

Peer reviewed paper

Rail Traffic Collision Protection for Station Bridges and Structures

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Abstract

Railway bridges and structures collision protection requirements are covered in many standards and codes across Australia and around the world. Design preference for bridges over railways is to have a clear span between abutments and to have supports at least 20m clear of tracks. However, due to many site constraints, particularly for existing bridge modifications and at railway stations, fully satisfying standard requirements may not be reasonably practicable.

AS 5100, being the primary Australian Standard covering railway bridge collision protection is also supplemented by relevant state transport authority standards and documents to address the multiple scenarios of bridge configurations and site variables. Associated with these many possibilities, AS 5100 has over twenty references back to the "relevant authority" and nine references to a "risk assessment" to resolve design decisions such as loading, geometry and available platform wall resistance predominately using lessons learnt from historical events and data, including catastrophic accidents. Also, AS 5100 only has very limited guidance for bridge supports on railway station platforms.

This paper provides an insight and compares standard requirements published within Australia and some key international codes such as UIC-777-2R associated with bridges over railways with supports at station platforms and presents a simple summary table of the results, together with recommendations. The aim is to assist bridge and transport asset managers to easily compare design requirements for overbridge, footbridge and airspace development collision protection at railway stations.

Keywords: Railway, Bridge, Collision, Protection, Station

1. Introduction

When designing for railway collision protection, including at stations, risk considerations can include a very broad range of potential scenarios, hazards, likelihoods, bridge types, structure types, train types, railway infrastructure and eventual broad range of potential consequences. Bridges and structures over and adjacent to rail tracks can vary significantly in terms of size, mass, clearance and function. Rail tracks approaching and within stations can vary significantly in terms of track numbers, geometry, line speed, track components and potential out-of-control speeds. Some major historical disasters due to train collisions causing catastrophic collapse of bridges and structures down onto trains include at Granville, Sydney (1977) and Eschede, Germany (1998).

Standards and codes typically provide design criteria and rules and guidance for protecting bridges and structures against potential accidental collision actions that will never likely occur over their design life, but as the occurrence of collision events cannot be fully eliminated, some provisions are deemed necessary. To address structure collision protections, standards requirements can also vary significantly in terms of setting structure design impact loads, structure clearances, robustness, redundancy and other protection details. Potential collision impact forces due to a derailed train can also be extremely high, particularly if the full mass of the train is mobilised at the point of impact at speed. Due to the variability, published standards typically refer to and impose 'risk assessments' for projects to further investigate site specific factors and determine agreed outcomes for their proposed optimal solution. Even though Standard objectives for collision protection are clear, project outcomes can also become subjective, particularly when site constraints prevent full compliance.

This paper provides an insight into and compares train collision protection primary requirements, mainly around railway stations using measurable parameters, from relevant Australian, Australia state authorities and international publications. Also, some typical station structure types are presented in an approximate order of collision risk category for comparison. Bridge structures spanning over rail traffic (e.g. overbridges) and other elevated structures over station platforms are generally included.

Due to the broad range of collision estimation and protection aspects and their detailed methods, not all topics are covered in this paper review and exclusions include the following:

- Risk assessment methods such as qualitative, quantitative and their associated analyses, scenarios, event trees and cost to benefit outcomes and the like.
- Associated safety and risk assurance principles such as SFAIRP, ALARP and risk management matrices.
- Structures carrying rail traffic such as multi-level track stations, underground stations, flyovers and underbridges including through type rail bridges.

2. Aim

The primary aim of this paper is to assist bridge and transport asset managers to more easily compare collision protection design requirements and provisions from Australian and International standard, code and guide type publications. The comparison of key design requirements is mainly summarised in a compilation table and particularly focuses on typical railway station bridges and structures and enhanced collision protection aspects of their supports and station platform structures.

Tabled topics include:

- Support hazard or danger zones near track
- Train speed groups
- Impact forces and their application
- Support geometries and robustness
- Station platform robustness

Using the compilation table data and other relevant extracted content from the reviewed publications, a short summary of primary risks and protections that would influence formal risk assessments for rail authority considerations are provided in sub-category format. A secondary aim is to provide a summary of key collision protection structural design parameters and details sourced from the 2000 plus pages of relevant content from the Australian and International standards and guides. Thirdly, relevant railway collision protection document references obtained from the standards and guidelines are listed for further information and research.

3. Background

Collision protection design provisions of bridges and structures over rail and at stations introduces additional structure robustness (and costs) in preparation for an extremely unlikely event and that typically will never happen. Unlike permanent and transient live loads which are generally predictably on bridges and structures throughout their working life, derailed train collision loads and their actual magnitude and positions are not so accurately predictable. Unfortunately, over the past years and decades, some very significant disastrous train accidents involving over track bridges and structures with occupants, collapsing onto trains and passengers have occurred. With the benefit of hindsight and accident investigations and understanding of the contributing factors leading to the accident, these past events can be analysed and then lessons learnt obtained to minimise consequences of any future unforeseen events.

Primary objectives of engineering Standards includes attempting to incorporate requirements and guidance based on lessons learnt to enhance future outcomes and particularly safety. The engineering field of railway collision protection typically involves balancing provisions for extremely unlikely events that have extremely high consequences into a practical solution for a railway system to actually operate reasonably safely. Due to such variable nature of railway train accidents, or any accident, and subjectivity to some extent, collision protection standard requirements and provisions can also be very somewhat varied.

Particularly at railway stations, collision protection provisions of station structures are sometimes not within scope for some major standards, yet these non-over track structures can also influence collision risks. Railway station type structures, still at-risk near to track, can include platform walls, staff facility buildings, waiting rooms, lifts, canopies, escalators, stairs, ramps and elevated walkways. Positioning, clearances, robustness, frangibility and potential "domino" effects of these station facility type structures in proximity to over-track support structures are also relevant to the overall station structure risk profile.

General high-level intentions for railway structure collision protection requirements can be as described within two relevant Standard references as follows:

- a. AS5100.1:2017¹:
 - i. "avoid collapse of structures over rail due to impact from derailed trains: and"
 - ii. "reduce the severity of impacts with structures to reduce the probability of injury to occupants of derailed trains".
- b. UIC777-2R¹⁶:
 - "managing the risk from derailed trains near structures built over railway lines. It distinguishes between structures that are generally occupied (for example, multistorey office blocks) and those that may not be occupied (for example, bridges). Different methods are proposed for these two types of structure. The methods take into account those people most at risk and the likely speed range for rail traffic passing under these structures".

Also due to the many variable multi-disciplinary aspects, unknowns, range of hazard likelihoods and potentially extremely severe consequences, the "Safety in Design" (SiD) process and other risk management tools are typically used for railway collision protection design and planning. These processes involve systematically identifying potential hazards and the potential risks to persons throughout the full asset lifecycle, so that risks are eliminated or minimised. Suitable risk ranking and risk controls and managing residual risks are attempted to be achieved and then incorporated into the overall design solution.

4. Historical Train Collision Events near Stations

Historical records of railway accidents are mostly available nowadays via media websites and transport accident bureau reports from around the world. Out of the hundreds and thousands of accident event records, below are a small sample of train accidents which have occurred at and near railway stations to highlight some potential high consequence and catastrophic nature of such events.

Potters Hill, UK, 2002: Passenger train travelling at 160km/h through a faulty turnout led to a derailment and impact with the end of a low through girder underbridge and a decoupled carriage mounted the platform ends and slid into a concrete station canopy. (Reported 7 killed, 76 injured).



Figure 1 Potters Hill passenger train collision at station platforms (2002)

Source: Office of Rail Regulation HSE Interim Report 2002

Bruhl, West Germany, 2000: Passenger train travelling at 120 km/h through a 40 km/h turnout limit led to derailment with two carriages mounting the platform and impacting the station building. (Reported 9 killed, 149 injured).



Figure 2 Bruhl passenger train collision at station platforms (2000)

Source: Internet

Spuyten Duyvil, Bronx NY US, 2013: Passenger train travelling at 132 km/h around a 48 km/h curve limit and derailing in advance of approaching platforms with a station footbridge. (Reported 4 killed, 61 injured).



Figure 3 Spuyten Duyvil passenger train derailment approaching station platforms (2013)

Source: Internet

Amagasaki, Japan, 2005: Passenger train travelling at 116 km/h around 70 km/h curve limit and with calculated curve derailment speed of 106 km/h, impacted an external development residential high rise building approximately within 10m of track. (Reported 107 killed, 562 injured).



Figure 4 Amagasaki passenger train impact with external development building (2005)

Source: Internet

5. Station Structure Types

Station structure types influencing overall collision protection structural performance can broadly be categorised into ground type (or barrier structures) and over track type (or airspace structures). At railway stations, on-ground type structures typically would include platforms and possibly deflection barrier wall type structures if near to a station precinct. Over-track, airspace, elevated and tower type structures can vary significantly in terms of collision protection and superstructure mass and occupancy. To categorise, they each can be broadly ranked from most at-risk to least at-risk in terms of collision protection measures, described as follows:

- 1. Multi-storey airspace over station development, including over station facilities
- 2. Station concourse bridge with facilities and/or low-level buildings (wider than 6m)
- 3. Road overbridge, often with footways and can lead to station access (wider than 6m)
- 4. Station concourse bridge pedestrian access only to platforms (wider than 6m)
- 5. Station footbridge (narrower than 6m)
- 6. Lift shaft not within a platform or at a weak platform
- 7. Lift shaft within a robust or earth filled platform
- 8. Station linking deck between other aerial access structures (narrower than 6m, not over track)
- 9. Stairs, ramps and escalators on a platform (not over track)
- 10. Station single level buildings on a robust or earth filled platform

Generally, for these structures, the more suspended mass and occupancy, the higher the potential hazard and collision consequence risk ranking. A nominal 6m deck width was selected as this width is approaching a two-lane road overbridge width with similar elevated superstructure mass and could be similarly categorised. Due to the variance of station structure types, specific or pro-rata collision protection design is not always outlined in standards for all structure type categorisations but typically are broadly categorised as either airspace or bridge structures and some include platform protections (also ignoring more complex multi-level stations and underground stations). Standards also typically require a risk assessment to be considered with all other site contributing risk factors, including track, rolling stock, domino potential and protections such as platforms and clearances, to determine appropriate final design loads, configurations and redundancies and the like. See figure 5.



Figure 5 Basic elevation diagram of some typical station structures configuration

6. Publications Review

Published railway collision protection provisions at stations have some differences and variations across the range of documents reviewed for this paper. However, all reviewed publications were typically based around three key reference documents being:

- UIC-7772R¹⁶ (UK/Europe)
- Arema²⁰ (USA/North America)
- AS5100^{1,2} (Australia/NZ)

Internationally, other jurisdictions would also have codes and standards for railways and collision protection, however not all could be included as part of this research paper. Other international areas likely to have well developed and relevant standards and requirements include Japan, China, India and Eastern Europe. It is suspected language translation and interpretation would also be applicable for the comparisons.

Additional to the data presented within the compilation summary table, some other relevant collision protection aspects related to bridges and structures at railway stations have been selectively extracted from the reviewed publications, and other references. The extracted points are not considered comprehensive, but the intention is to also highlight topics and references for any further investigation or research that may be relevant. Particularly for some projects unable to fully comply with standards for certain aspects due to strict site constraints, the list of provisions may highlight alternative provisions which could be utilised to possibly either offset or improve overall project risk outcomes. Also noting 'cherry picking' individual provisions from separate other standards needs detailed thorough engineering scrutiny if utilising these together with local suites of standards. To avoid duplication of the points and to focus on key collision protection themes, not all aspects are shown at each publication. The summary list is presented in short dot point format below.

(note that "support" refers to over-track structure support such as a pier or abutment)

Australian and New Zealand Publications

Australian Standard (AS5100.1¹ and AS5100.2²):

- Dedicated collision protection sub-clauses for general configuration and design loading.
- Structures include rail bridges, road bridges, footbridges, crash walls, air space developments.
- Head-on collision loads outside scope, but these at-risk supports to be protected by deflection walls (minimums include 2m above rail, 0.5m thick, length by risk assessment, collision load same as for at-risk support, load not transferred to support, allow for lateral movement for load absorption, continuous concrete wall, approach wall up to 20 degrees to track, smooth transitions, no snagging points, approach end rounded).
- Supports within 10m of track centreline to be continuous wall parallel to track and have smooth faces, rounded ends, no snagging points and minimum geometric requirements (minimums include 2m above rail, 0.8m thick, 4m length, extend 2m past rising column, 1.2m below ground level).
- Supports with 4m of track centreline have more stringent geometric requirements for collision robustness (includes blade wall 3.6m minimum height above rail).
- Frangible (or removable) type pier alternative provided superstructure has redundancy and does not collapse onto a derailed train (excludes rail bridge supports).
- Supports and structural components within 10m of track centreline and 10m vertically are subject to robustness type collision loads of up to **500kN** for bridges (**1500kN** for airspace developments) applied as a separate load case. Platforms not assumed to protect or to reduce this robustness type load.
- Supports 10-20m from track centreline to be designed for **1500kN** impact at 2m above ground, if redundancy inadequate (also notes some authorities permit collision load relaxation, under certain conditions).

New South Wales (TfNSW TS01715³ and TS02404⁴ and TS02400⁵):

- Primarily based on AS5100 zones and categories.
- Dedicated collision protection with separate bridge and airspace development documents.
- Station structure types of airspace developments, overbridges, footbridges, concourse bridges, stairs, ramps, lifts, elevated walkways, short linking decks and platforms and each have some separate collision load and robustness requirements.
- Head-on impact load and support redundancy provisions based on risk and in addition to minimum requirements. At-risk head-on supports to have deflection wall.
- Supports, if damaged, designed to avoid disproportionate collapse of all structure.
- Bridge piers can be complying AS5100 individual type on complying earth filled platforms, otherwise full AS5100 collision applies. Not frangible supports. Blade shaped wall supports preferred. Minimum thickness of any structural element of 800mm.
- Airspace supports on complying platforms have AS5100 (**4000/1500kN**) glancing blow loads applied to supports and platform. Airspace supports not on a platform subject to approval.
- Overbridge supports on complying platforms can reduce AS5100 (**4000/1500kN**) glancing blow loads by 50% to support.
- Footbridge supports on complying platforms can reduce AS5100 (**4000/1500kN**) glancing blow loads by 100% to support.
- Deflection wall and platform length for collision load based on capacity and risk.
- Platform structure isolation to bridge supports and footings in case of collision load transfer via platform structure (such as by train bumping platform coping).

- Platform structure also subject to accidental horizontal impact point load of **200kN** at coping level (applied parallel to track direction at any end 20m, and simultaneous with normal direction point load for any point along platform coping length).
- Lift shaft independent structure to bridge support and lift mechanism.
- Lift structure positioning and connection not to transfer collision load to bridge supports.
- Lift shaft collision protection covered in another document and includes horizontal loads of 500kN min where positioned outside platform walls and within 10m of track, or up to 200kN where within earth-filled platform walls. Incidental vehicle impact loads of up to 100kN also included where not on a platform.
- Stepways and ramps not to be supported from footbridge superstructure, not subject to collision protection (track clearances apply), positioned to prevent collision load transfer to either overbridge or footbridge over tracks.
- External development (not over track) supports are also referred to AS5100 for collision protection assessment, similar to bridges and airspace developments.
- Higher at-risk supports can include historical infrastructure such as steel trestles, slender columns and frames and shallow footings.
- Lower order protection devices include earth mounds, gabion walls and guardrails (subject to risk ranking and approval for temporary footbridges).

Queensland (QR CIVIL-SR-012⁶):

- Dedicated document for railway collision protection.
- Cover sheet has a tech note indicating AS5100 has been updated (from 2004 to 2017) and clarifies that the more onerous requirements apply, if a clash.
- Very detailed categories of train speed, support proximity to track and structure classifications, further developed from UIC-7772R categories and AS5100 loadings. (Not all data shown in compilation table). Slower speeds are 21-50km/h (Group 2) and 0-20km/h (Group 3).
- Three over track structure classes, with Class A (airspace development), Class B (Bridges) and Class C (Service bridges). Class B includes Overbridges, footbridges, station waiting areas and lifts.
- Clearance zone 1 includes design head-on collision loads of up to **10,000kN** for Class A and **5000kN** for Class B.
- Collision loads and support configuration requirements relax from slower than speed category 1 (51-160km/h) and further away from track than clearance zone 1 (0-3m). E.g. footbridge support in clearance zone 4 (10-20m away from track) in slower speed category 2 or 3 (0-50km/h) reduce collision load by 50% to **750kN**.
- Support geometry ratios of 'length to width' greater than '4 to 1' and support length greater than half height of support, similar to UIC777-2R ratios.
- Larger footbridges with deck area greater than 50m2 are treated as Class B road overbridges. Footbridges with less than 50m2 deck area have some collision protection relaxation provisions.
- Footbridge supports closer than 7.5m to track centreline have some relax collision loads of **2000kN** at 1.2m above rail or **500kN** at 3m above rail (compared with **4000kN** at 2m above rail).
- Supports protected by a platform where at least 20m length, can be treated like at deflection wall and with reduced design collision loads of 1500kN parallel (750kN normal) to track for slower speed categories, however the deflection wall or platform has to withstand nominal collision loads of 4000kN parallel and 1500kN normal to track.
- Some support redundancy provisions of permanent effects plus 60% live load with one or more supports removed.
- Steel columns groups of four may be approved with deflection walls and if redundancy with two of the steel columns removed.
- Columns not to be at bottom of embankments without protections.

• Other collision protection controls such as guardrails and widening embankments with retaining walls may be approved.

Western Australia (PTA 8880-450-083⁷ and 8880-450-060⁸):

- Dedicated document for railway collision protection.
- Dedicated section for station structures.
- Design collision loads in UIC Code 777-2R and AS 5100.2 are minimum loads and are considered less than head-on loads.
- Class A (airspace), individual or endangered supports within 3-10m of track centreline and in a switching zone, require crash wall or barrier.
- Class B (bridge) structures, crash wall to be integral with support. Class B category can include station buildings.
- Class B support locations optimum lateral clearance based upon UIC777-2R Appendix F risk method.
- Continuous superstructure over intermediate supports for bridges is preferred.
- Deflection wall length in UIC777-2R Appendix F and for existing bridges can be reduced by 45m representing length for train speed to fall below 60km/hr (12m minimum length).
- For supports on complying platforms, any design collision load reduction requires conditions of 4m track centreline clearance, 2.5m platform coping clearance and 12m non-ramped length to platform end.
- For trains passing, any collision load reduction at platforms is considered when train passing speeds are less than 50km/h, 90% or more stopping trains with speed less than 20km/h at station and less than 10% trains pass the station.
- For platforms, any collision load reduction requires 1085mm platform height above rail, space between platform coping and support to be filled with compacted earth for passive soil resistance, coping structure and compacted earth to resist half of AS5100 glancing blow collision load (4000kN/1500kN). With remaining half of AS5100 glancing blow collision load shared to support.
- For supports 10-20m further away from track centreline, similar collision load reduction criteria but with a lower AS5100 glancing blow collision load of **1500kN**, shared half between platform and support. Frangible supports also considered with minimum **500kN** (for non-rail bridges).
- Platform train derailment point load of **200kN** acting vertically at any part of platform structure in combination with permanent effects.
- Mechanical stabilised earth walls not permitted in or within rail reserve due to low impact resistance, unless 1.2m wide cement stabilised backfill for full wall height.

ARTC (ETS-09-00⁹ and EGS-09¹⁰):

- Piers and abutments shall be protected against head-on collision by deflection walls, unless robust heavy construction designed for head-on collision without loss of capacity for permanent and transient effect loads (supports within 10m of track centreline).
- Consider derailment effects treating bridge as a whole system including superstructure and substructure.
- Head-on collision impact loads of **4000-12,000kN**.
- Continuous concrete wall supports parallel to track.
- Airspace structure decking of reinforced or pre-stressed concrete.
- Double stacked freight wagon lines have higher robustness zone for structures up to 7m at 500kN point load and then transition to 0kN at 12m above rail (additional to AS5100.2 Clause 11.4.3).
- Collision load rational method presented (with nominal values) considering freight mass (m=1000t min), derailment angle (3.5deg), deceleration (3m/s2), derailment path slope, rail car stiffness (k=1200kN/m), impact velocity (V).

• Collision force calculation included based on the principle of energy conservation (also in BS EN 1991-1-7-2006 for hard impact) as follows:

$$F = V(km)^{0.5}$$

Where:

F = head-on collision load

V = velocity at impact with support

k = vehicle (car) stiffness

m = mass

RISSB (AS7636¹¹)

(Not included in compilation table as mostly refers to AS5100^{1,2})

 References AS5100, AREMA (where silent) and RISSB Derailment Containment Code of Practice¹².

Victoria (MTM A1546¹³ and MTM A1530¹⁴):

(Not included in the compilation table as mostly refers to AS5100)

- Railway traffic axle load design of 245LA, with 300LA design load for collision load design.
- Platform incidental impact design load of **300kN**, either parallel, normal or any direction to track.
- Other general risk criteria and topics included.
- Project risk assessment outcome score can determine relaxations to AS5100.2 loads such as the Clause 11.4.2.3 4000/1500kN may be reduced to 1500kN only and down to 500kN only with approved lower risk scenarios.

South Australia and Tasmania

(Not included for this paper)

New Zealand (KiwiRail B-ST-DE-3036¹⁵):

- Collision loads as per AS5100.2, except factored by 0.7 for lesser axle loads (210LA), proportioned of 300LA.
- Platforms provide protection if reinforced concrete facings and compacted fill of 1500kg/m3 minimum.

UK and Europe

UIC Code (777-2R¹⁶):

• Dedicated document for railway collision protection.

- Primary referenced document by other authorities, including Australian rail authorities.
- Refers to preventative and protective measures, including static design measures.
- Divides structures over tracks into two classes (Class A such as buildings and Class B such as bridges) and protections nominated for each class.
- Considers three danger zones or support distance from nearest track centre line for Class A, with zone 3 being area behind track ends and subject to head-on loads of **10,000kN**.
- Considers three groups of track speeds (0-20km/h, 0-50km/h, 50-120km/h).
- Support geometry ratios of 'length to width' greater than '4 to 1' (plan dimensions) and support length greater than half support height.
- Support continuous walls preferred, and where possible on platforms.
- Support collision loads higher at approach end column for groups of individual columns.
- Supports on platforms included, with support collision loads reduced by half.
- Platform minimum heights of 550mm for protection.
- Platform canopies and roofs do not apply to provisions.
- Support robustness geometric dimensions and ratios and redundancy guidance.
- Support fixed-end connection between foundation (and avoidance of pin-jointed piers).
- Deflecting devices include raised foundation plinths, platform edges, loading ramps, guide walls and check rails.
- Support raised foundations with end profiled "boat shape" for head-on deflection impacts.
- Absorbing devices include crash barriers with ability to absorb kinetic energy progressively.
- Avoid supports in line with turnouts.
- Detailed theoretical guidance for risk assessment procedure, methods, parameter values, likelihoods, event trees, resulting scenarios and optimal clearances.

Eurocode 1 (BS EN 1991-1-7¹⁷):

- Dedicated section for impact for railway collision protection.
- Superstructure (deck) impact from derailed rail traffic not generally considered.
- Risk assessment guidance for qualitative and quantitative analysis.
- At track ends, supports impact force is **5000kN** for passenger and **10,000 kN** for shunting and marshalling trains applied horizontally at 1m above rail.
- Dynamic design for "hard impacts" (rigid structure with colliding object linearly deforming) and "soft impacts" (structure deforms to absorb energy) in Annex C for information.

British Standard National Annexure (NA to BS EN 1991-1-7:2006¹⁸) adds for Class B:

- Support hazard zone extends 4.5m from cess rail (approximately 5m from track centre-line).
- Individual loss of one column in hazard zone not to lead to collapse of remainder of structure under permanent and traffic load.
- Supports in hazard zone have collision load of **2000kN** horizontally at 1.2m above ground and **500kN** at 3m above ground, but not simultaneously.

RSSB (GCGN5612¹⁹):

(Not included in the compilation table, refers to UIC777-2R, BS EN1991-1-7, BS EN1991-2)

- Guidance on rail traffic loading and risk assessment methods and examples, including derailment actions in Part 5 (including to BS EN 1991-1-7 and NAs)
- Where impractical or uneconomic design, railway infrastructure management permitted to use risk-based approach for alternative risk mitigation options.
- Support design compliance typically problematic at stations and utilisation of platform as protection set out in Network Rail NR/L3/CIV/020 Appendices B2 and B4.
- Not economically possible to design for potential maximum train impact force at high speed (such as at Eschede event). Approach to provide minimum robustness for columns in 'hazard zone' and allow for bridge redundancy.

- Hazard zone of 4.5m from cess rail, with track gauge of 1.435m, be taken as 5.2m beyond track centreline.
- Notes UIC777-2R methods do not consider all factors in GCGN5612 such as ground topography near track.

North America

USA (AREMA Volume 2²⁰):

- Volume 2 for reinforced concrete design also includes support geometry for collision protection provisions (support geometry, robustness and thicknesses).
- Refers to American National Transport Safety Bureau NTSB for commentary on pier protection adjacent to railroad tracks.
- NTSB found no clear break point in derailed travel distance from track centreline (for 7.6m zone) and that derailed distance related to train speed, equipment weight, side slopes (retain or distribute) and track alignment. Other structures (external developments) along right-of-way (corridor) may warrant crash walls or earthen berms.
- Support collision forces to be distributed over several columns via connecting walls.
- Supports less than 3.6m to track centreline to have 3.6m high crash wall, 0.76m thickness and 3.6m length.
- Crash walls for supports 3.6-7.6m away from track centreline to be 1.8m above rail.
- Supports less than 7.6m to track centreline to be heavy construction or protected by crash wall.
- Consider protection for supports further than 7.6m from track centreline.
- Provisions are not for full impact at high speed. Intent is to reduce damage by derailed equipment.
- Factors also described as overhead structures height, pier height, bearing type, structure redundancy, span length and consequences of structure loss.

California (HSR TM 2.3.2²¹ and TM 2.5.1²²):

- Support collision loads only for at-risk columns within 5m from track centreline and not protected by platforms.
- At risk columns to have a protection wall throughout its length, including lower and upper guide walls with collision loads (excluding supports on platforms).
- Leading columns in a group designed for head-on impact forces or a separate protective column device (up to 2m above rail, 3m long, thickness greater than at risk support column).
- Platform to be of massive construction at least 380mm above rail level.
- Platform collision load of **1000kN** normal to track.
- At platforms, 300mm wide void around columns to prevent transfer of collision loads to the column.
- Slipstream aerodynamic actions from passing trains noted.

Canada (Metrolinx RC-0506-04STR²³):

(Not included in compilation table, generally refers to AREMA)

Asia

Collision protection publications from Hong Kong and Singapore were also reviewed but as these both were based around BS EN 1991-1-7, UIC777-2 and applicable national annexures, results weren't compiled in the summary table. Also to note that these Hong Kong and Singapore publications cross reference to other railway structure requirement related publications that may contain further accidental collision content but were not reviewed as part of this paper investigation. However, some extracted key rail collision protection aspects are summarised below.

Hong Kong (Structures Design Manual for Highways and Railways²⁴)

- Large 301-page design manual covering varieties of road and rail structures, with accidental collision sub-sections.
- References include BS EN 1991-1-7 and its UK national annexure and PD6688-1-7 (recommendations for design of structures to BS EN 1991-1-7).
- Hazard zone up to 5m of track centreline for accidental collision requirements.
- Preference for over track structure supports to be further than 5m away from track centreline.
- Accidental collision type design loads of **1650kN for overbridges** or **825kN for footbridges**, both at 1.2m above rail and acting with permanent effects and variable actions at accident design situation.
- Bridge deck not to lift or slide off its bearings (for design collision loads).
- Whole structure not to collapse with any one of the individual column members being assumed to have failed.
- For bridge decks carrying a single member element, local damage is allowed but structure as whole not to collapse.
- Supports members not to be pin jointed at both top and bottom.
- Individual supports to have solid plinth to 1m above rail with 'cut water' ends for derailed train deflection.

Singapore (Land Transport Authority Civil Design Criteria for Road and Rail Transit Systems²⁵)

- Large 382-page design manual covering varieties of road and rail structures, with accidental collision sub-sections.
- References include UIC777-2R and its Singapore National Annexure.
- Design actions in SS EN 1991-1-7 and its national annex and UIC777-2R.
- Train speeds up to 100km/h.
- Class A airspace hazard zone up to 5m from track centreline.
- Class A airspace accidental collision type design loads of 2000kN at 1.1m above rail and 1000kN at 1.1m to 3.3m above rail at any direction.
- Class B bridge hazard zone up to 4.5m from track centreline.
- Class B bridge accidental collision type design loads of 2000kN at 1.2m above rail and 500kN above ground, not simultaneous.
- Individual supports to have solid deflector plinth up to 0.9m above rail or 1.2m above ground, with end shaped to deflect derailed trains.
- Individual support loss not to lead to structure collapse under permanent and primary traffic loads.
- Supports in danger zone to be part of monolithic structure such as a framed structural system.
- Supports at bottom of embankments, or on embankment, to have adequate protection measures for derailed trains rolling down the embankment.

The vast numbers and broad aspects of considerations included above highlight the volume of interrelated complexities.

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7. Collision Protection Compilation Table

Table 1 Collision protection provision data summary from reviewed publications

PUBLICATIONS	AUSTRALIA	NSW	QLD	WA	ARTC	EUROPE (U)	EUROPE (B)	USA	USA (CALIF)
Requirements or Categories	AS5100 ^{1,2} (2017) & Amdt (2024)	TS01715 ³ (2020) & TS02404 ⁴ (2021) & TS02400 ⁵ (2019)	CIVIL-SR-01 2 ⁶ (2021)	PTA 8880-450-08 3 ⁷ (2024) & PTA 8880-450-06 0 ⁸ (2022)	ETS-09-00 ⁹ (2024) & EGS-09 ¹⁰ (2005)	UIC777-2R ¹⁶ (2002)	Eurocode 1 BS EN 1991-1-7 ¹⁷ (2010)	AREMA Volume 2 ²⁰ (1999)	HSR TM2.3.2 ²¹ (2011) TM2.5.1 ²² (2010)
Collision Protection Standard References	-	AS5100 RISSB CoP	AS5100 UIC777-2R	AS5100 UIC777-2R GCGN5612 Civil-SR-012 ONRSR	AS5100 UIC777-2R BS EN 1991-1-7:200 6 AS7636 (RISSB)	-	UIC777-2R	NTSB Commentary	Arema EN1991-1-7 (2006) Taiwan HSR Vol9 design spec S1.3.9
Over-Track Categories	AS, BR	AS, OB, FB	Class A & B	Class A & B	AS, OB, FB	Class A & B	Class A & B	Structure	Structure
Redundancy Provisions for (Support Loss)	PE+20%LL (1+ piers)	Provisions	PE+60%LL (1 pier) PE+LL (50% XS)	PE+20%LL (1+ pier) (FB: 60%LL)	Assess	PE+LL (50% XS) PE (33% XS)	Assess	Assess	-
Train Speeds	160km/h (max)	160km/h (max)	51-160km/h (Group 1)	140km/h (max)	160km/h (max)	50-120km/h (Group 1)	50-120km/h	-	400km/h max (250mph)
Hazard Zone (HZ) Very Close	0-4m	0-4/4.3m	0-3m (Z1) 3-5m (Z2)	0-3m (Z1) 3-5m (Z2) 2.5-4.5m(Ap)	0-4m	0-3m (Z1)	0-3m 0-4.5m (BSI NA)	0-3.6m	-

PUBLICATIONS	AUSTRALIA	NSW	QLD	WA	ARTC	EUROPE (U)	EUROPE (B)	USA	USA (CALIF)
HZ Close	0-10m	0-10m	5-10m (Z3)	5-10m (Z3)	0-10m	3-5m (Z2)	3-5m	3.6-7.6m	0-5m
HZ Mid	10-20m	10-20m	10-20m (Z4)	10-20m (Z3)	10-20m	-	5m+	7.6m+	-
HZ Far	20m+	20m+	-	20m+	20m+	-	-	-	-
Head-On Collision Loads Parallel Dir (HZ)	Load outside scope Deflection wall if at-risk	Assess Deflection wall if at-risk	10,000kN (AS: 0-3m) 5,000kN (BR: 0-3m)	6,000kN (BR:0-3m) if no redund.	4,000-12,000 kN (0-10m)	10,000kN (0-3m)	Assess	-	10,000kN (Freight) 5,000kN (Passenger)
Head-On Collision Loads Normal Dir (HZ)	Outside scope	Assess	3,500kN (AS:0-3m) 1500kN (BR)	2,250kN (BR:0-3m) if no redund.	1,500kN (0-10m)	3,000kN (0-3m)	Assess	-	-
Glancing Blow Loads – Parallel Dir (HZ)	4,000kN (0-10m)	4,000kN (0-10m)	4,000kN (3-10m)	4,000kN (0-10m)	4,000kN (0-10m)	4,000kN (3-5m)	4,000kN (3-5m)	-	4,000kN (0-5m)
Glancing Blow Loads – Normal Dir (HZ)	1,500kN (0-10m)	1,500kN (0-10m)	1,500kN (3-10m)	1,500kN (0-10m)	1,500kN (0-10m)	1,500kN (3-5m)	1,500kN (3-5m)	-	1,550kN (0-5m)
Load Application	Simult. 2m above rail	Simult. 2m above rail	Simult. 2m above rail	Simult. 2m above rail	Simult. 2m above rail	Separate, 1.8m above rail	Separate, 1.8m above rail	-	Simult. 1m above rail
Support Geometry (LengthxWidth)	4m x 0.8m	4m x 0.8m	3.2m x 0.8m (AS) 2.4m x 0.6m (BR)	W:0.8m	4m x 0.8m	3.6m x 0.8m (Class A) 3.6m x 0.6m (Class B)	-	3.6m x 0.8m	-
Support & Deck Robustness Loads	0-1,500kN (AS) 0-500kN (BR)	0-1,500kN (AS) 0-500kN (BR)	0-1,500kN (AS) 0-500kN (BR)	0-1,500kN (AS) 0-500kN (BR)	0-1,500kN (AS) 0-500kN (BR)	-	-	-	-

PUBLICATIONS	AUSTRALIA	NSW	QLD	WA	ARTC	EUROPE (U)	EUROPE (B)	USA	USA (CALIF)
Platform Collision Load Sharing	No	100% GB relax to FB (50% for OB) (0% for AS)	Yes, but (not 0-3m zone or 51-160km/h) 500kN for FB	50% GB to BR, 50% GB to platform	No	50% of GB relaxation	Yes	-	100% GB relax to BR
Platform Robustness Criteria	-	GB loads, 10m length earth filled, square ends, footing isolation, pier clearances	20m length, FB support 2.5m to platform edge	1m high, compacted earth, square ends, train controls, pier and track clearances	Vertical ends, pier clearances	Height (550-760mm)	-	-	1,000kN GB, 300mm high, massive construction, void around supports

Where: Values shown are minimums, unless noted otherwise

AS = Airspace (structure)	PE = Permanent Effects	Ap = Approval	
BR = Bridge (structure)	LL = Live Load (traffic and floor loads)	Simult. = Simultaneously applied	
OB = Overbridge (structure)	XS = Cross Section (area)	Dir = Direction (relative to track)	
FB = Footbridge (structure)	HZ = Hazard Zone (from track centreline)	GB = Glancing Blow (load / force)	

8. Collision Protection Risk Assessment Criteria Recommendations

When reviewing each of the published standards and documents, it was found that variations and even omissions of some criteria was evident across the range of publications however, many had very detailed and explanatory content. Noting collision protection design considerations are very site risk specific, particularly due to many variations in track geometries and over track structures and existing infrastructure, some common themes are apparent from the document review. Some described requirements are prescriptive such as specific load magnitudes and dimensions and some are more performance based subject to risk assessment outcomes and rail authority approvals. Based on the review of all publication content reviewed, a summary compilation of collision protection risk assessment criteria recommendations is included for consideration. Risk points are each worded such that the more change in the criteria, the more severe risk to be considered. For example, the more people or higher mass or closer to track, the higher the risk etc. (Protection points are worded oppositely such as the more change, the lower the risk). The risk points are also split into sub-category topics (note that "support" refers to over-track structure support and that some points are trivial).

Site risks

- 1. Higher people numbers occupying structure or transiting bridge
- 2. Derailed train deceleration length longer after derailment (such as hard surface down slope)
- 3. Derailed train lateral travel distance wider (such as hard surface down slope or embankment)
- 4. Support lower elevation relative to track level
- 5. External development structure and supports close to track or over-track structures
- 6. Statistical high numbers of past derailments at site, across network or other rail network sites
- 7. Sabotage

Track risks

- 8. Turnouts, catch points and special trackwork numbers along train approaches
- 9. Open facing turnouts, catch points, switch rails, crossings and points for approach direction
- 10. Potential runaway train approach speed higher (out-of-control speed, down sloping approach)
- 11. Falling track approach (gradient) to support
- 12. Sleeper and track poor integrity poor (maintenance lack)
- 13. Track class and condition poor
- 14. Trailing turnout, catch points along train approaches
- 15. Support position at outside of sharp radius curve track (train overturning speed low)
- 16. More track numbers and other passing traffic types and frequencies

Train risks

- 17. Already partly derailed bogies or carriages passing supports (for minimum clearances)
- 18. Frequency and numbers of passing trains and stopping trains
- 19. Lines of travel for derailed trains into supports (estimated path)
- 20. Worn wheels and suspension
- 21. People numbers occupying train
- 22. Track speed higher
- 23. Train mass higher, such as heavier freight type locomotives and full bulk hopper wagons
- 24. Freight wagons unbalanced cargo and out-of-gauge loads (higher and wider kinematic envelopes)
- 25. Manual train control (compared to automatic train control)
- 26. Human factors principles lacking

Over-track structure risks

- 27. Airspace development buildings more than one storey
- 28. Superstructure deck wider spanning over track (such as more than 6m width)
- 29. Superstructure mass heavier spanning over track
- 30. Support clearance closer to track
- 31. Support with pin type connections/joints at top or bottom (such as not effectively rigid)
- 32. Support to superstructure connection without full restraint (including for collision loads)
- 33. Support destabilising domino type effects, from nearby structures along train approach direction
- 34. Support proximity and connection rigidity to other nearby structures, such as lifts, stairs, bridges
- 35. Historical infrastructure lacks robustness capacity for latest design collision loads (slender)

Platform structure risks

- 36. Platform wall and coping structure not continuous reinforced concrete
- 37. Platform structure without compacted earth fill mass for passive impact resistance
- 38. Platform structure short length available for passive impact resistance (such as less than 10m)
- 39. Platform wall structure with shallow footings (such as less than 0.4m below formation level)
- 40. Support clearance closer to platform wall structure (such as less than 1.7m)
- 41. Support clearance closer to platform coping edge (such as less than 2.5m)
- 42. Support clearance closer to platform end with vertical wall (such as less than 4m)
- 43. Support clearance closer to platform end with ramp (such as less than 20m)

Stairways and ramps and small linking deck risks

- 44. Support clearance closer to track (such as less than 4m)
- 45. Support clearance closer to platform coping edge (such as less than 2.5m)
- 46. Support clearance closer to platform wall structure (such as less than 1.7m)
- 47. Support structural connection to over-track structure
- 48. Domino effects with other structures
- 49. Superstructures with high mass or occupancy (can be footbridge category)

Lift shaft risks

- 50. Lift shaft supports an over-track structure
- 51. Lift shaft structural connection to over-track structure
- 52. Domino effects with other structures
- 53. Lift shaft closer to track (such as less than 10m to track centreline)
- 54. Lift shaft overturning onto track, if impacted by derailed train
- 55. Lift shaft not fully behind a continuous platform wall structure with earth fill mass resistance
- 56. Lift shaft close to other over-track structure supports along train approach direction

Structure protections

- 1. Support clearance moved further away from track
- 2. Support deflection wall length and train deflection ability (such as wall capacity, skew angle detail)
- 3. Support deflection wall or barrier collision deflection allowance (to avoid adjacent structures)
- 4. Support enhanced robustness capacity (such as thicker longer blade wall or abutment wall)
- 5. Support enhanced robustness capacity (such as intermediate walls between individual columns)
- 6. Support enhanced redundancy load paths (if one or more individual columns lost or damaged)
- 7. Structure higher capacity for permanent and live loads (in redundant state if support/s lost)
- 8. Support clearance further away from platform coping edge, platform wall, platform approach end

- 9. Station platform structure enhanced robustness (such as compacted earth filled mass)
- 10. Station platform structure enhanced robustness (such as continuous concrete walls and coping)
- 11. Station platform structure enhanced robustness (such as deeper more massive footings)
- 12. Station platform wall level higher and with higher condition integrity (higher access level coping)
- 13. Support and footing separate isolation zone for deformation of impacted rigid platform structures
- 14. Support and structure increased separation to nearby structures (avoiding "domino" effects)
- 15. Superstructure/deck level higher for over track clearance
- 16. Support positioned higher up a cutting face
- 17. Support partial deflection devices such as earth bunds, footing plinths, minor retaining walls
- 18. Guardrails and intermediate tracks acting as guardrails or derailment kerbs (and approach length)

Support detailing protections

- 19. Support and wall profile with rounded ends (in plan view) for derailed train deflection
- 20. Smooth wall faces without snagging effects (minimise large gaps or projections)
- 21. Smooth transition faces for change in barrier shapes or profiles (such as adjoining walls)
- 22. Blade shaped wall parallel to track (for train deflection)
- 23. Wall skew angles less to track direction (such as maximum 20 degrees)
- 24. Support wall thicker for robustness (such as 0.8m minimum)
- 25. Wall length longer for deflection (such as at least over-track deck width or 4 x wall thickness)

Structural redundancy protections

- 26. Structure permanent effects plus 0-20% or 60% live loading with one or more supports lost
- 27. Structure permanent effects loading with 33-50% support cross-section loss, without collapse
- 28. Support to superstructure connection enhanced minimum restraint capacity
- 29. Avoid disproportionate collapse with any support loss
- Even though the intent of the above list of over 80 potential risk and protection items is to provide a comprehensive summary of recommendations for consideration for station bridge and structure collision protection design and detailing and fine tuning, additional potential and relevant risks would not be out of the ordinary. With the vast numbers of bridge and structure configurations and broad range of available standard provisions and other variables and future events and studies, this risk list is also considered a "work in progress".

9. Further suggested studies

The field of railway collision protection in general and at stations and bridges has evolved due to significant accidents and will continue to evolve further with additional data and events and investigations. Some or all suggestions below have likely been undertaken to some extent but are included here for avenues of potential further investigation, particularly for standards and codes updates.

Collision protection publication further reviews

An investigation into codes and standard requirements, particularly for railway station collisions, from other countries and regions not covered within this paper review could be undertaken. Other already published collision protection provisions could lead to further preventions or protections or methods or lessons learnt that can be incorporated in local standards.

Collision protection historical event data compilation and register

Accurate records of past historical events can be difficult to obtain due to the high numbers, different site scenarios and ongoing crash records across multiple rail networks and jurisdictions around the world. Some form of common register and data compilation specific to accidents within and near railway stations and bridges would be useful to further estimate collision dynamics and potential collision load magnitudes based on actual rolling stock types and historical events.

Rolling stock crashworthiness

Rolling stock crashworthiness and implications for hard crash and soft crash aspects for rolling stock bodies and track side railway infrastructure is a potential field of further study. Particularly as the assumed energy absorption or crash deflection amount can significantly influence impact forces and survival rates. As this topic involves rolling stock and bridge structures, at least rolling stock engineering and structural engineering and finite element modelling would form part of the studies to estimate train collision impact magnitudes and appropriate design values.

Physical train crash testing

As life expired rolling stock is typically scrapped for future recycling, an intermediate use could be physical crash testing. Such controlled crash testing of say passenger car units, bulk freight wagons and locomotives with different test scenarios of say speed, track curves, derailed skew angle, track-form and ground terrain and then colliding into different structures types and barriers, could lead to further structure collision protection and rolling stock body crashworthiness findings. Associated rail vehicle wheel and track interaction and rollover aspects when derailing around curves can also be included. Comparison to already undertaken road vehicle crash test data is another avenue of study.

10. Conclusion

For ease of comparison of the broad array of collision protection design and detailing content across multiple Australian and International Authority publications, a data compilation table has been provided, which summarises relevant aspects of design collision loads, support robustness protections, structure redundancies, applicable train speeds, support hazard zones, station platform protections and other related remarks. From this collision protection data and other selected content extracted from all the publications reviewed, high level recommended lists of risk and protection assessment criteria, separated into broad topics have also been presented. The intent of the lists is mainly to assist station bridge and structure designers and rail authority asset managers to compare available data in a more concise format. The presented information could also be used for risk assessment inputs and alternative ideas, if say full standard compliance was not feasible due to site constraints and then say justifications for standard concessions or waivers were to be investigated by project teams. Some simple structure detailing and positioning could make significant risk improvements. Potential fields of further study ideas were also summarised.

Considering the vast array of possible collision scenarios, site structure risk variabilities at stations, unlikely but extremely severe consequences and potential high capital costs combined with standard robustness requirements associated with collision protection design development, this paper only summarised a portion of the complexities to be resolved by designers and asset managers for reasonably practical safe outcomes.

11. References

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