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Foreword

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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.

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.

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.

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.]

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.

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.

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 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 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.

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