AS 5100 Bridge Design Standard – Focus on Safety for Railway Bridges

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**SYNOPSIS**

The new Australian bridge design standard AS5100 contains provisions to maximise safety at bridges and structures over and under railway lines. The intent of AS5100 is to avoid catastrophic failures of bridges due to loading or collision impact by derailed trains or road vehicles and to provide a “forgiving” environment to minimise the probability of injury to the occupants of derailed trains.

The provisions are a legacy of the Granville (Australia) and the Eschede (Germany) bridge disasters and are designed to protect both the bridge and the train occupants in the event of a train derailment. These are general principles and it is the responsibility of bridge designers to apply them in any situation where there is a risk of bridge collapse due to a de-railed train.

The application of the provisions to some recent projects have highlighted that there is disagreement among designers and Rail Authorities in regards to the intent of the standard and interpretation of the provisions. The application of some of the prescriptive requirements is very difficult if not impossible in some situations and may be too costly in low risk situations. A risk analysis at the concept stage may be the only way to determine the appropriate course of action.

This paper discusses the intent of the standard, the application of the provisions in a case study and proposes some guidelines to assist designers and Rail Authorities in making decisions about the application of the provisions.

A methodology using a risk analysis approach is required to clearly, objectively and consistently assess optional bridging solutions taking safety aspects into account. A model to assess the risk profile of a project by quantifying the probability of derailment and by establishing the likely consequences has been developed by PB to the concept stage. This will be discussed with the Rail Authorities for further development.

**1 INTRODUCTION**

The intent of AS5100 is to

- avoid catastrophic failures of bridges due to loading or impact by derailed trains or road vehicles and
- provide a “forgiving” environment to minimise the probability of injury to the occupants of derailed trains. This requires avoidance of hard impact by a derailed train with an unyielding hazard, such as a concrete wall.

It is considered that the provisions in AS5100 are at the leading edge of world practice and will lead to much safer rail and road travel, however the application of the provisions to some recent projects have highlighted that:
• there is disagreement among designers and Rail Authorities in regards to the intent of the standard and interpretation of the provisions
• the application of the prescriptive requirements is very difficult if not impossible in some situations, such as retrofitting existing bridges to comply with the new provisions
• some of the provisions may be too costly in low risk situations and a risk analysis may be the only way to determine the appropriate course of action. Budgetary constraints need to be considered.

This paper discusses the intent of the standard, the application of the provisions in a case study and proposes some guidelines to assist designers and Rail Authorities in making decisions about the application of the provisions. A methodology using a risk analysis approach is proposed. A model to assess the risk profile of a project by quantifying the probability of derailment and by establishing the likely consequences has been developed by PB to the concept stage is presented.

2 BRIDGES OVER RAILWAYS

The train disasters in Granville (Australia) and Eschede (Germany) provided the catalyst for the provisions in the new Bridge Design Code (AS 5100 Part 1, Clause 11.3) developed for bridges over railways.

An earlier paper by the author (Rapattoni, 2002) discusses the above events in some detail. In brief,

• The collapse of the bridge at Granville (NSW) in 1977 (Fig. 1) led to 83 lives lost and 213 people injured. Most of the casualties (75 dead) occurred when the superstructure collapsed, crushing the train carriages, after the supporting steel trestles were demolished by the derailed locomotive. The investigation that followed led to the conclusion that piers should be avoided if at all possible and that, when this is impractical, frangible piers with a superstructure which would not collapse with the piers removed (‘pier-redundant’ bridge) should be used (HH Judge Staunton, 1977)

• Another major disaster was the derailment and bridge collapse at Eschede in Germany on 3 June 1998 (Fig. 2). The derailment of the Inter City Express from Munich to Hamburg caused the carriages to swing around and smash against the supporting columns which were just 3.3m away from the outside track. The bridge superstructure collapsed onto the carriages behind, crushing several of them and chopping one in half. The rest of the carriages piled up as they slammed against the collapsed bridge in an extreme concertina fashion. Ninety eight people lost...
their lives in the accident. In early reports, engineers argued that the death toll would not have been so high if the superstructure had not collapsed.

The objectives of the new Code provisions are to minimise the probability of injury to rail travellers by ensuring that derailed trains meet with a more ‘forgiving’ environment and that they do not cause a total bridge collapse. Avoidance of a total bridge superstructure collapse is the prime objective of the provisions as this caused most of the injuries in both the above accidents.

For bridges over railway lines, AS5100 provisions are as follows:

11.3.1 General

For collision from railway traffic, to minimize the likelihood of damage and collapse of bridges and other structures over or adjacent to railway tracks as a result of collision from railway vehicles, the following shall apply:

(a) Unless approved otherwise by the relevant authority, bridges over railways shall have a clear span between abutments.

(b) Where the relevant authority agrees that the requirement of Item (a) is not achievable, supports adjacent to railway tracks may be permitted subject to the following conditions being met, and in the following order of preference:

   (i) Alternative load paths are available through the structure to ensure that the superstructure does not collapse in the event of removal of the supporting piers or columns as a result of collision. In this case, the supporting piers shall not be of heavy construction. They may have independent deflection walls. However, they shall not have integral deflection walls.

   (ii) The support piers are of heavy construction designed to resist the loads specified in AS 5100.2. Such supports shall be protected from head-on collision by deflection walls or the like. Any supports that cannot be protected from head-on collision shall be designed to be removable in accordance with Item (b)(i).
AS 5100.2 Clause 10.4.3 specifies design collision loads of

a) 3000 kN parallel to rails and
b) 1500 kN normal to rails

It is important to note that the loads specified in this Clause allow for “…moderate derailments and minor collisions but not major derailments of a 300LA train… This may also represent a self-propelled passenger train derailing at moderate speed” (Ref. Clause C.10.4.3). In effect these loads represent “… only a glancing blow, not a head-on collision” (Ref. Clause C11.3.2).

The application of the above provisions has proved difficult on recent projects in Victoria. One of the projects is discussed below.

2.1 Case study - Strengthening an existing pier between two tracks

The strengthening works was included in a design-and-construct tender won by John Holland Group. The project involved 1.5km of new track and a duplicate railway bridge over Merri Creek at Clifton Hill, Victoria.

The RC pier of the existing bridge (Heidelberg Road Bridge) over the railway required strengthening to “comply with AS5100 provisions” as it is adjacent to the new rail track.

The existing bridge comprises multiple simply-supported spans. The existing pier consists of RC columns with a 1.5m high wall between the columns. This wall was of insufficient height and strength for the collision loads specified in AS5100, hence a retrofit was required.

The adopted design is as follows:

- The pier was considered to be of “heavy construction” as defined by AS5100. The simply supported spans would collapse if the pier was removed hence the pier requires strengthening to prevent failure from collision loads.
- Design collision loads of 3000 kN longitudinally and 1500 kN normal to the pier applied anywhere along the length of the pier were adopted as per AS5100.2 Clause 10.4.3.
- Prevention against head-on collision by a de-railed train, as required by Clause 11.3.1(b)(i), was investigated comprehensively but not considered practical. In order to prevent such a collision, a long deflection wall would be required with re-direction capability and an appropriate end treatment (e.g. energy-absorbing system) to prevent a hard impact with a derailed train.
- A “nosing” or “deflection wall” 3.6m high above the rail track (in compliance with AS5100 for tracks within 4m of track centreline) and 5m past the ends of supporting columns was adopted. The 5m length was required to cap 3 no. piles added at each end to strengthen the pier.
This design was considered to be in compliance with AS5100 Clause 11.3.2 which states: “Deflection walls shall provide a continuous protective face to the railway and shall extend to a minimum of 2.0 m past the end of each bridge support column, unless determined otherwise by the relevant authorities”, however it can be argued that this deflection wall would be of inadequate length and design to prevent a head-on collision by a train derailing just before the pier.

Discussions took place with VicRoads and the Department of Transport (DoT) to resolve the issue of head-on impact prevention but we could not find a practical solution.

- We considered approach deflection walls of various lengths, geometry and end treatments to mitigate the hard impact from a head-on collision. The works were considered to be very costly with significant impact on the operation of the existing track
- Limited research of overseas practice revealed no known precedents for this type of treatment. There are no prescriptive requirements in the European standards to avoid potential head-on collisions by de-railed trains.

Ultimately, it was agreed that

- the adopted design represents current best practice. Discussions with other Australian consultants revealed that they would adopt similar designs in analogous circumstances
- AS5100 provisions should be reviewed and clarified to ensure a consistent approach in future. Consideration should be given to distinguish between new and existing bridges as retrofitting the latter to comply with the new provisions may prove impractical
- in future, the requirements for protection of bridge supports from railway traffic collisions should be resolved at the concept stage in conjunction with the Rail Authority, before calling public tenders for design and construction.
2.2 Provisions and practice in overseas projects

Limited research has been carried out by the author and is summarised below:

2.2.1 European EN 1991 1-7

The European EN 1991 1-7 specifies a risk assessment procedure to determine appropriate provisions for accidental actions by rail traffic for the individual project.

- Guidance is given in that standard to take into account potential loss of life, injury, economic loss, environmental damage, disruption to users and the public, both in the short and long term.
- Both qualitative and quantitative risk analysis methods are outlined.
- The adopted provisions are subject to acceptance by the key stakeholders.
- Dynamic design for impact is also outlined. This allows design by considering actual impact situations between rail traffic and objects struck.

2.2.2 CTRL Bridges, UK (Dyson, 2007)

The CTRL (UK) includes a number of structures, ranging from the Medway Viaduct to numerous pedestrian bridges. Some features for the high speed track bridges are as follows:

- Derailment containment
  Most of the CTRL bridges have some built-in derailment protection through the provision of the upstand walls that contain the ballast. These walls project 100mm above rail level and are designed for a concentrated lateral load of 200kN. However, risk assessment identified certain structures that required a higher level of derailment containment – generally either long viaducts or bridges where the consequences of derailment could be particularly severe. For these structures, the upstand kerbs are increased in height to 200mm above the rails and designed for an increased lateral force of 300kN. These criteria were established from a study of European practice.

- Train impact
  The supports to the bridges that cross the CTRL are designed for train impact to UIC Code 777-2: ‘Structures built over railway lines – Construction in the track zone’, adapted to the particular circumstances of the CTRL. This code identifies a ‘danger zone’ within 4.5m of the rail, inside which it is preferable to avoid having supports. Where piers have to be present in the danger zone, they are designed as walls rather than columns to resist forces of 4000kN parallel to the track and 1500kN perpendicular to the track; such piers are also designed to remain functional if a section 1m long x 3.7m high above track level is removed by train impact.

There are no particular requirements to safeguard against head-on collision with a pier by a derailed train.

It is considered that the above provisions are substantially less onerous than the ones specified by AS5100.
3 RAILWAY UNDERBRIDGES

AS 5100.2 Clause 10.5.1 specifies that “Railway bridges designed to carry 300LA loads shall be designed for two separate train derailment load cases as set out in Clauses 10.5.2 and 10.5.3”.

For most under-bridges the specified train loads will be applied at the most critical location, at the edge of the bridge deck. It is noted that there are no provisions intended to retain a de-railed train on the bridge. This is left to the discretion of the Rail Authority.

3.1 Through-girder and truss bridges

AS 5100 does not prescribe particular requirements for through-girder or truss bridges. Given the high vulnerability of these bridges to collision loads, it is considered important to consider protection to avoid catastrophic failure, in compliance with the intent of AS5100.

Limited research carried out to date by the author to establish current practice has shown that, on recently constructed through-girder bridges:

- some bridges incorporate continuous concrete crash barriers within the bridge length and for some distance on the approaches.
- some bridges incorporate crash barriers of either concrete or steel within the bridge length but not on the approaches. The crash barriers are of different heights and strength.
- some bridges incorporate “guard rails” (also known as check rails) within the length of the bridge.
- a number of bridges have no crash barriers at all.
- protection against collision loads appears to have been ignored altogether in some designs.

The various arrangements are inconsistent and may indicate:

- Different risk of derailment and consequences at each location.
- Acceptance of different risks by the Authorities, probably influenced by varying legislative requirements in each State or dictated by budget constraints.

It is considered that:

- Through-girder and truss bridges are highly vulnerable to collision loads from de-railed trains and should be protected from such incidents or designed to withstand such loads (e.g. provide alternative load paths to avoid total collapse).
- A risk assessment should be carried out at the feasibility or concept stage to determine the level of protection required.
- The level of protection should be commensurate to the risk at the particular location. For high-risk locations, protection should consist of crash or deflection walls on the bridge continuing for some length on the approaches. The appropriate length should be determined by considering the design speed and loads.
- Further studies should be carried out to develop guidelines which will enable a consistent approach in the design of these bridge types.
5 DISCUSSION

In order to arrive at an appropriately engineered solution the following should be considered:

- Who is responsible for rail safety?
- What is the probability of a rail derailment in any given situation?
- What are the consequences both in cost to the community and human trauma?
- What is the cost of a particular prevention or ameliorating solution?
- How can we objectively make a decision about the “right” solution?

This discussion will attempt to answer these questions with the focus on safe design for rail derailment.

5.1 Rail safety in Australia

Legislation dealing with Rail Safety in Australia varies among the various States. The concept can be outlined as “Managing risk so far as is reasonably practicable”.

The legislation under different jurisdictions is broadly summarised in simple terms as (ATSB, 2008):

“The responsibility for rail safety in Australia is shared by government and industry.

To assist in both maintaining and continuously improving rail safety, each state and territory government has implemented rail safety legislation and established a rail safety regulator. The regulators are responsible for establishing standards in rail safety management and monitoring the industry’s compliance with the standards in order to meet community expectations and maintain public confidence.

Industry is responsible for addressing risks to safety by identifying and implementing the most effective and efficient solutions via their safety management systems. Industry is accountable for achieving required safety outcomes.

As part of this process of shared responsibility, industry reports rail safety occurrences to the regulators. The regulators and operators use this data to assist with their safety analyses and programs.

The present count data is designed to assist rail safety professionals and researchers in understanding and mitigating risk. In addition, it can be used for international comparative research, while informing the public about emerging issues in rail safety. The present database contains frequency counts of the following safety-critical event types:

- Derailment
- Collision
- Level Crossing Occurrence
- Signal Passed at Danger (SPAD)
- Loading Irregularity
• **Track and Civil Infrastructure Irregularity**

It can be concluded that engineering consultants advising on design solutions can be held accountable for achieving safety outcomes but the regulators are responsible for establishing the safety standards.

### 5.2 Derailment statistics

The following (Fig. 5) is a summary of rail derailment statistics in Australia (ATSB, 2008):

![Derailment statistics in Australia from 2001 to 2008](image)

Comprehensive statistics about human trauma caused by derailments are not available to the author however the accidents reported above show that consequences can be catastrophic and probably unacceptable by today’s community standards.

### 5.3 AS 5100 Provisions

The intent of AS5100 in regards to design for collision by de-railed trains is considered to be at the leading edge of world practice and will lead to much safer rail and road travel, however the application of the provisions to recent projects have highlighted that current practice varies markedly across Australia. It is considered that

- the provisions in AS5100 require further clarification and guidance.
- specifying that **“the design shall be in accordance with AS5100”** in D&C tenders is not adequate as solutions can only be developed in conjunction with the Rail Authority. Different interpretations of the requirements can lead to significantly different designs.
- the provisions require expansion to include through-girder and truss bridges
- strict compliance with the prescriptive requirements in the Code may not necessarily achieve a desirable solution.
- procedures should be developed to arrive at appropriate safe solutions taking into consideration individual projects
- irrespective of the provisions in the standard it is the responsibility of the designer and the Rail Authority to ensure that safety be considered for individual projects to comply with the intent of the standard.
The author believes that

- a safety audit should be undertaken at the feasibility stage to identify all the hazards and the required provisions should be specified by the Authority in accordance with the requirements in Appendix A of AS5100 in the tender documents.
- a methodology using a risk analysis approach is required to clearly, objectively and consistently assess optional bridging solutions taking safety aspects into account.

5.4 Proposed Risk Analysis

The proposed methodology is based on

- determining the probability of a train derailment at a particular site, and
- establishing the likely consequences of major derailment in terms of human trauma – fatalities and major injuries.

These are quantified to determine the risk profile of the proposed structure as shown in Fig. 6 below.

![Risk profile matrix](image)

**Figure 6 – Risk profile matrix. The ‘X’ indicates the risk profile for a particular project.**

A model has been developed by PB to the concept stage by considering historical data on causes and factors which contribute to derailments. More research is required to compile a more comprehensive list and assign a weighting for their importance. The probability of a derailment can then be quantified. A measure of the likely consequences in terms of human trauma is quantified by taking into account the function of the train (i.e. passenger, freight etc.), the type and function of the overbridge and its supports, the speed of the train, adjacent development and a number of other factors.

The model is still under development and will be discussed with the relevant Rail Authorities for further development.

6 CONCLUSIONS

- The intent of AS5100 is to avoid catastrophic failures of bridges due to loading or collision impact by derailed trains and to provide a “forgiving” environment
to minimise the probability of injury to the occupants of derailed trains. These are considered to be visionary objectives at the leading edge of safety in design.

- The current prescriptive provisions do not provide adequate direction for designers on some projects and require the Rail Authority to make important decisions in regards to acceptable risks. This is as a result of differing legislative requirements and risk acceptance by different Authorities. It is difficult to prescribe solutions at individual sites with particular risks and particular designs.

- Specifying that “the design shall be in accordance with AS5100” in D&C tenders is not adequate as solutions can only be developed in conjunction with the Rail Authority. Different interpretations of the requirements can lead to significantly different designs.

- Improved guidelines are required to avoid inconsistencies in designs among designers and costly time wasting trying to resolve these issues for each project. Reliance on the prescribed provisions may not achieve desirable solutions and Authorities should develop comprehensive policies to address safety provisions, keeping in mind the intent of the Standard.

- Through-girder and truss bridges are highly vulnerable to collision loads from de-railed trains and should be protected from such incidents or designed to withstand such loads to comply with the intent of the provisions. Further studies should be carried out to develop guidelines for these bridge types.

- The use of dynamic design models for impact may be required to assess the safety of some particular arrangements. Software to model crashes is available and may be used more extensively in future.

- Application of the provisions in the retrofit of existing bridges may prove impractical and consideration should be given to distinguishing between new and existing bridges as retrofitting the latter to comply with the new provisions may prove impractical.

- A methodology using a risk analysis approach is required to clearly, objectively and consistently assess optional bridging solutions taking safety aspects into account.

- A model to assess the risk profile of a project by quantifying the probability of derailment and by establishing the likely consequences has been developed by PB to the concept stage. This will be discussed with the Rail Authorities for further development.

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8 REFERENCES


3 EN 1991-1-7 European Standard
