‘Safety first’ for bridges – by design

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SYNOPSIS

‘Safety first’ is the overriding criterion which governs key provisions in the new Australian Bridge Design Code. The safety provisions for bridges over railways are at the leading edge of world practice with emphasis on catering for derailed trains by providing clear spans or *‘pier-redundant’* bridges with frangible piers. The catalyst for the provisions was provided by the train disasters at Granville and at Eschede, Germany. *‘Pier-redundant’* bridges are also recommended for bridges over navigable waterways to avoid collapses such as that of the Tasman Bridge. This concept can minimise risks in many other situations such as bridges over streambeds susceptible to unpredictable or high rates of scour and piers susceptible to impact by road traffic. Two *‘pier-redundant’* bridges have been constructed in Australia over the Murray River at Berri and at Hindmarsh Island. These bridges enabled substantial savings in construction costs as well as ensuring the maximum safety for traffic on and under the bridge. Bridges over roads, especially freeways, can provide significant safety hazards to road traffic. The benefits of using safer bridging options by eliminating accident costs and human trauma need to be recognised in selecting the best bridging solutions. The prescriptive requirements for safety provisions in the Code are designed to ensure that bridges are selected taking a holistic view of the project, by considering the hazard they create as well as their function. This should ensure that bridge solutions are not selected just on the basis of lowest initial cost, which currently is the prevailing criterion. A methodology is required to clearly and objectively select the best bridging solutions taking safety aspects into account within available funds.

1 INTRODUCTION

‘Safety first’ is the new catch-phrase in the modern world. Technology has evolved to the point that the community expects safety in all aspects of modern life - no compromises! Some examples are:

- Sweden has adopted the *‘Vision Zero’* approach to road trauma requiring that the road environment be designed to allow for human error, with safety taking priority over cost. This requirement is enshrined in an act of Parliament.

- Australian WORKSAFE legislation which stipulates heavy penalties to employers for accidents at work. Companies are complying and most are making safety a prime business objective with employee incentive payments subject to achieving certain standards

- The Australian Government is committed to significant reduction to the road trauma through road improvements, vehicle design requirements, education and policing. There is strong community support for these initiatives

This worldwide trend towards zero tolerance for human trauma is being reflected in bridge engineering.

- Transport South Australia has led the way with safety provisions for bridges over navigable waterways. The Berri Bridge (1997) and Hindmarsh Island Bridge (2000) over the Murray River were designed using the *'pier-redundant'* concept. The *'pier-redundant'* bridge concept is such that the bridge superstructure does not collapse with any one pier removed.

- Some recent bridge specifications by other Authorities have similar provisions, although this is not common yet.

The new Bridge Design Code AS 5100 has captured these advances which are discussed in this paper. Provisions for railway bridges and bridges over navigable waterways are aimed at averting the repeat of past catastrophes. The author proposes an extension of this approach to the selection of bridges over roads to safeguard against the hazards they pose to road traffic.

Traffic barriers on bridges and approaches are discussed in another paper at this Conference. The new Code provisions represent a significant step forward toward maximum safety for bridge traffic.

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2 BRIDGES OVER RAILWAYS

The Granville, Australia, and Eschede, Germany, train disasters provided the catalyst for the provisions in the new Bridge Design Code (Part 1, Clause 11.3) developed for bridges over railways. These provisions were championed by the Australian Rail Authorities. The tireless efforts of the Australian Rail Authorities committee representatives, in developing and advocating the provisions are duly acknowledged.

Figure 1: Derailment and the collapse of the Bold Street bridge at Granville (NSW), 1977

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.

Figure 2: Carriages were crushed and piled up against the

collapsed bridge at Eschede, Germany, 1998.

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 consideration of the provisions as this caused the most injury in both the above cases.

The provisions stipulate a clear order of preference for bridges spanning over railways, subject to approval by relevant Rail and Road Authorities, as follows:

1 Clear span over the railways is the preferred option. When this not achievable, the following may be used in order of preference
2 Frangible piers with *'pier-redundant'* superstructure
3 Piers of heavy construction to withstand train impact. This is the least preferred system.

Head-on collision with any non-frangible supports must be avoided. Deflection walls may be appropriate in some cases but care must be taken to ensure these do not become hazards in their own right by using appropriate end treatments.

It is believed that these provisions are at the leading edge of world practice and will lead to much safer rail and road travel.

3 BRIDGES OVER NAVIGABLE WATERWAYS

The new Code (Part 1, Clause 11.4) stipulates that the piers for bridges over navigable waterways must be either

- protected by auxiliary structures designed to absorb the collision impact energy from a design craft of particular mass and speed as determined by the Authorities or
- designed to resist collision from the design craft

Alternatively piers can be designed at the Serviceability Limit State for a moderate ship impact load accepting that the piers will fail at the Ultimate Limit State provided the superstructure is designed not to collapse with any one pier removed. It is accepted that the superstructure will deflect substantially with some damage in this situation. This is the essence of a *'pier-redundant'* superstructure.

Figure 3: Bridge over the Murray River at Berri, South Australia, 1997. First 'pier-redundant' bridge

Bridges with *'pier-redundant'* superstructures complying with the above provisions have already been constructed over the Murray River at Berri (1997) (Fig. 3) and Hindmarsh Island (2000), South Australia . The concept had the added bonus of reducing the piling costs whilst providing a virtually indestructible bridge.

The attractiveness of this concept depends on the type of craft using the waterway. If river traffic comprises large vessels, even at low speed, the consequences of pier failure can be catastrophic as demonstrated by the collapse of the Tasman Bridge (Tasmania, Australia) in 1975. In that instance two piers collapsed along with 127 metres of bridge superstructure after impact by the bulk ore carrier "SS Lake Illawarra" loaded with zinc concentrate. Four cars drove into the Derwent and five occupants died, while several others managed to escape from their vehicles which were hanging on the edge of the gap. Seven crewmen from the "SS Lake Illawarra" also lost their lives when the bridge crushed the vessel.

Similar accidents have been experienced overseas. In the USA, with many more and much larger bridges over navigable waterways, a number of catastrophes have occurred in the recent past (*Source: Dateline NBC):*

- in 1980 a tanker ship slammed into the Skyway Bridge, Tampa Bay, Florida. Eight vehicles including a Greyhound bus drove into the water and 35 people died
- in 1993 a tow boat in Alabama slammed into a railroad bridge. A passenger train fell into the river and caught fire. Forty seven people were killed
- in 2001 a barge hit a bridge at South Padre Island. Eight people died
- in 2002, the I-40 bridge over the Arkansas River in Oklahoma collapsed when a barge hit a pier. Fourteen people lost their lives.
- in the USA
  - it is estimated that on average, a barge or boat hits a bridge every day
  - there have been 2700 records of vessels hitting bridges in 34 States in a recent 10-year period

Clear spans should be the choice solution over navigable waterways. This would ensure maximum safety for both river and road traffic. Where this is not practical or too costly the *'pier-redundant'* bridge system could be used to avert major disasters and human trauma in the future. This concept could also be used when there is a risk of pier failure caused by undermining of foundations due to river bed scour, corrosion, earthquakes or other causes. A risk analysis for particular bridges could be used to determine an optimum solution.

4 BRIDGES OVER ROADS

Bridges over roads, especially freeways and high speed highways, can provide significant safety hazards to road traffic. The provisions in the new Code (Part 1, Clause 11.2) are only minimum requirements. Owners, usually Road or Rail Authorities, should recognise that by complying with the Code will not necessarily achieve a desirable solution. Designers must use their skills and judgement to assess the safety implications of their design. The advice of safety experts should be sought in some cases.

The potential for costly vehicle collisions with piers and the associated human trauma caused by these accidents need to be considered in the evaluation of bridging options.

Having determined the functional needs, aesthetic requirements and likely environmental impact, possible bridging options should be considered to minimise the hazard they present to road traffic. This will include:

  - Spanning arrangements to minimise hazardous piers or wall abutments
  - Location of required piers or walls and safeguards against vehicle impact
  - Horizontal and vertical alignment to minimise risk of impact

It is considered that

- Clear spans, with no piers or wall abutments likely to be impacted by vehicles, should be provided if at all possible, as stipulated for bridges over railways (above)
- locating piers or wall abutments beyond the typical 9m clear distance (adjusted for site conditions) does not adequately address the safety hazard to vehicles. It is well known that many accidents with roadside objects occur at distances well beyond this.
- Providing crash attenuators will diminish the severity of vehicle impact against piers and should be considered when it is impractical to remove the piers.
- The commonly used arrangement with steel guardrail with a frangible (B.C.T.) terminal to shield piers is of dubious effectiveness and constitutes a safety hazard to cars in its own right.

Road Authorities recognise the safety implications outlined above and some have their own policies. For example, VicRoads prescribes that pedestrian bridges must span the whole freeway with no piers in the median, due to the relatively low strength of these piers which are vulnerable to collapse in a collision with a heavy vehicle. This policy was a result of recent accidents involving pedestrian bridges. In the case of pedestrian bridges, the use of long spans is relatively easier than road and rail bridges.

The author believes that Authorities should develop comprehensive policies to eliminate or decrease the safety hazard provided by bridge piers and wall abutments. Strict compliance with the Code, the role of which is to stipulate minimum requirements, may not necessarily achieve a desirable solution.

5 DISCUSSION

The prescriptive requirements for safety provisions in parts of the Code are designed to ensure that bridges are selected taking a holistic view of the project, by considering the safety hazard they create as well as their function. This should ensure that bridge solutions are not selected just on the basis of lowest initial cost, which is often the overriding criterion in the selection of bridge solutions, especially in very competitive design-and-construct contracts.

It is recognised that in some cases the achievement of the safest possible solution is beyond the available funds or may not be practical and compromises need to be made by balancing priorities, however in many cases substantial improvements in design can be made at little cost.

Strict compliance with the minimum requirements in the Code may not necessarily achieve a desirable solution. A safety audit at the feasibility stage should be undertaken to identify all the hazards.

The author believes that a methodology using a risk analysis approach is required to clearly, objectively and consistently assess optional bridging solutions taking safety aspects into account. The likely higher cost of longer spans must be weighed against the cost of probable accidents and human trauma which must be added to the considerations.

6 CONCLUSIONS

- *'Safety first'* is the new catch-phrase in the modern world. Technology has evolved to the point that the community expects a safe environment. This is the overriding criterion which governs key provisions in the new Australian Bridge Design Code.
- The safety provisions for bridges over railways are at the leading edge of world practice with emphasis on catering for derailed trains by providing clear spans or *'pier-redundant'* bridges with frangible piers. The catalyst for the provisions was provided by the train disasters at Granville, Australia, and at Eschede, Germany.
- '*Pier-redundant'* bridges are also recommended for bridges over navigable waterways. Collapses such as that of the Tasman Bridge could be avoided by the use of the system.

- Two *'pier-redundant'* bridges have been constructed in Australia over the Murray River at Berri and at Hindmarsh Island. These bridges enabled substantial savings in construction costs as well as ensuring the maximum safety for traffic on and under the bridge.
- The *'pier-redundant'* concept can minimise risks in many other situations such as bridges over streambeds susceptible to unpredictable or high rates of scour and piers susceptible to impact by road traffic.
- The prescriptive requirements for safety provisions in parts of the Code are designed to ensure that bridges are selected taking a holistic view of the project, by considering the hazard they create as well as their function. This should ensure that bridge solutions are not selected just on the basis of lowest initial cost, which often is the overriding criterion in the selection of bridge solutions, especially in very competitive design-and-construct contracts.
- Bridges over roads, especially freeways, can provide significant safety hazards to road traffic. The benefits of using safer bridging options by eliminating the safety hazards need to be recognised. The provisions in the new Code in this situation are only minimum requirements. Reliance on Code provisions may not achieve desirable solutions and Authorities should develop comprehensive policies to address safety provisions.
- Limited funds and practical considerations may limit the viable options, however in many cases substantial improvements in design can be made at little cost.
- A methodology using a risk analysis approach is required to clearly, objectively and consistently assess optional bridging solutions taking safety aspects into account. The likely higher cost of longer spans or ameliorative treatments must be weighed against the cost of probable accidents and human trauma which must be added to the considerations.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

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