy dissipation (the relative deceleration at the point of contact) on impact. The rate of energy dissipation is related to the stiffness of the contact surface, the concentration of energy per unit area at the point of contact and the body region involved.

To minimize the severity of injuries, design for interior passive safety would therefore take account of the following:

a) the occupant's velocity and kinematics at the point of contact;

b) the characteristics of features or structures impacted;

c) probable impact areas relative to the occupant and their proximity to vital organs.

6.5.3 Secondary impact review

UK practice, as stated in GMRT2100[14], is to subject areas which are accessible to occupants in normal service to a secondary impact review; this examines the general features and detailing of the vehicle interior considering the risk of injury due to secondary impact against surfaces or items.

The design and installation of the interior (with the exception of seats and tables, which are subject to separate specific requirements) are examined for potentially aggressive features with respect to:

a) exposed corners and edges;

b) recesses;

c) protrusions.

The secondary impact review is often simplified, since in a rail vehicle there will be many items which are repeated throughout the train, such as handholds, partitions, draught screens and doors; therefore, it is only necessary to assess one example of an item or component that is repeated.

A further possible simplification of the review is to use a risk-based approach, e.g. in areas which are infrequently used. A risk-based approach includes the following considerations for determining, sorting and assessing the level of risks for an occupant to be injured in a train accident because of projection to the train's interior surfaces:

— The likelihood of occupants being positioned in a zone, including the frequency of occupation.

— The credible approach path of occupants during an accident, addressing the credibility of their trajectory to impact a given item/surface. It generally assumes a given initial position of the occupant.

  — For initially standing occupants, priority is given to exposed surfaces in a height range from 1,1 m to 1,9 m from the floor. The 1,1 m covers the height of the head of a 6-year-old child and the height at which a tall person would hit a surface during his/her fall.

  — For initially seated occupants, priority is given to exposed surfaces up to 1,5 m from the floor. Regardless of the height of 1,5 m, the undersides of overhead luggage racks are included as priority surfaces.

— Exposure of a surface, e.g. edges and corners are exposed only where a theoretical 100 mm diameter sphere can make contact (165 mm diameter for surfaces with a predominant probability to be impacted by the head of an occupant); see 6.6.2. The exposure is inherent to the integrated items in the train, and excludes the notion of a credible approach path.

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— Compartmentalization ability of a surface/item, e.g. a transverse seat or a transverse partition is efficient to limit occupant excursions in the case of accidents leading to longitudinal accelerations, and therefore these surfaces are regarded as a priority.

— Repeated items and/or radius of an item in a train. Typically, an interior item of the same design that is implemented several times in a train has more probability to be impacted during an accident compared to a unique item, even though the credible approach trajectory is estimated as low.

— Surface rigidness, addressing the ability of an impacted surface to deflect locally (shore hardness) or globally.

— The shape of the rigid surfaces:

  — Radii ≥ 20 mm for head impact;

  — Radii ≥ 5 mm to 10 mm for limb impact.

— Constraints that can limit changes to meet interior passive safety design rules, including:

  — manufacturing and/or geometrical constraints (including aesthetics);

  — overriding requirements, such as sightlines, persons with reduced mobility (PRM) TSI[57] and human factors.

6.5.4 Secondary impact design scenarios

The initial effect of many rail vehicle accidents is predominantly longitudinal, but even in these cases, due to the dynamics of the train or external influences such as, for example, track curvature, switches and crossings, some or all of the vehicles involved can come to rest having been subject to large lateral, vertical, yaw, pitch or roll movements. Accidents due to defective track or landslides can include significant non-longitudinal effects from the outset.

NOTE Some countries have measures to detect defective track and landslides (such as concrete reinforced slopes and rockfall detecting systems), which can help to prevent derailments.

The Railway Group Standard (GMRT2100[14]) used in the UK assumes a nominal 5*g* longitudinal crash pulse as the principal design scenario (see Clause A.2). This pulse is derived from post-accident collision research, and generates secondary impact velocities (of at least 5 m/s) and loadings which have been shown to be consistent with the severity of injuries encountered in typical accidents. Where dynamic assessments are used, this pulse therefore permits injury criteria to be assessed.

The collision pulse used in the US is of a triangular shape, with an 8*g* peak and a duration of 250 ms; this yields secondary impact velocities around 10 m/s. The pulse represents an in-line train-to-train collision in which the cars remain upright and in-line and the occupant volume is severely challenged or crippled.

Specific interior design scenarios have not been developed for situations where lateral, vertical, yaw, pitch and roll accelerations, or a combination of these, occur. For this type of scenario, any additional risks can be controlled using design relating to shape and geometry and proof loads.

6.5.5 Containment and compartmentalization

The general principle of containment is to prevent occupants from being ejected from the vehicle, on the basis that this can allow better control of the potential for injury.

The principle of internal compartmentalization is that, in the event of a collision or derailment, passengers or staff are contained in the area of the vehicle where they are located, and equally, that heavy items such as luggage or on-board equipment are contained in their respective areas. The principal objectives are to prevent long excursions through the vehicle and therefore reduce the velocity of secondary impacts and interaction with other occupants.

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Research has shown that unidirectional seating provides a better level of restraint for seated occupants compared to bay seating, as the occupants' movements are restricted to the immediate area (e.g. see RSSB research report T910[30], and US DoT report numbers 61614[54], 54597[55] and 35576[56]).

Bay seating is provided on many European trains because of passenger preference. Where fixed tables are installed, bay seating can also give a level of constraint by limiting the distances in which occupants can be displaced. Bay seating without tables provides a lower level of constraint.

Longitudinal seating is often preferred for suburban operations where station-to-station times are short, and passenger boarding and alighting times are critical. Longitudinal seating arrangements will not always appear to give the same control as transverse seating, but when groups of longitudinal seats are sub-divided, for example, by armrests, grab poles or draught screens, it is considered that the risk is adequately controlled.

Aspects of vehicle layout design, such as the location of draught screens and grab poles, can influence the risk of injury to standing occupants. Other design considerations include the relationships between standing areas and seating areas, and operational parameters, e.g. whether standing occupants are unlikely (such as for intercity services where seat reservations are required) or if a metro style operation is envisaged. Grab poles, grab rails and grab handles can provide elements of constraint for standing occupants.

6.5.6 Minor impacts with interior features

Accident investigations and research (see RSSB Research Report T910[28]) have shown that the majority of injuries in an accident or collision can be attributed to impact against seats and tables. The causes of a significant proportion of injuries were uncategorised. This research therefore recommended consideration of the potential effects of impacts with other interior features.

Accident injury data are often not able to directly identify the effects or influence of other interior features; however, the detail design of these features (e.g. partition edges, luggage racks, coat hooks, magazine racks, table lights) can significantly influence injury levels.

6.6 Geometric criteria

6.6.1 Standards with geometric requirements

Linked to the need to reduce the consequences of slips, trips and falls, GMRT2100[14] contains detailed geometric requirements for interior equipment to reduce the risk of injury.

Similarly, Japanese standard JIS E 7103[25] requires that:

> "the facility installed in an area where it is likely to touch with human bodies shall be free from sharp edge, protrusion and the like so that human bodies, clothes and other articles are not injured or damaged".

In addition, US standard APTA PR-CS-S-006-98, Rev. 2, 2021[47] requires that:

> "To the extent possible, all interior fittings in a passenger car shall be recessed or flush-mounted. Sharp edges and corners shall be either avoided or padded to mitigate the consequences of an impact with such surfaces. Where protrusions are unavoidable, rounded edges shall be used. Materials that may fracture to reveal sharp edges or dangerous inserts shall not be used. Wherever possible, use shall be made of energy-absorbing features in areas where passenger impact may occur."

6.6.2 Geometric principles

The following geometric principles are set out in GMRT2100[14] for the secondary impact assessment.

An assessment of what constitutes an exposed rigid edge:

— that which can be contacted by a 100 mm diameter sphere;

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NOTE 1 A 165 mm sphere is used in the automotive industry to assess head injury potential (see clause 5.3.2 and Annex V of Directive 74/60/EEC[58]). It is understood that the SafeInteriors[59] research recommended the use of a smaller diameter sphere in the rail environment, to facilitate an indication of potential injuries to limbs as well.

— that with a Shore hardness greater than 50 (as set out in clauses 5.1.6, 5.2.4, 5.3.5, 5.7.2 and 5.8 and Annexes V and VI of Directive 74/60/EEC[58]).

Minimum radii: GMRT2100[14] states that radii of 3 mm should be used, except:

— for longitudinal partitions, edge radii of at least 10 mm and a minimum edge thickness of 35 mm, unless the partition is shielded by a grab pole, grab rail or other feature;

— for transverse partitions, edge radii of at least 5 mm, and a minimum overall thickness of 20 mm, unless the partition is shielded by a grab pole, grab rail or other feature;

— 20 mm is preferable where there is a risk of head injury.

NOTE 2 It is understood that these radii are also derived from the SafeInteriors[59] research recommendations.

Details, formulae, figures and guidance are provided to enhance and assist users with implementing these requirements.

Details are also provided regarding recesses, to reduce the risk of hand or foot entrapment; GMRT2100[14], G.B.4.10, states:

> "When subject to secondary impact, gaps between items or recesses could be significant causes of injury due to entrapment. For locations around seats where hands could become entrapped, it is good practice to ensure that there are no gaps or recesses smaller than 25 mm in width with a depth greater than 20 mm. For areas where feet could become entrapped, for example beneath seats, it is good practice to ensure that any gaps are either smaller than 100 mm × 50 mm or greater than 300 mm × 150 mm."

The dimensions are understood to be based on the anthropometric measurements set out in ISO/TR 7250-2[60], and are intended to ensure that recesses or gaps are too small for fingers or feet, or large enough that fingers or feet can be easily moved out. GMRT2100[14] also suggests the use of concealed, recessed or domed fasteners to reduce the risk of injury from impacting them.

The APTA table standard APTA PR-CS-S-018-13[50] specifies minimum geometry requirements for the table top radii of 25,4 mm (one inch) for aisle-side corners and 4,76 mm (3/16 inches) radii for top/bottom edges. It also specifies a maximum gap of 50,8 mm (2 inches) between the table top and the wall to minimize the risk of entrapment.

For reference, it is understood that reference is made in some train technical specifications to EN 1176-1; this requires gaps to be less than 8 mm or greater than 25 mm, to reduce the risk of finger entrapment.

6.7 Computer simulations, calculations and testing

As computing power increases and simulation methods are continuously improving, there is increasing reliance on simulation with consequent reduction in the need for costly testing. It is common practice to validate simulations with testing (e.g. European Standards EN 12663-1[20] and EN 15227[19] describe when tests are needed as part of the verification process for rail vehicle static and collision performance, respectively).

This principle is already used in the UK railway standard GMRT2100[14].

Proprietary software models of the standard automotive anthropomorphic test devices (ATDs) are already available, which are compatible with typical finite element analysis software (such as Ansys LS-DYNA, Altair® Optistruct® and Altair® Radioss®[1)]). These ATD models have already been validated, which means that validation is generally only needed for the items being tested (seat, table, cab desk, etc.).

1) Ansys LS-DYNA, Altair® Optistruct® and Altair® Radioss® are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

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